



Enhancing Analytical Thinking in Biology Through Project-Based Learning and Self-Regulated Learning: The Moderating Role of Prior Knowledge

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ABSTRACT

Analytical thinking skills are a crucial competency in 21st-century biology education but remain a significant weakness at the senior secondary level. This study is driven by the need to develop learning strategies that are not only active and constructive but also adaptable to differences in student characteristics, particularly regarding initial abilities and self-regulation. The main issue addressed is how to combine Project-Based Learning (PjBL) and Self-Regulated Learning (SRL) to enhance students' analytical thinking skills, and how prior knowledge influences the effectiveness of these strategies. The novelty of this study lies in integrating two pedagogical approaches—PjBL and SRL—within a single learning framework evaluated through cognitive outcomes and processes, as well as analysing the role of prior knowledge as a moderating variable. This research employs a quantitative method with a 2×3 factorial quasi-experimental design, involving two learning models (PjBL and Discovery Learning), three SRL categories (high, medium, low), and prior knowledge as a covariate. Findings reveal that PjBL is significantly more effective than Discovery Learning in developing analytical thinking skills, particularly among students with medium and low SRL levels. Additionally, a notable interaction exists between the learning model and SRL, suggesting that the model's effectiveness heavily depends on the student's level of self-regulation. Prior knowledge also significantly impacts learning outcomes. These results contribute both theoretically and practically to designing biology education that responds to student differences and underline the importance of structural support in fostering higher-order thinking skills through project-based learning.

KEYWORDS

Analytical thinking; project-based learning; discovery learning; biology learning.

INTRODUCTION

Analytical thinking skills are a key competency needed in 21st-century biology education (Sukma et al., 2021). This ability is not only crucial for solving scientific problems but also for data-based decision-making, interpreting complex information, and addressing real-world issues faced by individuals in social and environmental contexts. However, studies indicate that students' analytical thinking skills in biology are still relatively limited, especially at secondary and tertiary levels, with difficulties in identifying problems, formulating hypotheses, drawing conclusions, and designing experiments (Fernández et al., 2022).

This argument is supported by initial observations and interviews with biology teachers conducted by researchers at SMA Negeri 8 Kendari. It is explained that the learning model used so far in schools is the discovery learning model. The application of this model can gradually increase and stimulate students' curiosity to continue learning until they find answers to the problems posed by the teacher (Rahayuningsih et al., 2023). However, in practice, teachers face several obstacles when implementing the discovery learning model. These include students' difficulties in connecting concepts they have learned with the problems they encounter in learning, and at times students are unable to find concepts, resulting in unmet learning objectives. Students also struggle with analysing, integrating, reorganising materials, and drawing conclusions. Additionally, there is a lack of motivation for students to learn independently, as they do not have clear learning goals and tend to rely on guidance from others. Their analytical skills tend to be unstable, often depending on the level of support they receive; without guidance, these skills tend to decline. Students also find it difficult to manage their study schedules and often lack a sense of responsibility. Consequently, the minimum completion criteria set by the school have not been met, with only 75% of students achieving a score of 70 or above (Data and information obtained from the biology teacher at Senior High School 8 Kendari). This data illustrates that many students still do not meet the minimum competency standards established by the school, particularly in the topics on the structure and function of organs in class XI. This signals an urgent need to develop a learning approach capable of systematically stimulating higher-level thinking processes.

One effective method for enhancing higher-order thinking skills is Project-Based Learning (PjBL), which enables students to acquire knowledge and skills through investigation and response to engaging and complex problems or challenge (Coyne et al., 2016). Project-based learning provides opportunities for collaboration, reflection, and engagement with meaningful content. It is a student-centered approach that empowers learners to take responsibility for their own learning while teachers act as facilitators (Kim et al., 2021). Multiple studies have indicated that PjBL fosters active and experiential learning, transforming students from passive recipients into active participants (Günzel & Brehm, 2024). PjBL can be conducted individually or collaboratively over a designated period, with the objectives potentially including the creation of a product, delivery of a presentation, or performance. This pedagogical approach facilitates the development of skills and encourages greater engagement in learning by allowing

students to address real-life problems through project work (Botes & Philip, 2025; Fayanto et al., 2024; Muliawan et al., 2016). Therefore, PjBL is deemed suitable for meeting the educational needs of students, particularly in overcoming challenges encountered during biology instruction at Senior High School 8 Kendari. The implementation of PjBL is anticipated to promote active participation across various cognitive and behavioural systems, thereby fostering the formation of patterns and components essential for achieving an optimal learning environment.

