The Effects of Problem-Based Learning (PBL) Model, Educational Techniques, Creative Thinking Skills, Self-Confidence and Metacognitive Skills on Students' Biology Information Retention

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Received: May 5, 2025 Accepted: June 23, 2025 Online Published: August 14, 2025

doi:10.5430/jct.v14n3p319 URL: https://doi.org/10.5430/jct.v14n3p319

Abstract

Student retention in science education remains a critical challenge, particularly in Biology, where conceptual complexity often leads to limited long-term understanding. This study aims to investigate how metacognitive skills mediate the relationship between instructional strategies and students' retention in Biology, focusing on the effects of Problem-Based Learning (PBL), educational technology, creative thinking skills, and self-confidence. A quantitative, cross-sectional research design was used, involving 329 senior high school students in Gorontalo, Indonesia. Data were gathered through validated questionnaires and observation sheets, then analyzed using descriptive statistics and Structural Equation Modeling-Partial Least Squares (SEM-PLS). Descriptive results showed that the PBL model and educational technology were rated positively, while creative thinking, self-confidence, metacognitive skills, and retention were rated moderately high. SEM-PLS analysis revealed that PBL, educational technology, creative thinking, and self-confidence significantly influenced metacognitive skills. Creative thinking and self-confidence also had significant direct and indirect effects on retention. However, PBL and educational technology had no significant direct effects on retention, although their indirect effects through metacognitive skills were significant. Metacognitive skills play a pivotal mediating role in enhancing student retention in Biology. The findings underscore the need to integrate instructional methods and learner attributes that support metacognitive development, offering valuable insights for science educators and curriculum designers.

Keywords: metacognitive skills; biology retention; problem-based learning, educational technology, creative thinking, self-confidence

1. Introduction

Education is the foundation for the development of individuals and society. One of the main goals of education is to ensure that students acquire knowledge, retain it, and apply it in real life (Payu et al., 2022; Saleh et al., 2022). Learning is an activity undertaken with full responsibility to master competencies, skills, and other specific aspects, focusing on acquiring experiences and change (Yusuf & Hasan, 2019). One of the key indicators of successful learning is student retention, which reflects the extent to which the knowledge acquired by students is retained over the long term and can be applied in the future (Wicaksono & Corebima, 2015; Nusantari, 2015), including in the context of Biology education.

As a part of science education, Biology presents various challenges (Bulowe et al., 2020; Yusuf et al., 2022; Makalunsenge et al., 2022), one of which is student retention. In many Indonesian high schools, especially in Gorontalo City, Biology students often experience difficulties retaining and applying knowledge after instruction. This issue is critical, given that student retention is strongly associated with long-term academic success and readiness for higher education entrance exams. Addressing student retention is not only essential to ensure students' academic achievement but also to support their ability to transfer knowledge into real-life contexts—an increasingly important aspect of 21st-century education. Therefore, investigating the factors that influence retention in Biology learning is necessary to improve educational outcomes and learning quality.

1.1 Research Problem and Questions

This research is grounded in the problem that student retention in Biology subjects among XI-grade students in Gorontalo City senior high schools remains suboptimal. Field observations and interviews reveal that students often forget material after learning and struggle to apply concepts in daily life. Furthermore, students' metacognitive skills—such as planning, self-monitoring, and reflection—are also found to be underdeveloped. Based on these issues, the research questions of this study are:

1. How do students' metacognitive skills influence retention in Biology learning?
2. To what extent do external factors, such as the Problem-Based Learning (PBL) model and educational technology, impact student retention through the mediation of metacognitive skills?
3. What is the role of internal factors such as creative thinking and self-confidence in supporting student retention via metacognitive processes?

1.2 Research Gap and Scientific Justification

Previous studies have widely addressed factors influencing student retention, but few have explored the mediating role of metacognitive skills in the context of high school Biology education (Makmur et al., 2019; Usman et al., 2021; Yusuf et al., 2023). Moreover, limited empirical models examine how metacognitive skills connect external strategies (like PBL and technology use) and internal traits (such as creative thinking and self-confidence) to retention outcomes. Therefore, this study offers a new contribution by proposing and testing a structural equation model that positions metacognitive skills as a mediating variable. This model not only highlights the critical role of metacognition but also provides scientific direction for future interventions in improving student retention, especially in science learning. Further research can build upon this framework by incorporating other psychological or environmental variables and expanding the study across different educational levels or disciplines.

1.3 Purpose of the Study

The purpose of this study is to examine the influence of various internal and external factors on student retention in Biology subjects among XI-grade high school students in Gorontalo City, with a particular focus on the mediating role of metacognitive skills. This research aims to construct and validate a structural equation model that demonstrates how problem-based learning, educational technology, creative thinking, and self-confidence contribute to student retention through metacognitive processes.

2. Literature Review

2.1 Student Retention and the Need for Deeper Learning Approaches

Student retention—defined as the ability to remember, recall, and apply knowledge over time—has long been recognized as a core indicator of learning effectiveness. In the context of science education, particularly Biology, retention poses a notable challenge. Existing research shows that Biology is perceived as abstract and demanding, resulting in students' frequent inability to retain learned material and apply it meaningfully (Bulowe et al., 2020; Yusuf et al., 2022). Nusantari (2015) and Wicaksono and Corebima (2015) emphasized that low retention in science is often rooted in surface-level learning strategies, where students are conditioned to memorize facts without understanding the conceptual connections.

These findings highlight a broader pedagogical issue: the need to shift from traditional, teacher-centered instruction toward approaches that promote meaningful engagement and cognitive depth. While prior interventions have focused on enriching content delivery, few have explored the cognitive and metacognitive processes required to support retention over time. Consequently, there is a growing demand for research that not only identifies which instructional approaches are effective but also unpacks how and why they impact long-term learning outcomes. This provides the initial justification for the current study: to explore the mechanisms behind student retention, with a particular focus on the cognitive strategies students use to process and retain information.

2.2 The Mediating Role of Metacognitive Skills

Metacognitive skills—students' ability to plan, monitor, and evaluate their learning—are increasingly recognized as vital in sustaining long-term knowledge retention (Makmur et al., 2019; Usman et al., 2021). Students who possess these skills tend to be more independent, strategic, and reflective in their learning approaches. Metacognition supports not only the acquisition of knowledge but also its retention, by enabling learners to regulate their cognitive efforts and make adjustments when facing difficulties (Oyovwi et al., 2021; Erwinsyah et al., 2022).

Several studies have confirmed that metacognition serves as a foundation for other learning competencies, such as problem-solving, comprehension, and conceptual integration (Nunaki et al., 2019). Yet, while its importance is acknowledged, many students—particularly at the secondary school level—still exhibit weak metacognitive awareness (Yusuf & Yusuf, 2019). In Biology education, this underdevelopment results in a disconnect between understanding and retention. Most existing literature explores metacognition either as an outcome of specific instructional models or as a separate variable in achievement studies, leaving a gap in research on its mediating role—how metacognitive skills link external teaching strategies and internal learner attributes to the outcome of knowledge retention. The present study addresses this gap by positioning metacognitive skills not only as a variable of interest but also as a central explanatory mechanism in a larger causal model.

2.3 External and Internal Factors Affecting Retention: Fragmented Findings, Missing Integration

A growing body of literature has examined how different instructional strategies and psychological factors influence student outcomes. For instance, Problem-Based Learning (PBL) has consistently been associated with deeper learning and better retention through student-centered problem-solving and active engagement with content (Jaya et al., 2019; Sembiring, 2020). Similarly, educational technology has been shown to enhance interactivity and student autonomy, which in turn contributes to more meaningful learning experiences (Ginting et al., 2016; Yusuf et al., 2023). Both PBL and technology-driven learning environments offer affordances that could support metacognitive development, yet few studies investigate how these benefits are translated into improved retention via metacognitive pathways.

On the other hand, internal learner factors such as creative thinking and self-confidence have been positively linked with academic performance. Neolaka et al. (2023) assert that creative thinkers are more adept at integrating new information and adapting learning strategies, while Lone (2021) notes that confident students are more likely to persist through learning challenges and engage in self-monitoring. However, most existing studies tend to isolate these variables, rarely considering how they interact or contribute to knowledge retention within a comprehensive framework.

In light of this fragmentation, there is a strong theoretical need to consolidate these findings into an integrated model—one that not only measures the direct effects of instructional and personal factors but also examines how they operate through metacognitive skills to influence retention. This is the core contribution of the present study: providing empirical evidence through a structural equation model that can capture both direct and indirect relationships among these factors in the context of Biology education.

3. Methods

3.1 Conceptual Framework and Hypotheses

Based on the literature review, this study proposes a structural model in which metacognitive skills function as a mediating variable that connects both external factors (Problem-Based Learning and educational technology) and internal factors (creative thinking and self-confidence) with student retention in Biology learning.

Previous research suggests that Problem-Based Learning (Yusuf & Yusuf, 2019), educational technology (Yusuf et al., 2023), creative thinking (Neolaka et al., 2023), and self-confidence (Taufik & Vandita, 2023) influence student learning outcomes. However, their effects on retention have been understudied in a unified framework. Building on this, the literature underlines metacognitive skills as a crucial linking mechanism (Makmur et al., 2019; Usman et al., 2021), providing a scientific basis for the current research model.

3.2 Research Model

The assumed research model is illustrated in the following figure:

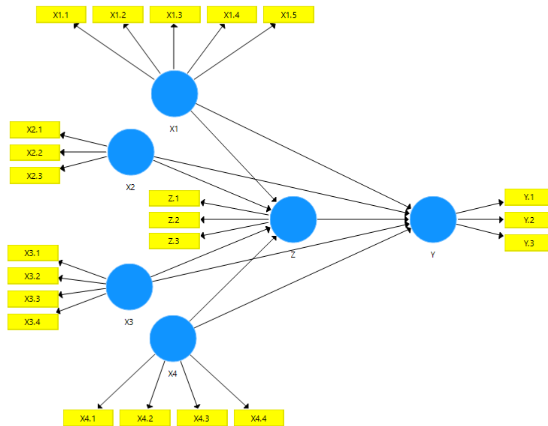


Figure 1. SEM-PLS Research Design

3.3 Research Hypotheses

The following hypotheses were developed based on the conceptual model:

- H1: Problem-Based Learning has a positive effect on metacognitive skills.
- H2: Educational technology has a positive effect on metacognitive skills.
- H3: Creative thinking has a positive effect on metacognitive skills.
- H4: Self-confidence has a positive effect on metacognitive skills.
- H5: Metacognitive skills have a positive effect on student retention.
- H6: Metacognitive skills mediate the relationship between external/internal factors and student retention.

3.4 Research Design

This study adopted a quantitative correlational design using cross-sectional data to test the structural model and hypotheses. The research was conducted over four months, from February to May 2024. The analytical framework was based on Second-Order Structural Equation Modeling with Partial Least Squares (SEM-PLS).

3.5 Research Tools and Instruments

To ensure comprehensive data collection, this study used three main tools: structured observations, semi-structured interviews, and standardized questionnaires. Each tool was constructed based on relevant theoretical constructs derived from the literature.

1. Observation

Observation was used to identify contextual classroom conditions related to student engagement, teaching methods, and use of educational technology. Observations were guided by a checklist adapted from Yusuf et al. (2023) and validated through expert review.

2. Interview

Semi-structured interviews were conducted with:

- Teachers of Biology subjects,
- School principals,
- Department heads at the Gorontalo Provincial Education and Culture Office.

The interviews aimed to understand perceived challenges in student retention, metacognitive awareness among students, and the implementation of PBL and educational technology. Interview questions were aligned with the research model constructs.

3. Questionnaire

The core data source was a standardized questionnaire distributed to XI-grade students. The questionnaire consisted of five main sections:

- Problem-Based Learning (PBL) scale: based on Yusuf & Yusuf (2019),
- Educational Technology scale: adapted from Scarpin et al. (2018) and Yusuf et al. (2023),
- Creative Thinking scale: based on Neolaka et al. (2023),
- Self-Confidence scale: adapted from Sari and Purwaningsih (2018),
- Metacognitive Skills and Retention scale: modified from Makmur et al. (2019) and Usman et al. (2021).

All items were measured using a Likert scale (1–5), and instruments were validated through expert judgment and pilot testing (Cronbach's alpha > 0.7 for all constructs).

3.6 Population and Sample

The population consisted of all XI-grade students in public and private senior high schools across Gorontalo City, totaling 1,824 students. Using the Slovin formula with a 5% margin of error, the required sample was calculated as 329 students. Stratified random sampling was employed to ensure representation from various schools.

3.7 Data Analysis Technique

The data analysis combined descriptive and inferential statistics:

1. Descriptive Analysis

Descriptive statistics were used to describe the general trends in student responses. As outlined by Sugiyono (2018), actual scores were compared to ideal scores and categorized using percentage thresholds:

- Very Poor (20.01–36.00),
- Poor (36.01–52.00),
- Fair (52.01–68.00),
- Good (68.01–84.00),
- Very Good (84.01–100.00).

2. Inferential Analysis using SEM-PLS

The inferential analysis was conducted using Structural Equation Modeling-Partial Least Squares (SEM-PLS) to test the model and hypotheses. A Second-Order SEM-PLS approach was employed to model hierarchical constructs (e.g., metacognitive skills). Analysis followed two key stages:

- Outer Model analysis: validity and reliability testing of indicators and latent variables (loading factor, AVE, CR).
- Inner Model analysis: evaluation of structural paths, including direct, indirect, and mediating effects (Budhiasa, 2016).

This method was selected for its suitability in exploratory modeling and small-to-moderate sample sizes.

3.8 Contribution of the Literature

The development of the research model and tools was grounded in a strong theoretical foundation. Prior studies informed the selection of constructs, item development, and path relationships. Unlike previous works that treated metacognitive skills or retention as isolated outcomes, this study contributes by integrating them into a unified, testable model. This structural approach offers both theoretical advancement and practical guidance for Biology education by revealing how instructional strategies and student traits interact to affect long-term learning outcomes.

4. Results and Discussion

4.1 Operational Definition of Research Variables

The operational definitions of the research variables are presented in the following table:

Table 1. Operational Definition of Variables

No	Variable	Indicator	Item
1	Problem-Based Learning Model (X1) (Astuti et al., 2020; Aslam et al., 2021; Muerza et al., 2024)	1. Orientation of students toward problems 2. Organizing students 3. Guiding students in investigation 4. Developing and presenting results 5. Analyzing and evaluating problem-solving	15
2	Utilization of Educational Technology (X2) (Scarpin et al., 2018; Permatasari et al., 2018; Nuralan, 2021; Georgiou et al., 2023)	1. Availability of educational technology 2. Usefulness of educational technology 3. Ease of use of educational technology	9
3	Creative thinking ability (X3) (Sumarni & Kadarwati, 2020; Rizal et al., 2022; Rahmawati et al., 2023)	1. Fluency Thinking 2. Flexible Thinking 3. Original Thinking 4. Elaboration Ability	12
4	Student Self-Confidence (X4) (Khoirunnisa & Malasari, 2021; Taufik & Vandita, 2023)	1. Belief in personal ability 2. Acting independently in decision-making 3. Valuing oneself and one's efforts 4. Willingness to face challenges	12
5	Metacognitive Skills (Z) (Sukarelawan et al., 2021; Jamaluddi et al., 2023)	1. Declarative Knowledge 2. Procedural Knowledge 3. Conditional Knowledge	12
6	Student Retention (Y) (Umainingsih et al., 2017; Nofindra, 2019; Polem et al., 2023; Sudsom & Phongsatha, 2024)	1. Recall (memory of learning material) 2. Recognition (identification of learning material) 3. Reintegrative (reintegration of learning material)	12