Previous studies have shown that PjBL can significantly improve students' analytical abilities in biology learning. For instance, research by Jagantara et al. (2014), as well as Chiang & Lee (2016), found that students taught using PjBL performed better in biological analysis tasks compared to those taught through direct instruction. Additional studies Wekesa & Ongunya (2016) have also demonstrated PjBL's positive effects on students' academic achievement and attitude by improving understanding of complex topics such as organism classification. However, the practical application of Project-Based Learning (PjBL) in Indonesian classrooms often falls short in achieving its intended impact, particularly in fostering analytical reasoning and promoting learner autonomy. This disconnects between the theoretical potential of PjBL and its classroom implementation highlights a crucial gap that warrants further empirical investigation. Challenges include students' limited engagement in complex problem-solving and teachers' inconsistent facilitation of autonomous learning processes

Additionally, Self-Regulated Learning (SRL) plays a crucial role in supporting reflective and autonomous learning processes, which are highly pertinent in addressing the complexities inherent in biological content. Self-regulation constitutes an active and constructive process whereby students regulate and monitor their behavior, motivation, and cognition through the establishment of personal goals during the learning process (Kayacan & Sonmez-Ektem, 2019). Self regulated was a crucial ability that influences both personal and social life. It helps individuals distinguish appropriate behavior and adapt effectively to their environment for personal growth (Aktas & Sop, 2022; Rafni et al., 2024). The SRL process employs effective strategies to acquire knowledge or skills and is influenced by motivation, metacognitive processing, and behavior (Ratnayake et al., 2024). Although each of these approaches has been extensively studied, the integration of Project-Based Learning (PjBL), SRL, and prior knowledge into a comprehensive learning framework remains underrepresented in the literature. Furthermore, the impact of prior knowledge as a moderating variable on the efficacy of these approaches has not been thoroughly examined.

The main problem in this study is designing a biology learning strategy that is active, constructive, and adaptive to differences in students' initial abilities. In other words, the challenges are: how can PjBL and SRL be synergistically integrated to improve analytical thinking, and how does students' prior knowledge influence the strategy's effectiveness? This question is important because in many cases, the failure of implementing innovative approaches is often caused by not considering students' initial characteristics, such as student mastery of basic concepts or readiness for independent learning.

The review of current literature reveals a research gap. Most studies on PjBL, Prior knowledge, and SRL tend to examine each approach separately without considering their integration, especially in biology learning (Based on keywords on the Scopus page "Project Based Learning", "Prior knowledge", "self regulated learning"). Project-Based Learning (PjBL) is a natural context for cultivating analytical thinking—understood here as the ability to decompose problems, examine relations among parts, and justify conclusions (often treated as the “analysis–evaluation–inference” core within critical thinking). Reviews and frameworks in Thinking Skills and Creativity emphasise that analysis sits at the heart of critical/analytical thinking outcomes educators target (Dwyer et al., 2014). In PjBL, authentic, open-ended tasks require learners to scope a problem, gather and interrogate evidence, compare alternatives, and defend solutions—all behaviours aligned with analysis. Large-scale evidence backs this a recent meta-analysis of PjBL studies reported positive effects on learning and higher-order thinking, with stronger results when projects were well-scaffolded (Zhang & Ma, 2023). Complementary syntheses also tie PBL/PjBL to measurable critical-thinking processes (e.g., analysis and inference) used in widely adopted assessments (Loyens et al., 2023).

Self-Regulated Learning (SRL) provides the mechanism for how PjBL translates into gains in analytical thinking. SRL’s cyclical phases—planning (goal-setting/strategising), performance (self-monitoring/strategy use), and self-reflection (self-evaluation/adaptive regulation)—map cleanly onto the project cycle (project planning, milestone monitoring, post-mortem reflection)(Zimmerman, 2002). When PjBL environments deliberately cue SRL (e.g., planning prompts, monitoring dashboards, structured reflection), students take more responsibility for evidence use and reasoning quality. Design papers and studies in problem-/project-based settings show that explicitly supporting SRL in PjBL boosts students’ regulation and deep approaches to tasks, which are proximate drivers of analytical performance (English & Kitsantas, 2013; Splichal et al., 2018). Meta-analytic evidence further indicates that (a) SRL instruction and scaffolds have reliable, positive effects on achievement, especially when they target planning, monitoring, and reflection, and (b) regulated-learning scaffolds in tech-rich settings improve both regulation and academic performance. These findings justify building SRL supports into PjBL to elevate analytical thinking rather than assuming such skills emerge spontaneously (Donker et al., 2014; Shao et al., 2023; Zheng, 2016).