Source: Processed Data by the Author, 2024

4.2 Descriptive Analysis Results

The results of the descriptive analysis are presented in the following table:

Table 2. Descriptive Analysis Results

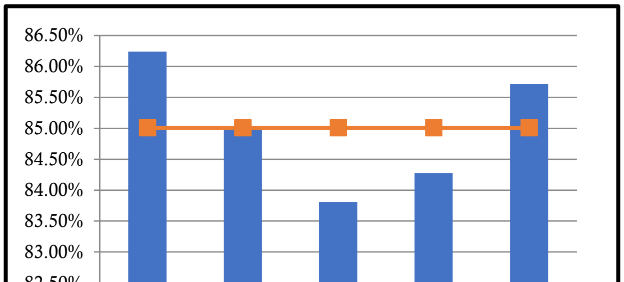
No	Variable	Response Frequency (%)					Actual	Score (%)	Criteria
		Not Appropriate	Less Appropriate	Fairly Appropriate	Appropriate	Very Appropriate			
1	X1	0.34%	2.25%	11.02%	44.78%	41.60%	20,976	85.01%	Good
2	X2	0.61%	3.28%	8.92%	49.68%	37.52%	12,443	84.05%	Good
3	X3	0.43%	3.50%	8.71%	54.76%	32.60%	16,408	83.12%	Fair
4	X4	0.53%	3.70%	15.15%	53.67%	26.95%	15,903	80.56%	Fair
5	Z	0.35%	3.04%	11.07%	53.19%	32.35%	16,350	82.83%	Fair
6	Y	6.84%	5.50%	13.55%	36.50%	37.61%	15,498	78.51%	Fair

Source: Processed Data, 2024

Based on the table above, the descriptive results for each variable can be interpreted as follows:

4.2.1 Problem-Based Learning (PBL) Model

The achievement score for the PBL learning model variable was 85.01%, which includes the good category. This indicates that high school students in Gorontalo City demonstrate active engagement during the learning process. Students tend to consistently participate in group discussions, ask in-depth questions, and collaborate to find solutions to problems posed by the teacher related to biology subjects. PBL requires students to analyze problems, identify relevant information, and evaluate various alternative solutions (Aslam et al., 2021). This approach helps students develop higher-order thinking skills that are crucial for understanding complex biological concepts. The results for each indicator are as follows:



	Indc. 1	Indc. 2	Indc. 3	Indc. 4	Indc. 5
Indc	86.24%	85.01%	83.81%	84.28%	85.71%
X1	85.01%	85.01%	85.01%	85.01%	85.01%

Figure 2. Results for Each Indicator of the PBL Model

The results for each indicator show that the highest-performing indicator is the student orientation toward the problem. This suggests that teachers are effective in presenting a problem, and students have a strong foundation in systematically approaching the problem. This includes understanding the problem's background, identifying the necessary information, planning the steps for resolution, and thinking critically and analytically. Moreover, students possess the basic skills required for conducting further investigations. On the other hand, the lowest-performing indicator is guiding students in the investigation. This indicates that while students can identify and formulate problems effectively, they still require more guidance and support from teachers during the investigation process and in finding solutions. The low performance of this indicator may be attributed to several factors, such as students' lack of skills in scientific investigation techniques, insufficient resources or materials to support investigations, or ineffective teacher guidance methods.

4.2.2 Utilization of Learning Technology

The achievement score for the variable of utilizing educational technology was 84.05%, which falls into the good category. This indicates that teachers and students have successfully utilized technology to enhance the effectiveness and efficiency of learning, or in this case, schools in Gorontalo City have successfully integrated technology into the biology curriculum. This integration has created a more dynamic, interactive learning environment that supports the development of 21st-century competencies. Teachers use various media such as videos, animations, and simulations to explain complex biological concepts. For instance, videos illustrating the process of photosynthesis or interactive simulations of ecosystems aid students in better comprehending the material. Additionally, students have access to various digital learning resources, such as e-books, online journals, and educational websites, allowing them to deepen their understanding of the subject beyond the available textbooks (Nuralan, 2021). The results for each indicator are as follows:

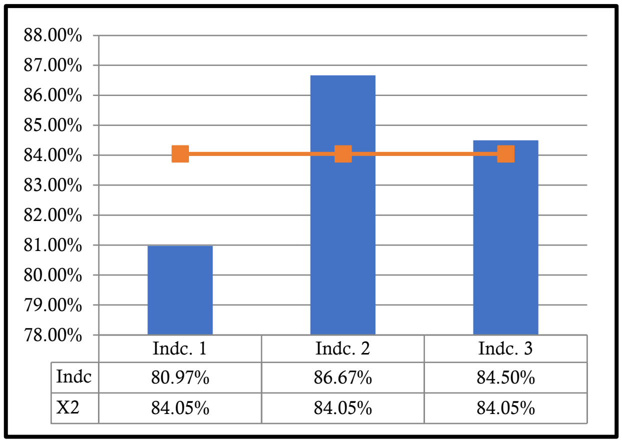


Figure 3. Results for Each Indicator of the Utilization of Educational Technology

The results for each indicator showed that the highest-scoring indicator was the utilization of educational technology. This indicated that the technology used in Biology instruction was perceived as highly beneficial by both students and teachers. This technology facilitated the learning process, made the material easier to understand, and improved students' interest and motivation. On the other hand, the lowest-scoring indicator was the availability of educational technology. This suggests that, despite the significant benefits of the existing technology, its availability remains limited. Factors such as limited hardware (computers, tablets, projectors), restricted access to a stable and fast internet connection, and a shortage of digital materials aligned with the Biology curriculum pose major challenges. Therefore, providing adequate hardware, improving internet infrastructure, and developing and distributing digital learning materials aligned with the Biology curriculum should be prioritized. Thus, the benefits of technology in education can be more evenly distributed among all students and teachers.

4.2.3 Creative Thinking Abilities

The achievement score for the creative thinking ability variable was 83.12%, which is included in the fairly good category. This indicates that students are capable of generating new and original ideas in biology learning. For example, when given a problem related to ecosystems, students can propose various ways to maintain the balance of the ecosystem. This suggests that students already have a sufficient foundation in creative thinking, although there is still room for improvement. To elevate students' creative thinking abilities to a higher category, schools and teachers can take several actions, such as providing more opportunities for students to engage in creative activities, using innovative teaching methods, and offering constructive support and feedback (Apriwanda & Hanri, 2022). With appropriate efforts, students' creative thinking skills in Biology in senior high school throughout Gorontalo city can be further developed, ultimately improving the quality of learning, student achievement, and retention. The results for each indicator are as follows:

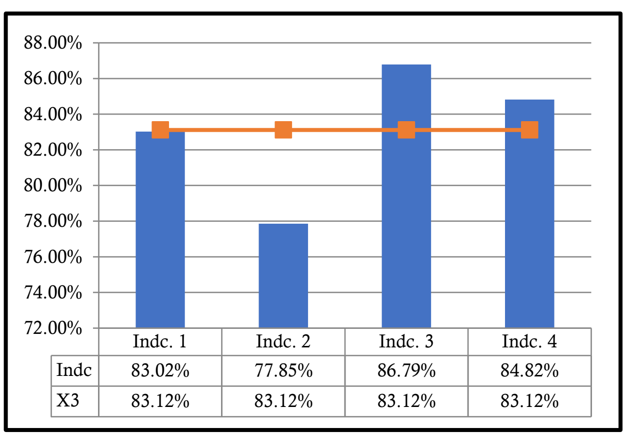


Figure 4. Results for Each Indicator of the Creative Thinking Ability Variable

The results for each indicator revealed that the highest indicator was Original Thinking. This indicates that students are capable of expressing ideas that may differ from those of the majority or show an openness to exploration, as well as the ability to integrate existing knowledge in new and different ways. This is a positive sign for the development of education, as original thinking often leads to breakthroughs and advancements in various fields of knowledge. On the other hand, the lowest indicator was Flexible Thinking. This suggests that students still struggle to change their approach or strategy when faced with problems that cannot be solved using conventional methods. Flexible thinking includes the ability to quickly adapt to changing situations or new information and the ability to view problems from multiple perspectives. The low level of flexible thinking indicates that students tend to be fixated on one particular way of thinking or approach and find it difficult to consider alternative options.