Prior knowledge is expected to moderate these effects. A recent meta-analysis in Educational Psychologist synthesising ~500 longitudinal studies show prior, domain-specific knowledge is a strong positive predictor of subsequent learning—though the relation can differ by outcome type (e.g., memory vs. problem-solving)(Simonsmeier et al., 2022). So that need to assess students’ prior knowledge, as sufficient initial understanding may reduce the need for extensive guidance—aligning with the cognitive load perspective that instructional supports should be adapted to learners’ expertise levels (Nurfadillah et al., 2020). Cognitive load theory deepens the prediction: for novices (low prior knowledge), heavy guidance and explicit SRL supports are beneficial; as knowledge grows, the same supports can become redundant or even

counterproductive—the classic “expertise-reversal effect (Kalyuga, 2007; Kalyuga et al., 2003). This explains why minimally guided, discovery-style approaches tend to underserve novices but can suit more knowledgeable learners who can self-provide internal guidance; it also implies that structured SRL scaffolds should matter most for students entering PjBL with lower prior knowledge (Kirschner et al., 2006).

Put differently: in a hybrid PjBL + SRL design, gains in analytical thinking should be larger for low-knowledge students when planning/monitoring/reflection are scaffolded, while high-knowledge students may benefit from gradually faded scaffolds and greater autonomy—an aptitude-by-treatment interaction your moderation test is well-positioned to detect (English & Kitsantas, 2013; Shao et al., 2023). So, based on the explain, reseracher interesting to investigation effect of learning models and self-regulated learning on students' analytical abilities by controlling students' prior knowledge.

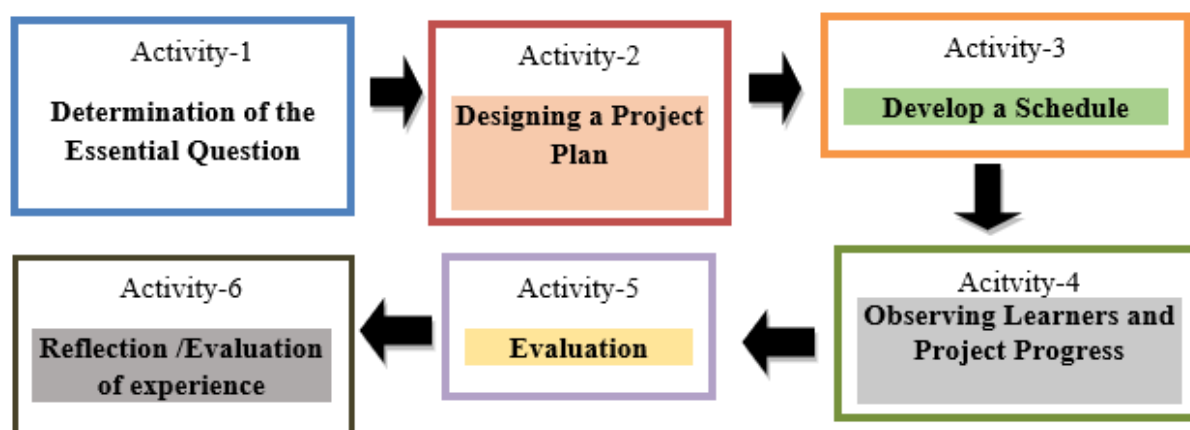
METHOD

Research Design

This study was conducted using a quantitative approach with a quasi-experimental design to examine the causal relationship between instructional models and students’ analytical skills, while considering the role of Self-Regulated Learning (SRL) and prior knowledge. The novelty of this study lies in integrating the Project-Based Learning (PjBL) model with the SRL approach to investigate their combined effects. A non-equivalent control group design was employed, involving two instructional models—PjBL and Discovery Learning—as independent variables. The moderator variable was students’ SRL, categorized into high, moderate, and low levels, while the dependent variable was students’ analytical skills in biology. The study followed a 2 × 3 treatment-by-level factorial design, which allowed for testing the main effects of the instructional model and SRL, as well as their interaction. Prior knowledge was measured through a pre-test and treated as a covariate in the ANCOVA to statistically control for baseline differences.

Figure 1.

PjBL activity for activity biology learning in class



(Adaption from Educational Technology Division, Ministry of Education, 2006).

Participants and Data Collection Tools

The population in this study comprised all Grade XI science students at Senior High School 8 Kendari, Kendari City, Southeast Sulawesi, Indonesia, totaling 123 students across four parallel classes. To ensure the representativeness of the sample and the feasibility of the research implementation, a purposive sampling technique was employed. The selection of classes was based on specific criteria, including similar average academic performance, being taught by the same biology teacher, and having class schedules compatible with the project-based learning approach. Homogeneity testing indicated no significant differences among the classes, justifying the selection of two comparable groups. Following this, Class XI Science 1 ($N = 27$ students) was randomly assigned as the experimental group, and Class XI Science 2 ($N = 30$ students) as the control group through a lottery method. Prior to the instructional intervention, students from both classes were assessed using a Self-Regulated Learning (SRL) questionnaire to determine their SRL levels. Based on the scores, students were categorized into high, moderate, and low SRL levels, with each category comprising approximately one-third of each class. The categorization follows a percentile-based approach using the SRL score distribution within the sample (P30 and P70 as lower and upper thresholds), aligning with best practices in learning analytics research the final sample consisted of 57 students, with a balanced distribution across SRL levels and learning models, ensuring the adequacy and fairness of the factorial design used in this study.