4.2.4 Student Confidence

The achievement score for the student confidence variable was 80.56%, which included in the fair category. This indicates that students have a generally positive belief in their own abilities. They feel capable of following lessons, understanding biology concepts, and completing tasks assigned by their teachers. Students with good confidence are more likely to ask questions when they do not understand something and are more actively involved in class discussions and biology practicum activities. However, their confidence is still not fully optimized, which may be due to several factors, such as a lack of support or positive feedback from teachers, unpleasant past learning experiences, or feelings of intimidation by more advanced peers (Taufik & Vandita, 2023). The results for each indicator are as follows:

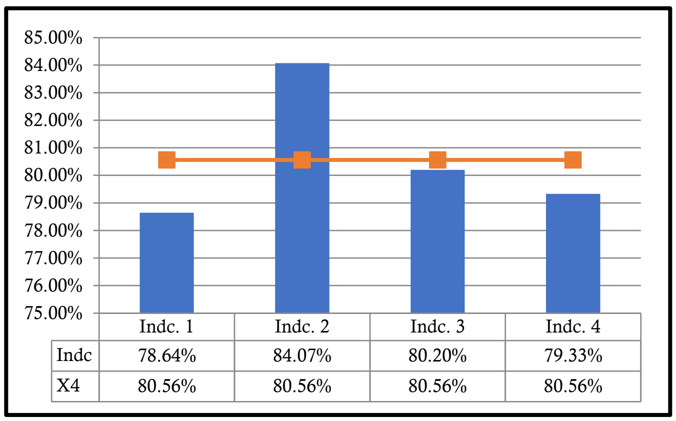


Figure 5. Results for Each Indicator of the Student Confidence Variable

The results for each indicator revealed that the highest indicator was the ability to act independently in decision-making. This indicates that students have the capability to make independent decisions related to their biology studies. They can evaluate information, analyze situations, and choose the actions or solutions they deem most appropriate without needing excessive assistance from others. On the other hand, the lowest indicator was self-confidence in their abilities. This suggests that some students are less confident in their own ability to master biology material. They feel less assured when answering questions in class, participating in discussions, or facing exams. This lack of self-confidence could hinder their academic achievement, even though they possess the potential and actual ability.

4.2.5 Student Metacognitive Skills

The achievement score for the student metacognitive skills variable was 82.83%, which included in the fairly good category. This indicates that students possess adequate abilities in understanding and managing their own thinking processes related to biology learning. Metacognitive skills include the ability to be aware of, control, and regulate thinking processes, as well as the ability to monitor and evaluate their understanding and learning strategies. Although this variable is in the fairly good category, there is still room for improvement and further development. Teachers can continue to enhance students' metacognitive skills by providing in-depth feedback on their learning strategies, encouraging deeper reflection, and offering opportunities to practice and apply metacognitive skills across various topics (Ramadhanti & Yanda, 2021). The results for each indicator are as follows:

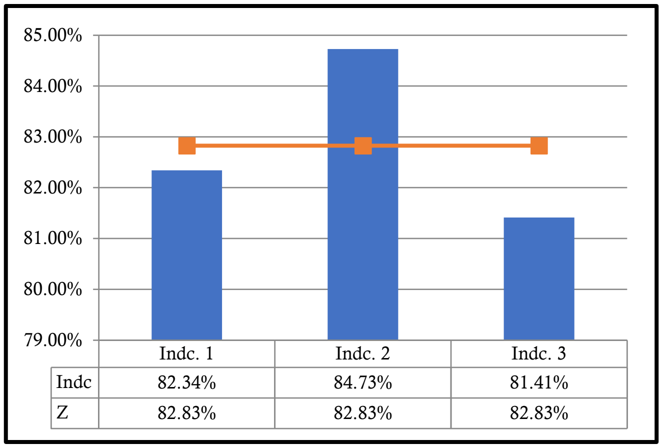


Figure 6. Results for Each Indicator of the Student Metacognitive Skills Variable

The results for each indicator revealed that the highest indicator was Procedural Knowledge. This indicates that students understand the steps or procedures necessary to complete tasks or comprehend concepts in biology learning. Procedural knowledge includes understanding how to perform certain tasks, such as the steps in conducting experiments, procedures for breaking down biological concepts, or strategies for solving biology-related problems. Students with strong procedural knowledge are able to consistently and effectively apply these procedures. They can follow instructions well, correctly conduct experiments or practical work, and produce reports or presentations that meet scientific standards. On the other hand, the lowest indicator was Conditional Knowledge. This suggests that students may struggle to recognize or evaluate the contexts that influence the use of specific strategies or procedures. For example, students may not always be able to adapt their learning methods or strategies when faced with complex problems or new situations. To help improve students' conditional knowledge, teaching approaches that promote deep reflection and self-evaluation can be implemented.

4.2.6 Student Retention

The achievement score for the student retention variable was 78.51%, which falls into the fairly good category. This indicates that students have a good ability to retain and recall information they have learned over a certain period. Retention is storing information in short-term or long-term memory and retrieving it when needed to solve problems or apply the knowledge learned to new contextual situations (Danil et al., 2023). Students are able to remember facts, concepts, and principles taught in biology lessons fairly well. They can recall important details, such as scientific terms, biological processes, relationships between organisms, and the application of theories in real-world contexts. This ability is crucial as it allows students to build a strong foundation of knowledge in biology. The results for each indicator are as follows:

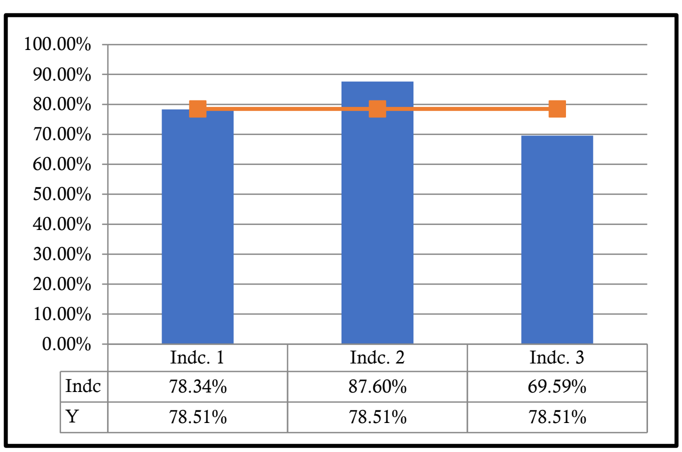


Figure 7. Results for Each Indicator of the Student Retention Variable

The results for each indicator revealed that the highest indicator was recognition of the lesson material. This indicates that students are capable of recalling and recognizing the biology information or concepts that have been taught in class. This ability includes recognizing facts, specific terms, theoretical concepts, and fundamental principles relevant to biology studies. For instance, students can recognize the names of organs in the human body, understand the process of photosynthesis, or identify the life cycle of an organism.

On the other hand, the lowest indicator was reintegrative, which refers to the reintegration of lesson material. This suggests that students struggle to connect the information they have learned with other biology concepts or real-life applications. Limitations in reintegrative ability may be due to several factors, including a lack of opportunities to practice and apply knowledge in various contexts or its relevant use in everyday life. Students understand individual concepts but have difficulty seeing the connections between them and how they can be applied in different situations. A more holistic and integrated learning approach can be applied in order to improve students' reintegrative abilities. Teachers can assist students in understanding the connections between various biology concepts, illustrating how learned information is interrelated, and demonstrating how these concepts play a role in broader contexts, such as ecosystems or in technological and health applications.

4.3 SEM-PLS Analysis Results

The analysis in this study employed Partial Least Squares Structural Equation Modeling (SEM-PLS) using SmartPLS 4. The evaluation consists of two main stages: the outer model analysis (measurement model) and the inner model analysis (structural model). Each stage includes assessments of reliability, validity, and overall model fit.

4.3.1 Outer Model Evaluation (Measurement Model)

The outer model measures how well the observed indicators reflect the underlying latent constructs. The indicators were evaluated using outer loading values, Average Variance Extracted (AVE), Composite Reliability (CR), and Cronbach's Alpha (CA). The results are summarized below:

Table 3. Outer Model Results

No	Variable	Outer Loading Value					AVE	CR	CA
		1	2	3	4	5			
1	Problem-Based Learning Model (X1)	0.781	0.840	0.873	0.888	0.816	0.706	0.923	0.895
2	Utilization of Learning Technology (X2)	0.828	0.799	0.860			0.688	0.868	0.775
3	Creative thinking ability (X3)	0.750	0.719	0.717	0.796		0.557	0.834	0.734
4	Student Confidence (X4)	0.710	0.794	0.873	0.734		0.609	0.861	0.784
5	Student Metacognitive Skills (Z) (Z)	0.851	0.856	0.858			0.731	0.891	0.816
6	Student Retention (Y)	0.878	0.842	0.751			0.681	0.864	0.766

Source: Processed with SmartPLS, 2024

The evaluation of the outer model in this study confirms that all indicators are valid and reliable measures of their respective latent constructs. Specifically, the outer loading values for each indicator surpassed the minimum threshold of 0.60, indicating that each observed variable has a strong association with its underlying construct (Hair et al., 2019). This suggests that the instrument items were well-designed and capable of capturing the theoretical dimensions of constructs such as Problem-Based Learning (PBL), educational technology, creative thinking, self-confidence, metacognitive skills, and student retention.

Furthermore, the Average Variance Extracted (AVE) values for all constructs were above 0.50, demonstrating adequate convergent validity. This means that over 50% of the variance in each construct is explained by its indicators rather than by error, aligning with the criteria proposed by Fornell and Larcker (1981). The ability of indicators to converge on a single latent factor is critical, particularly in psychological and educational research, where constructs such as metacognition and creative thinking are often abstract and multidimensional. The findings here provide empirical support for the theoretical assertion that metacognitive awareness and retention can be reliably measured through carefully designed indicators (Makmur et al., 2019; Usman et al., 2021).

In addition to validity, the study demonstrates high internal consistency reliability, as reflected in both Composite Reliability (CR) and Cronbach's Alpha (CA) scores. All CR values exceeded 0.70, indicating that the constructs are internally coherent and that the indicators are consistent in measuring the same underlying concept (Hair et al., 2019). Similarly, Cronbach's Alpha values for all constructs were above 0.70, further validating the robustness of the measurement instruments used in this study. These results align with prior research, such as that by Yusuf & Yusuf (2019) and Feyzioğlu et al. (2018), which emphasized the importance of developing reliable and valid scales to assess complex constructs like self-confidence and educational technology use in learning.

The strength of the outer model confirms that the conceptual framework derived from the literature review is not only theoretically sound but also empirically valid. In particular, constructs such as metacognitive skills—which are central to this study—were measured with high reliability and validity, reinforcing their role as a legitimate mediating factor. Previous studies (e.g., Oyovwi et al., 2021; Nunaki et al., 2019) have stressed the need for robust measurement of metacognitive processes to understand their role in academic outcomes. The successful validation of these constructs supports the continuation of the structural model analysis and enhances confidence in the interpretation of the path coefficients in the inner model.

Thus, outer model in this research offers strong psychometric evidence that supports the measurement validity and reliability of all constructs. This provides a solid foundation for interpreting the structural relationships between Problem-Based Learning, technology use, creative thinking, self-confidence, metacognitive skills, and student retention in the subsequent inner model analysis.

4.3.2 Inner Model Evaluation (Structural Model)

The inner model evaluates the strength and significance of the relationships between latent variables. The coefficient of determination (R^2) and path coefficients were analyzed to assess the predictive power of the model. The resulting structural equations are presented below:

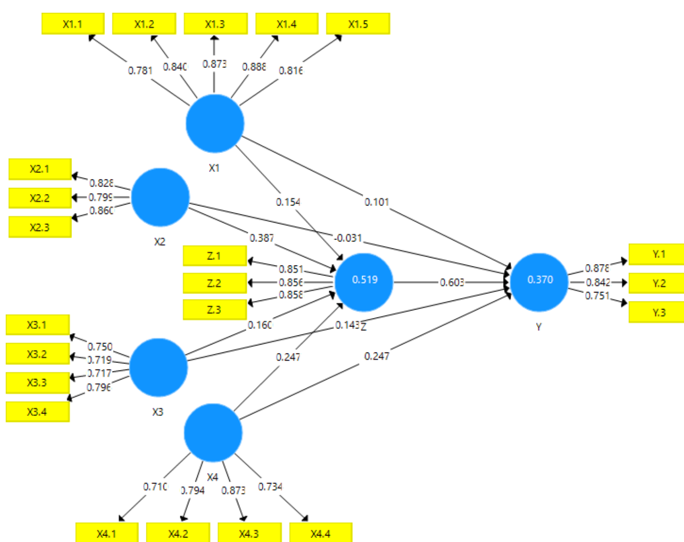


Figure 8. SEM-PLS Structural Model

Based on Figure 8, the Structural Equation Modeling (SEM) equations can be outlined as presented in the following table:

Table 4. Structural Equations

No.	Structural Equation	Description
1	$Z= 0,154X_1+0,387X_2+0,160X_3+0,247X_4$	$R^2 = 0,519$
2	$Y= 0,101X_1-0,031X_2+0,143X_3+0,247X_4+0,603Z$	$R^2 = 0,370$

Source: Processed with SmartPLS, 2024

The results of the inner model analysis provide meaningful insights into the structural relationships among the studied variables. First, the R^2 value of 0.519 for metacognitive skills indicates that 51.9% of the variance in students' metacognitive abilities can be explained collectively by four predictor variables: Problem-Based Learning (PBL), utilization of educational technology, creative thinking ability, and self-confidence. According to Hair et al. (2019), this represents a moderate to substantial effect size, which suggests a solid predictive relationship. This finding supports theoretical claims that metacognitive development does not occur in isolation but is influenced by both instructional strategies and individual learner attributes.

More specifically, the positive path coefficients from PBL and educational technology to metacognitive skills are in line with the constructivist view of learning, where students become active participants in constructing knowledge through engagement, reflection, and self-monitoring (Yusuf & Yusuf, 2019; Ginting et al., 2016). PBL, by requiring students to identify problems, formulate hypotheses, and evaluate solutions, inherently demands metacognitive engagement. Similarly, the integration of educational technology—such as interactive simulations or online platforms—can foster metacognitive awareness by enabling learners to set goals, monitor their progress, and receive immediate feedback (Feyzioğlu et al., 2018; Yusuf et al., 2023).

Moreover, the contributions of creative thinking and self-confidence to metacognitive skill development are also noteworthy. Students with high levels of creativity are often more flexible in thinking, more open to alternative approaches, and more adept at reflecting on their own thought processes (Neolaka & Corebima, 2018). This flexibility naturally aligns with metacognitive practices such as evaluating one's own learning strategies. Meanwhile, self-confidence serves as a motivational anchor that encourages students to take control of their learning, persevere in monitoring comprehension, and make adjustments as needed—behaviors central to metacognitive functioning (Lone, 2021; Taufik & Vandita, 2023). Thus, the model supports the conceptualization of metacognition as a bridge variable that connects instructional context and personal learner traits with learning outcomes.