The SRL instrument used in this study is a non-test instrument in the form of a questionnaire designed to diagnose students' learning autonomy levels, categorized as high, medium, and low. The questionnaire employs a modified Likert scale with four response options: Strongly Agree (SA) = Score 4, Agree (A) = Score 3, Disagree (D) = Score 2, and Strongly Disagree (SD) = Score 1. The instrument covers metacognitive, motivational, and behavioral dimensions, with content validated by three experts and reliability confirmed through Cronbach's alpha ($\alpha > 0.70$). This instrument aims to explore several key aspects of SRL, including metacognition, motivation, and behavior during the learning process. In terms of metacognition, the questionnaire covers aspects such as practice strategies, elaboration strategies, organization strategies, and self-regulation in metacognition. For motivation, it includes indicators like relevance enhancement, situational interest, self-directed task performance, mastery of tasks, extrinsic performance, self-consequences, and environment structuring. Under behavior, the focus is on effort regulation, time management, and seeking help. To determine the percentage of respondents falling into the low, medium, and high categories based on the class intervals of the research data for each aspect, a simple percentage formula was applied. This involved dividing the frequency of respondents in each category by the total number of respondents, and then multiplying the result by 100 to obtain the percentage. The percentage values obtained were then interpreted based on standardized criteria using the following categorization scheme:

Table 1.*Standard criteria for self regulated learning categorization*

Self regulated learning Level	Criteria
High	$N \geq P70$
Moderate	$P30 \leq N < P70$
Low	$N < P30$

Table 2.*Analysis skills categorization criteria*

Score Range (%)	Category	Description
86 – 100	Very High	Demonstrates excellent analytical skills. Able to break down complex information, identify relationships logically, and draw conclusions based on data independently and accurately.
71 – 85	High	Able to analyze information well, find most relationships between elements, and make reasonably logical conclusions, although there may be minor errors.
56 – 70	Medium	Able to perform basic analysis, but there are still mistakes in identifying relationships or drawing conclusions. Requires guidance in solving complex problems.
41 – 55	Low	Shows limited ability to analyze information. Tends to memorize or state facts without understanding deeper relationships or meanings.
≤ 40	Very Low	Unable to analyze well. Struggles to break down information, cannot identify relationships, and conclusions drawn are illogical or irrelevant.

Analytical thinking was assessed through a content-validated multiple-choice test aligned with Bloom's Revised Taxonomy (analysis level), focused on the excretory system. Each item included one correct answer and four distractors, scored dichotomously (1/0). Score interpretation followed a standardized five-level categorization. This instrument is aligned with Bloom's Revised Taxonomy Anderson & Krathwohl (2001) focusing on higher-order thinking skills, particularly the ability to analyze. The indicators for analysis in the excretory system material include; (1) identifying the structure and function of excretory organs, (2) analyzing the process of urine formation, (3) explaining the relationship between organ damage and symptoms, (4) analyzing the causes of excretory system disorders based on symptoms, and (5) developing prevention strategies for excretory system diseases through a healthy lifestyle. After the data is collected and scores are obtained, students' analytical skills are categorized into five levels: very high, high, medium, low, and very low. This categorization is determined based on the percentage range of scores obtained by students from the total number of questions given.

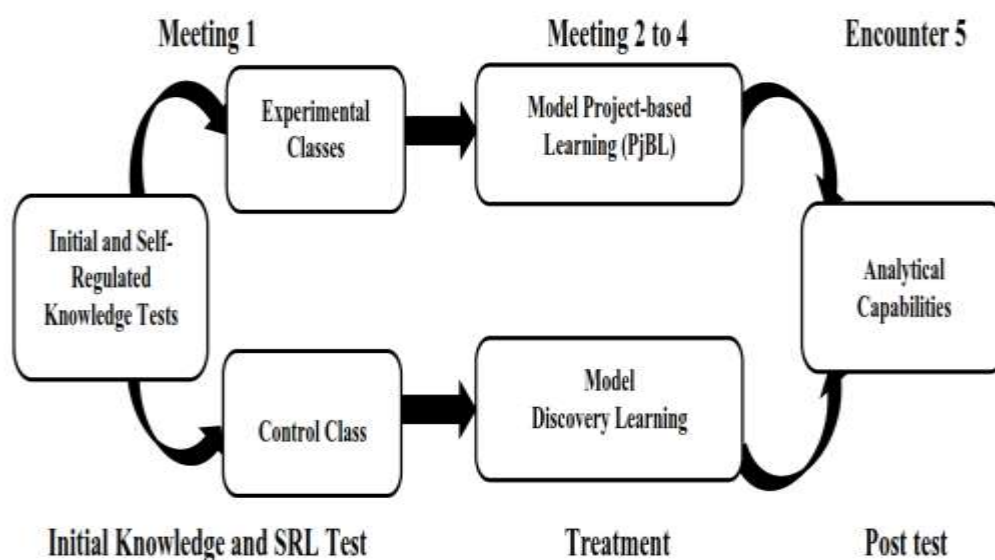
The standard criteria for categorizing analytical skills used in this study are presented in the following Table 2.