Turning to student retention as the ultimate dependent variable, the R^2 value of 0.370 suggests that the combination of five predictors—PBL, educational technology, creative thinking, self-confidence, and metacognitive skills—explains 37.0% of the variance in student retention in Biology learning. Although this effect size is classified as moderate, it provides robust evidence that these factors, taken together, play an important role in influencing how well students retain and apply knowledge over time. Crucially, the path coefficient of 0.603 from metacognitive skills to retention is the most substantial among the predictors, reinforcing its role as a central mediator in the model.

This strong influence of metacognition on retention echoes findings from previous research (Usman et al., 2021; Nunaki et al., 2019), which argue that students with developed metacognitive abilities are better equipped to regulate their learning strategies, reflect on their understanding, and link new knowledge with existing mental frameworks—leading to deeper and more durable learning. From a theoretical perspective, this supports Flavell's metacognitive theory, which emphasizes the importance of awareness and regulation in achieving meaningful learning outcomes.

Interestingly, while PBL and creative thinking show direct and positive effects on both metacognition and retention, educational technology's direct impact on retention appears weak and slightly negative in the model. This may suggest that while technology can enhance how students learn (by boosting metacognitive engagement), it does not automatically enhance what students retain unless mediated by effective strategy use. This finding aligns with Scarpin et al. (2018), who caution that the effectiveness of educational technology depends heavily on its pedagogical integration and students' ability to self-regulate in digital environments.

In summary, the inner model analysis confirms that both external instructional methods (like PBL and technology) and internal learner attributes (such as creativity and confidence) are important predictors of metacognitive skill development, which in turn significantly influences student retention in Biology. These findings validate the study's conceptual model and offer empirical support for designing more holistic and strategy-based interventions in science education. They also reinforce the need for future studies to explore how instructional designs can more effectively support students' metacognitive growth and long-term knowledge retention.

4.3.3 Model Fit Assessment

To evaluate the overall adequacy of the structural model, several model fit indices were used, including the Standardized Root Mean Square Residual (SRMR) and the Normed Fit Index (NFI). The SRMR value obtained in this study was 0.061, which is well below the generally accepted threshold of 0.08, as recommended by Hu and Bentler (1999). This indicates that the difference between the observed and predicted correlations is minimal, and the model has a good absolute fit to the empirical data. A low SRMR value suggests that the model effectively captures the underlying structure of the relationships among the latent constructs, which strengthens the credibility of the model in explaining student retention in biology learning.

Similarly, the NFI value was found to be 0.921, which exceeds the conventional benchmark of 0.90 (Bentler & Bonett, 1980). The NFI assesses the incremental fit of the proposed model compared to a null or baseline model with no relationships among variables. An NFI greater than 0.90 is generally interpreted as indicating that the hypothesized model significantly improves the explanation of variance over a non-structured model. This high NFI provides strong support for the argument that the inclusion of both external (e.g., Problem-Based Learning and educational technology) and internal (e.g., creative thinking and self-confidence) predictors—along with metacognitive skills as a mediating variable—is theoretically justified and statistically sound.

In addition to the fit indices, the study also assessed the predictive relevance (Q^2) of the model using blindfolding procedures within the SEM-PLS framework. The Q^2 values for both endogenous constructs—metacognitive skills and student retention—were found to be greater than zero, which indicates that the model has acceptable predictive relevance (Hair et al., 2019). In other words, the model is not only statistically fit but also useful in predicting outcomes beyond the sample data. This is especially significant in the context of educational research, where models must not only explain past learning behaviors but also inform future instructional design and decision-making.

The overall model fit confirms that the theoretical structure proposed in this study—anchored in constructivist learning theory, metacognitive theory, and self-regulated learning frameworks—is consistent with empirical data. These results align with previous SEM-based educational studies that emphasize the importance of establishing model validity through multiple fit indices to support hypothesis testing and theoretical contributions (e.g., Feyzioğlu et al., 2018; Usman et al., 2021).

In summary, the combination of low SRMR, high NFI, and positive Q^2 values demonstrates that the structural model presented in this study is both well-fitting and predictive. This reinforces the model's utility for explaining how instructional strategies and student attributes interact to influence metacognitive development and long-term retention in Biology education.

4.4 Hypothesis Testing Results

The results of hypothesis testing using Structural Equation Modeling (SEM) in this study are presented in the following table:

Table 5. Hypothesis Testing Results

No	Influence	$t_{Stat.}$	P_{Value}
1	PBL Learning Model -> Students' Metacognitive Skills	2.690	0.007***
2	Utilization of Educational Technology -> Students' Metacognitive Skills	7.273	0.000***
3	Creative thinking abilities -> Students' Metacognitive Skills	2.843	0.005***
4	Students' Confidence -> Students' Metacognitive Skills	3.729	0.000***
5a	PBL Learning Model -> Students' Retention	1.805	0.072^{ns}
5b	PBL Learning Model -> Students' Metacognitive Skills -> Students' Retention	2.679	0.008***
6a	Utilization of Educational Technology -> Students' Retention	-0.545	0.586^{ns}
6b	Utilization of Educational Technology -> Students' Metacognitive Skills -> Students' Retention	5.461	0.000***
7a	Creative thinking abilities -> Students' Retention	2.247	0.025**
7b	Creative thinking abilities -> Students' Metacognitive Skills -> Students' Retention	2.782	0.006***
8a	Students' Self-Confidence -> Students' Retention	3.304	0.001***
8b	Students' Self-Confidence -> Students' Metacognitive Skills -> Students' Retention	3.364	0.001***
9	Students' Metacognitive Skills -> Students' Retention	9.323	0.000***

^{ns} not significant

*. Significant at the 0.1 level (2-tailed).

** Significant at the 0.05 level (2-tailed).

***. Significant at the 0.01 level (2-tailed).

Source: Processed with Smart-PLS, 2024

Based on the above analysis, the hypothesis testing can be interpreted as follows:

4.4.1 The Influence of the PBL Learning Model on Students' Metacognitive Skills in Biology Subjects

Based on the table above, the results indicate that the t_{count} or the influence of the PBL (Problem-Based Learning) model on students' metacognitive skills in biology is 2.690, with a probability value (P-value) of 0.007. The t_{count} is greater than the t-table value of 1.96. Since the P-value is smaller than the significance level, it can be concluded that the PBL model positively and significantly affects students' metacognitive skills in biology in senior high school throughout Gorontalo city. The positive effect suggests that the more effectively the PBL model is implemented by teachers in senior high schools across Gorontalo City, the better the students' metacognitive skills in biology will be. PBL is a learning approach that places students in an active role in solving real-world problems or complex situations relevant to the subject matter. This approach encourages students to develop a deep understanding through investigation, collaboration, and reflection on their learning process (Sembiring et al., 2021; Kusuma & Nurmawanti, 2023).

4.4.2 The Effect of Utilizing Educational Technology on Students' Metacognitive Skills in Biology Subjects

The t_{count} for the impact of utilizing educational technology on students' metacognitive skills in biology is 7.273, with a probability value (P-value) of 0.000. This t_{count} value is greater than the t_{table} value of 1.96. Since the P-value is smaller than the 5% alpha value, it can be concluded that the utilization of educational technology has a positive and significant effect on students' metacognitive skills in biology subject in senior high school throughout Gorontalo city. The positive effect indicates that the more effectively and adequately educational technology is utilized, the better the improvement in students' metacognitive skills in biology. Effective use of educational technology enriches the learning experience and enables students to develop essential metacognitive skills (Danardono et al., 2019; Pirrone et al., 2021). By facilitating access to diverse resources, supporting collaborative learning, providing self-reflection tools, and enabling adaptive learning, technology can significantly improve students' ability to manage and organize an effective and efficient learning process for complex knowledge acquisition.