Experimental Process

The research procedure was carried out in three main stages. First, in the preparation stage, the researcher developed lesson plans for the excretory system topic based on the curriculum, with separate plans for the experimental group (using PjBL) and the control group (using Discovery Learning). Instruments for prior knowledge tests, analytical ability tests, and SRL questionnaires were also developed through a rigorous process including content review, item writing, validation, revision, trial testing, and reliability analysis. Second, during the implementation stage, a pretest on prior knowledge and an SRL questionnaire were administered to categorize students into high, moderate, and low SRL levels. Both the experimental and control groups received several sessions of treatment according to the school schedule: the experimental group with the PjBL model and the control group with the Discovery Learning model. Third, in the final stage, a post-test on analytical ability was given to both groups simultaneously under the same conditions. This was to examine the effect of the instructional models in relation to students' SRL levels. The test lasted 60 minutes. The three procedural stages of the research implementation are presented in Figure 1 below.

Figure 2.

Overview of the three-phase research procedure: preparation, implementation, and evaluation



Data Analysis Techniques

To ensure the validity and reliability of the study, several procedures were carried out based on the data analysis approach described. The validity of the instruments was maintained by using appropriate tools for each variable: tests were employed to measure students' analytical skills and prior knowledge, while a questionnaire was used to capture data on self-regulated learning (SRL). Reliability was supported through systematic data analysis using both descriptive and inferential approaches, assisted by SPSS version 21 and Microsoft Excel 2007, which ensured

accuracy in processing and interpreting the data. In addition, assumption testing, including normality, homogeneity, linearity, and regression line parallelism tests, was conducted to guarantee that the inferential analysis met the required statistical assumptions. Furthermore, the use of ANCOVA, followed by the Tukey test when interactions were found, reinforced the consistency of the findings and strengthened the study's overall reliability.

After the data collection process and implementation of learning interventions based on a 2×3 quasi-experimental design, an analysis was conducted to evaluate the effect of the learning model and the level of Self-Regulated Learning (SRL) on students' analytical abilities in the excretory system material. This analysis includes data descriptions, assumption tests, and inferential analysis using ANCOVA with control of students' prior knowledge as a covariate. This approach aims to gain an objective understanding of the effectiveness of the Project-Based Learning (PjBL) model compared to Discovery Learning and its interaction with the level of SRL in improving students' analytical thinking skills.

RESULTS

The results presented in this section include the distribution of scores based on indicators of analytical ability, comparisons between treatment groups, and the results of statistical significance tests to identify differences and interactions between the variables studied.

Table 3.

Average Scores of Students' Analytical Skills by Indicator

Indicator	A1B1	A1B2	A1B3	A2B1	A2B2	A2B3
1. Identifying important information	92	81	61	83	73	65
2. Explaining relationships between concepts	86	75	53	75	60	60
3. Explaining the relationship between organ damage and symptoms	78	56	52	67	57	53
4. Analyzing the causes of excretory system disorders based on symptoms	61	50	50	60	55	50
5. Evaluating arguments or proposed solutions	50	39	28	40	40	45
Note: By % (percentage)						

Based on Table 3, it can be seen that students' analytical abilities vary depending on the indicators tested. The highest ability is shown in the "Identifying important information" indicator, especially in groups A1B1 (92%) and A2B1 (83%). This means that most students are able to find important information from the material being studied. This can happen because this ability is still classified as a basic level of thinking ability, such as remembering and understanding, which students usually have mastered. On the other hand, the lowest score was found in the "Evaluating arguments or proposed solutions" indicator, especially in group A1B3 (28%). Evaluating arguments requires more complex thinking, such as assessing the truth of an idea or finding the most appropriate solution. This skill is included in high-level thinking and is

usually more difficult for students who are not used to discussing or thinking critically. This is why their scores tend to be low.

In addition, students' scores tend to decrease in almost all indicators. This decrease can be caused by several factors, such as increasingly difficult material, lack of understanding of previous concepts, or differences in teaching methods. Scientifically, this can be explained through the cognitive load Theory, which states that when students receive too much information at once, they have difficulty processing it, so that their learning outcomes decline. In indicators such as "Explaining relationships between concepts" or "Explaining the relationship between organ damage and symptoms", student scores also vary quite a bit. This shows that not all students can connect concepts well. This ability is important so that students can understand the lesson as a whole, not just memorize it. This low ability may be due to a lack of practice or learning activities that encourage students to think deeply. These results show that students need more critical thinking practice, not just memorizing. Teachers can help by giving challenging questions, group discussions, and problem-based learning. In this way, students will get used to analyzing, evaluating, and making decisions independently. Furthermore, Figure 2 reveals a clear relationship between the instructional model, SRL category, and analytical skill indicators. It is evident that students in the high SRL category consistently demonstrated higher analytical ability in the PjBL class compared to other groups. The scores for each indicator—such as identifying, comparing, connecting, and drawing conclusions—were consistently higher in this group, often falling within the high to very high categories. This indicates that a combination of project-based learning and high self-regulated learning yields more optimal outcomes for developing students' analytical thinking skills.

Figure 3.

The Relationship of Learning Models, SRL and Analytical Ability Indicators

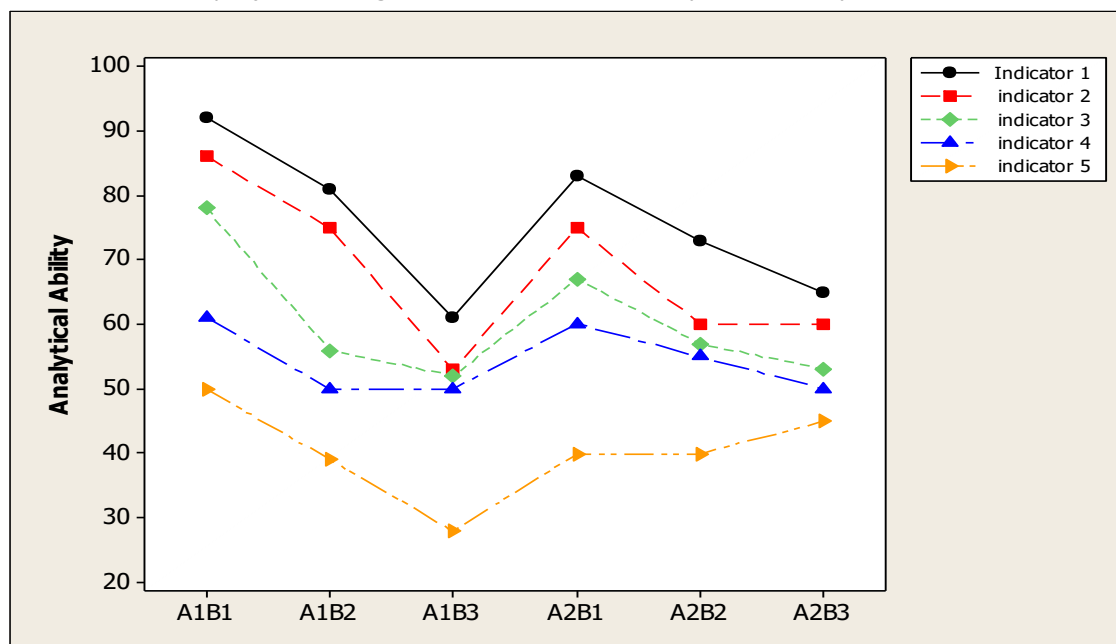


Figure 3 shows students' analytical skills in biology learning based on five indicators of analytical skills in several groups (A1B1 to A2B3). In general, Indicator 1 (Identifying important information) has the highest score consistently compared to other indicators, indicating that students tend to be more able to identify important information in a biological context. Indicator 2 (Explaining relationships between concepts) also shows high performance, reflecting students' ability to connect relevant biological concepts. However, a drastic decline in all indicators was seen in group A1B3, indicating possible pedagogical constraints, lack of understanding, or other external factors that hinder students' analytical skills. Interestingly, students' abilities increased again in group A2B1, indicating a recovery or improvement in learning strategies, before experiencing a moderate decline again in A2B2 and A2B3. Indicator 5 (Evaluating arguments or proposed solutions) consistently shows the lowest score, indicating that students still have difficulty in evaluating arguments or solutions to biological problems. This indicates that higher-order thinking skills still need to be improved, especially through a learning approach that emphasizes scientific argumentation and complex problem solving. Figure 1 suggests that sometimes students are able to perform basic analysis, such as identifying information and explaining conceptual relationships, but these students still need support in analyzing biological causes in depth and critically evaluating solutions.

To provide a more comprehensive of students' analytical skills performance in biology learning, the following quantitative data are presented in the form of descriptive tables. This presentation aims to show the differences in students' analytical skills achievement based on the learning model used and the level of Self-Regulated Learning (SRL).

Table 4.