4.4.3 The Effect of Creative thinking ability on Students' Metacognitive Skills in Biology Subjects

The t_{count} value for the effect of creative thinking ability on students' metacognitive skills in biology subjects is 2.843, with a probability value (P-value) of 0.005. This t_{count} value is greater than the t_{table} value of 1.96. Since the P-value is smaller than the 5% alpha value, it can be concluded that creative thinking ability positively and significantly affects students' metacognitive skills in biology in senior high school throughout Gorontalo city. The positive effect indicates that students in Gorontalo City's senior high schools who are more creative in their thinking tend to have better metacognitive skills in biology. Creativity and metacognitive skills complement and reinforce each other. Students who develop creative thinking become more innovative and adaptive in responding to learning challenges and more skilled in managing an ideal learning process (Wilis et al., 2023). Therefore, education that supports and promotes creative thinking can significantly improve the quality of students' metacognitive skills, equipping them with a strong foundation for successful learning and academic achievement.

4.4.4 The Effect of Students' Self-Confidence on Their Metacognitive Skills in Biology

The t_{count} value for the effect of students' self-confidence on their metacognitive skills in biology subjects is 3.729, with a probability value (P-value) of 0.000. This t_{count} value is greater than the t_{table} value of 1.96. Since the P-value is smaller than the 5% alpha value, it can be concluded that students' self-confidence positively and significantly affects their metacognitive skills in Biology in senior high school throughout Gorontalo city. The positive effect suggests that the higher the students' self-confidence, the better their metacognitive skills in biology in senior high school throughout Gorontalo city. High self-confidence also influences students' ability to overcome obstacles or difficulties in learning. Students who have confidence in their abilities are more likely to take risks when facing learning challenges, seek alternative solutions, and use learning experiences as opportunities for growth and improvement (Bozgün & Kösterelġoğlu, 2023). With strong metacognitive skills, students can manage frustration or disappointment constructively and focus on making improvements. Hence, education that fosters and builds students' self-confidence can help create a learning environment that supports and promotes the development of strong and sustainable metacognitive skills.

4.4.5 The Effect of the PBL Learning Model on Students' Retention in Biology Subjects

The t_{count} value for the effect of the PBL model on students' retention in biology subjects is 1.805, with a probability value (P-value) of 0.072. This t_{count} value is smaller than the t_{table} value of 1.96, and the P-value is greater than the 5% alpha value. Thus, the PBL model has a positive but not significant effect on students' retention in biology in senior high school throughout Gorontalo city. The positive effect indicates that when the PBL model is well-implemented in teaching and learning activities, it can benefit students' retention in biology in senior high schools throughout Gorontalo City. When students solve problems or explore authentic case studies, they are more likely to understand the relevance of the subject matter to real-life situations.

This engagement makes students more emotionally and cognitively involved in the learning process, strengthening their retention of the information learned (Lailaturrahmah et al., 2020). However, the non-significant effect is suspected due to students' limited understanding of the PBL structure or insufficient experience working in teams, which may require additional guidance to understand the objectives of PBL, utilize effective problem-solving strategies, and develop the collaborative skills necessary for PBL activities.

Furthermore, for the indirect effect (through students' metacognitive skills), the t_{count} value is 2.679, with a probability value (P-value) of 0.008. This t_{count} value is greater than the t_{table} value of 1.96, and the P-value is smaller than the 5% alpha value. Therefore, the PBL model, through students' metacognitive skills, has a significant impact on students' retention in biology subjects in senior high school throughout Gorontalo city. This indicates that students' metacognitive skills can effectively serve as an intervening variable to enhance the impact of the PBL model on students' retention in biology. Consequently, metacognitive skills play a crucial role in helping students manage and organize their learning processes effectively, allowing them to better understand and internalize the biology material. Thus, this leads to students retaining information in the long term and applying that knowledge in various contexts and situations, thereby demonstrating good retention.

4.4.6 The Effect of Utilizing Educational Technology on Students' Retention in Biology Subjects

The t_{count} value for the effect of utilizing educational technology on students' retention in biology subjects is -0.545, with a probability value (P-value) of 0.586. This t-value is smaller than the t-table value of 1.96, and the P-value is greater than the 5% alpha value. Therefore, the utilization of educational technology has a negative but not significant effect on students' retention in biology subjects in senior high schools throughout Gorontalo City. The negative effect suggests that the advancement of technology in learning has not improved students' retention of biology, and there is even a tendency for retention to decline with the use of educational technology. Advanced educational technology often focuses on the rapid and interactive delivery of information but lacks emphasis on deep processing and reflection by students. For instance, although there are many online learning resources such as videos, interactive simulations, and educational apps, not all of these platforms are designed to encourage deep reflection and critical consideration of the subject matter by students. Students' dependence on technology in learning can reduce opportunities for direct learning experiences or active involvement in the learning process. Direct interaction with teachers and peers is crucial in building deep understanding and retaining information in long-term memory. When technology is used excessively, it can diminish the social and collaborative interactions that support effective learning.

The non-significant effect may be due to the lack of intensive training for teachers in effectively utilizing technology in learning or the insufficient integration of technology into the curriculum to meet students' learning needs, which can diminish the positive effect of technology on student retention. Meanwhile, from the students' perspective, there are times when they are less focused on using technology for learning because they tend to use it for other activities they find more enjoyable. A careful approach is needed in designing the use of technology to support the development of metacognitive skills, deep reflection, and social interaction, which are essential for maintaining and deepening students' understanding of the subject matter.

Furthermore, for the indirect effect (through students' metacognitive skills), the t_{count} value is 5.461, with a probability value (P-value) of 0.000. This t_{count} value is greater than the t_{table} value of 1.96, and the P-value is smaller than the 5% alpha value. Therefore, the utilization of educational technology, through students' metacognitive skills, significantly affects students' retention in biology subjects in senior high school throughout Gorontalo City. This indicates that students' metacognitive skills can effectively serve as an intervening variable to improve the impact of utilizing educational technology on students' retention in biology. The combination of effective use of educational technology and strong metacognitive skills forms an effective intervention to maximize student retention. A well-integrated approach between educational technology and the development of students' metacognitive skills enables more adaptive and personalized education, supporting strong retention and deep understanding of the subject matter (Alsarayreh, 2021; Villegas-Ch et al., 2023). Students who can manage their learning, take responsibility for the learning process, and actively participate in self-reflection and self-evaluation are more likely to retain the information learned longer.

4.4.7 The Effect of Creative Thinking Abilities on Students' Retention in Biology Subjects

The t_{count} value for the effect of creative thinking abilities on students' retention in biology was 2.247, with a probability value (P-value) of 0.025. This t_{count} value is greater than the t-table value of 1.96, and the P-value is smaller than the 5% alpha value. Therefore, creative thinking abilities positively and significantly affect students' retention in biology subjects in senior high school throughout Gorontalo City. Students with strong creative thinking abilities not only retain information more effectively but can also integrate new knowledge into their existing knowledge structures more deeply (Suciati et al., 2024). This improves students' retention of the subject matter and prepares them to face more complex and various learning challenges in the future. Therefore, it is important for education to encourage and develop creative thinking abilities in students as an integral part of the learning process, ensuring that subject matter and practices can be remembered and accessed by students (Khofifah et al., 2023).

Further, for the indirect effect (through students' metacognitive skills), it was found that the t_{count} value for the indirect effect of the creative thinking abilities variable was 2.782, with a probability value (P-value) of 0.006. The t_{count} value is greater than the t-table value of 1.96, and the P-value is smaller than the 5% alpha value. Therefore, creative thinking skills, through students' metacognitive skills, positively and significantly impact students' retention in biology subjects in senior high school throughout Gorontalo City. This indicates that students' metacognitive skills can serve as an effective intervening factor in improving the effect of creative thinking abilities on students' retention in biology subjects. Metacognitive skills promote deep reflection on learning experiences. Students who can metacognitively reflect on their creative thinking processes are able to identify factors that support or hinder their success in understanding the material (Meitiyani et al., 2022). As a result, metacognitive skills lead to deeper, more sustainable, and relevant learning for students, allowing them to retain information in the long term and apply it in different contexts.