Descriptive Statistics of Analytical Ability by Learning Model and SRL

Variable	Treatment	Data of statistic											
		Date total (n)		Average		Median		Minimum		Maximum		Standard Deviation	
		X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
A1		27	27	70.67	73.89	70.00	75.00	60.00	60.00	85.00	95.00	7.34	9.64
A2		30	30	62.00	66.11	60.00	70.00	40.00	45.00	85.00	85.00	13.62	11.27
A1B1		9	9	77.22	83.33	75.00	85.00	70.00	75.00	85.00	95.00	5.65	7.91
A2B1		10	10	75.50	78.50	75.00	80.00	70.00	75.00	85.00	85.00	4.97	3.37
A1B2		9	9	70.00	72.22	70.00	75.00	60.00	60.00	85.00	80.00	7.91	6.67
A2B2		10	10	58.50	58.50	60.00	62.50	45.00	45.00	65.00	85.00	6.26	10.66
A1B3		9	9	67.78	66.11	65.00	65.00	60.00	60.00	75.00	75.00	5.07	4.86
A2B3		10	10	49.50	49.00	50.00	55.00	40.00	45.00	60.00	70.00	6.58	10.29

Table 4 presents descriptive statistics of students' analytical abilities based on the Discovery Learning (X) and Project-Based Learning (Y) learning models and the level of Self-Regulated Learning (SRL). In general, group A1B1 (model A1 with high SRL) showed the highest average in both Discovery Learning (77.22) and Project-Based Learning (83.33), indicating that

the combination was the most effective in improving students' analytical abilities. In contrast, group A2B3 (model A2 with low SRL) had the lowest average (49.50 in Discovery Learning and 49.00 in Project-Based Learning), indicating the lowest effectiveness. This confirms that variations in learning models and SRL levels have a significant influence on students' analytical achievements. In addition, variations in scores are also seen from the high standard deviations, such as in A2 in Discovery Learning (13.62) and A1 in Project-Based Learning (9.64), reflecting differences in students' responses to the learning interventions provided. Furthermore, to find out the influence of learning models and levels of Self-Regulated Learning (SRL) on students' analytical abilities in more depth, an analysis of covariance (ANCOVA) was conducted. This analysis aims to test the significance of differences in analytical ability scores between treatment groups after controlling for relevant covariate variables.

Table 5.

ANCOVA Test Results of Students' Analytical Ability

Source	Type III Sum of Squares	df	Mean Square	<i>F</i>	Sig.
Corrected Model	8550.211 ^a	6	1425.035	56.772	<.000
Intercept	902.779	1	902.779	35.966	<.000
Prior knowledge	634.392	1	634.392	25.274	<.000
Learning models	1110.883	1	1110.883	44.256	<.000
Self-regulated learning	1921.927	2	960.964	38.284	<.000
Learning models- self regulated learning	203.448	2	101.724	4.053	<.023
Error	1255.052	50	25.101		
Total	270525.000	57			
Corrected Total	9805.263	56			

R-Squared = .872 (Adjusted R Squared = .857)

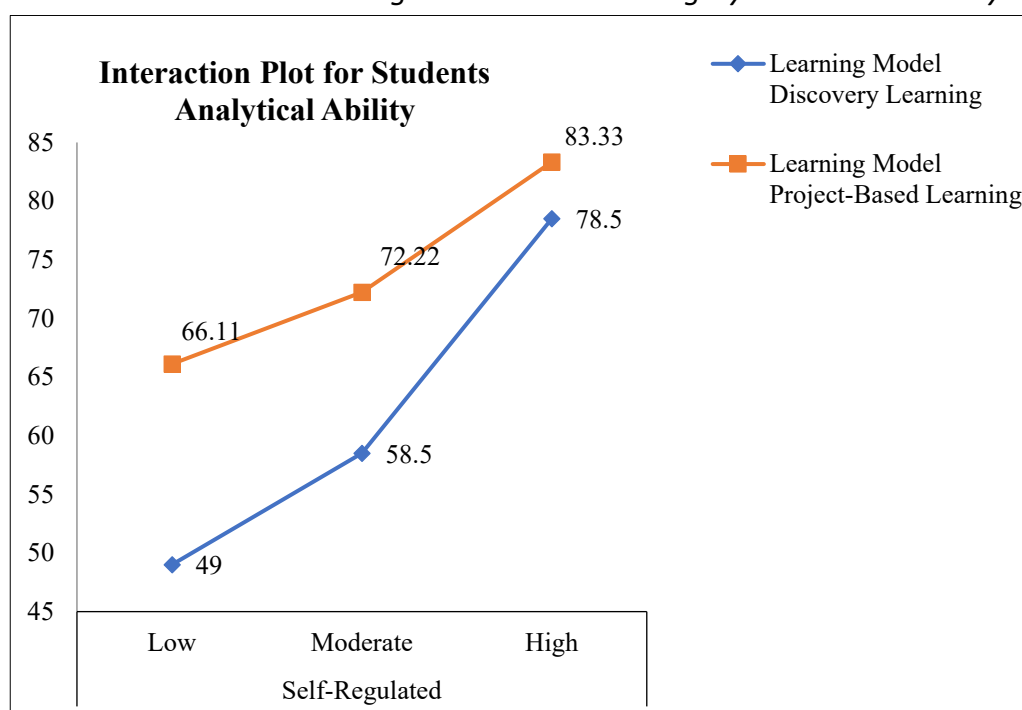
Based on the results of the ANCOVA test presented in Table 5, it is known that the prior knowledge variable has a significant effect on students' analytical abilities with a value of $F = 25.274$ and a significance of 0.000 ($p < 0.05$). This shows that prior knowledge contributes significantly to the difference in students' analytical ability scores. Furthermore, the learning model (Project-Based Learning and Discovery Learning) also has a significant effect on analytical abilities, with a value of $F = 44.256$ and a significance of 0.000. This finding indicates that the type of learning model applied has an effect on improving students' analytical abilities. In addition, the self-regulated learning (SRL) variable also shows a significant effect on analytical abilities, with a value of $F = 38.284$ and a significance of 0.000. This means that students' self-regulation abilities in learning are an important factor in supporting the development of analytical abilities. Furthermore, there is a significant interaction between the learning model and self-regulated learning on students' analytical abilities, as indicated by the F value = 4.053 and a significance of 0.023 ($p < 0.05$). This interaction indicates that the effectiveness of a learning model on analytical abilities is influenced by the level of students' self-regulated