4.4.8 The Effect of Students' Self-Confidence on Their Retention of Biology Subjects

Self-confidence significantly affects student retention in biology subjects, as demonstrated by a t_{count} of 3.304 and a probability value (P-value) of 0.001. The t_{count} is greater than the t_{table} value of 1.96, and the P-value is smaller than the alpha value of 5%, indicating that confidence positively and significantly influences student retention in biology subjects in senior high school throughout Gorontalo City. The positive impact suggests that students with high self-confidence levels are more likely to retain information effectively in biology subjects. High self-confidence plays a crucial role in influencing retention by affecting motivation, resilience in facing challenges, and the use of effective learning strategies. Students who believe in their abilities are more likely to confront and overcome learning difficulties and develop strong memory skills. Hence, educators and learning environments need to foster and support the development of student self-confidence as part of efforts to improve academic achievement and deep understanding of the subject matter (Kim, 2022; Handayani et al., 2023).

The indirect effect (through students' metacognitive skills) revealed that the t_{count} value for the indirect impact of students' self-confidence was 3.364 with a probability value (P-value) of 0.001. Since the t_{count} value is greater than the critical t-table value of 1.96 and the P-value is less than the alpha value of 5%, it indicates that students' self-confidence significantly affects their retention of biology subject subjects in senior high school throughout Gorontalo City. This indicates that students' metacognitive skills can serve as an effective intervening variable to improve the impact of self-confidence on students' retention in biology subjects. Thus, they create a supportive learning environment that facilitates better retention. Confident students who can effectively manage their learning processes are more likely to remember and retain the information they have learned for a longer period. Therefore, educators should focus on developing metacognitive skills in instructional design to foster self-confidence and improved student retention.

4.4.9 The Effect of Students' Metacognitive Skills on Student Retention in Biology Subjects

The t_{count} value for the effect of students' metacognitive skills on their retention in biology subjects was found to be 9.323, with a probability value (P-value) of 0.000. Since the t_{count} value is greater than the critical value of 1.96 and the P-value is less than the 5% alpha value, it indicates that students' metacognitive skills significantly affect their retention in senior high school throughout Gorontalo City. The positive effect indicates that students with strong metacognitive skills tend to have better retention in biology subjects. Metacognitive skills are a crucial aspect of effective and sustainable learning processes. A student's ability to regulate and manage their learning process, as well as to monitor and evaluate their understanding, directly contributes to their retention of the subject matter. Therefore, educators should support the development of students' metacognitive skills through structured teaching and integrated reflection within the learning experience, leading to improved and sustained retention, even in different contexts.

Based on the various results above, it can be concluded that students' metacognitive skills serve as an effective intervening variable, improving the impact of Problem-Based Learning (PBL) models, the use of educational technology, creative thinking abilities, and students' self-confidence on their retention levels. This highlights the importance of developing metacognitive skills in effective and sustainable learning design to achieve optimal learning outcomes (Ramadhanti & Yanda, 2021). Metacognitive skills enable students to manage and regulate their learning process. They can plan effective approaches to solving problems or tasks, monitor their progress in understanding concepts, and evaluate their strategies. This ability directly supports deeper understanding and better retention of learning material, as students actively link new information with existing knowledge in their memory.

Metacognitive skills enable students to effectively utilize various technological tools and resources in the learning process. Students can identify the best ways to leverage technology to support their understanding of the material and retain the information they have learned. Creative thinking abilities can also be improved through metacognitive skills, as students can plan and evaluate various creative problem-solving strategies. When students connect different concepts and create new solutions, they are more likely to understand the material thoroughly and retain their understanding in the long term (Ernawati et al., 2022). Additionally, students who can effectively monitor and evaluate their learning progress (i.e., those with strong metacognitive skills) tend to have a more positive perception of their own abilities as competent learners. This contributes to higher motivation to learn and to invest the time and effort needed to deeply understand and retain the material.

5. Conclusion

This study investigated the effects of the Problem-Based Learning (PBL) model, the use of learning technology, students' creative thinking abilities, and self-confidence on metacognitive skills and retention in high school Biology learning in Gorontalo City. The descriptive results indicated that both the PBL model and the use of educational technology were rated as "good," whereas creative thinking ability, self-confidence, metacognitive skills, and retention were rated as "fairly good." Through SEM-PLS analysis, it was found that the PBL model, educational technology, creative thinking ability, and self-confidence had significant and positive effects on metacognitive skills. In turn, metacognitive skills played a crucial mediating role in influencing student retention.

Although the PBL model and educational technology did not have significant direct effects on student retention, their indirect effects through metacognitive skills were significant, indicating the importance of fostering self-regulated and reflective learning processes. Creative thinking and self-confidence emerged as strong predictors, showing both direct and indirect positive effects on retention. These results reinforce the theoretical proposition that internal learner attributes and external instructional strategies converge through metacognitive engagement to support long-term knowledge retention.

However, the study is not without limitations. First, it utilized a cross-sectional design, which restricts causal inference and does not capture changes over time. Second, the sample was limited to grade XI students in one city, which may limit the generalizability of the findings to broader populations or educational levels. Additionally, the reliance on self-reported data from questionnaires may be subject to response bias, despite efforts to validate the instrument.

Despite these limitations, the study offers important practical and theoretical contributions. It provides empirical support for integrating metacognitive skills as a mediating construct in educational models and underlines the need to develop policies and teaching strategies that promote creativity, self-confidence, and reflective learning practices in science education. For educational practitioners and policymakers, this research offers an evidence-based framework for improving retention outcomes by addressing both pedagogical methods and student-centered learning traits.

6. Recommendations and Future Research Directions

Based on the findings and limitations of this study, the following three key recommendations are proposed to improve student retention and metacognitive development in Biology education:

1. Embed Metacognitive Skills into Biology Instruction

Schools and educators should intentionally integrate metacognitive strategies—such as self-questioning, learning goal-setting, and reflective journals—into Biology learning. These practices can help students monitor their understanding, evaluate their learning strategies, and improve long-term retention. Metacognitive training should not be treated as a separate module but woven into daily classroom instruction through guided reflection and teacher feedback.

2. Enhance Learning Environments that Foster Creativity and Confidence

Learning environments should be designed to stimulate creative thinking and build students’ self-confidence. Teachers are encouraged to use open-ended tasks, project-based learning, and collaborative activities that allow students to express ideas, experiment with problem-solving, and take ownership of their learning. Confidence can also be nurtured through continuous formative assessment and positive reinforcement, which in turn contributes to stronger metacognitive engagement and knowledge retention.

3. Strengthen the Pedagogical Use of Educational Technology

The use of technology in Biology education must go beyond content delivery. Digital tools should be selected and implemented in ways that encourage interaction, exploration, and self-regulation. For example, simulations, quizzes with instant feedback, and virtual labs can enhance students' active engagement and metacognitive monitoring. Future research should also explore which types of technology-supported interventions most effectively contribute to metacognitive development and retention.

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Acknowledgments

The authors extend their gratitude to Universitas Negeri Gorontalo's Research and Community Service Institute (LPPM) for their support and confirm no conflicts of interest.

Authors contributions

Frida Maryati Yusuf and Elya Nusantari were responsible for the study design, literature review, and revision of the manuscript. Isnanto and Ilyas Husain conducted data collection and analysis. Nur Mustaqimah drafted the manuscript and prepared the initial interpretation of the findings. Frida Maryati Yusuf and Elya Nusantari provided final revisions and supervision of the overall research process. All authors read and approved the final version of the manuscript. Frida Maryati Yusuf and Elya Nusantari contributed equally to this work and share first authorship.

Funding

Not applicable.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Sciedu Press.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.