learning. So, from the results of the ANCOVA statistical analysis, it can be concluded that the three main variables—prior knowledge, learning model, and self-regulated learning—and their interactions significantly affect students' analytical abilities in biology learning.

Additionally, to enhance the understanding of the relationship between self-regulated learning (SRL) levels and students' analytical abilities, data visualization is employed to complement the results of the statistical analysis. This visual representation aims to illustrate the distribution pattern of students according to their SRL categories and the corresponding levels of analytical ability. Figure 3 displays the distribution of students across high, medium, and low SRL categories, along with their respective analytical abilities.

Figure 4.

Interaction between Learning Model and SRL Category on Students' Analytical Ability



Based on Figure 4, the analytical abilities of students with high, medium, and low Self-Regulated Learning (SRL) categories show consistent differences between the two learning models used, namely Project-Based Learning (PjBL) and Discovery Learning. In general, students who follow learning with the PjBL model show higher analytical abilities than students who follow Discovery Learning, especially in the medium and low SRL categories. This difference is likely caused by the more systematic learning structure in PjBL, such as the planning, implementation, and reflection stages, which provide stronger learning support (scaffolding) to students, especially those with low levels of learning independence. However, in students with high SRL, their analytical abilities are relatively equal between the two learning models. This shows that students with high SRL can learn optimally both in structured learning situations, such as PjBL, and in freer models, such as Discovery Learning. Conversely, in students with medium and low SRL, there is a striking difference. Students in the PjBL group show much higher

analytical abilities compared to those in the Discovery Learning group. These findings indicate that PjBL is more effective in developing the analytical skills of students with moderate to low learning self-regulation because this model provides explicit support in the thinking and problem-solving processes.

To solidify the findings regarding the interaction between learning models and categories of Self-Regulated Learning (SRL) on students' analytical abilities, we conducted a thorough analysis using the independent sample t-test for each SRL category. This analysis is designed to definitively determine whether there are significant differences between the Project-Based Learning (PjBL) and Discovery Learning (DL) models at various levels of students' SRL.

Table 6.

T-Test Results: PjBL vs. Discovery Learning by SRL Category

Category SRL	Significance	α	t_{value}	t_{table}
High SRL (PjBLdan Discovery Learning)	> 0.095	0.05	1.707	1.74
Medium SRL (PjBLdan Dsiccovery Learning)	< 0.000	0.05	4.628	1.74
Low SRL (PjBLdan Dsiccovery Learning)	< 0.000	0.05	6.382	1.74

Based on the results of the t-test analysis presented in Table 6, it can be concluded that there are differences in the influence of the Project-Based Learning (PjBL) and Discovery Learning models on students' analytical abilities that vary according to the Self-Regulated Learning (SRL) category. In the high SRL category, a significance value of 0.095 was obtained, which is greater than $\alpha = 0.05$, and a t_{count} value of 1.707, which is smaller than t_{table} (1.74). This shows that there is no significant difference between the application of the PjBL and Discovery Learning models in improving the analytical abilities of students with a high level of SRL. Thus, both learning models are equally effective for use on students who already have good self-regulation skills, especially in the topic of the excretory system.

Conversely, in the moderate SRL category, a significance value of 0.000 was obtained, which is smaller than $\alpha = 0.05$, and a t_{count} value of 4.628, which exceeds t_{table} (1.74). These findings indicate a significant difference between the two learning models, where the PjBL model is proven to be more effective than Discovery Learning in improving the analytical skills of students with moderate SRL levels. This effectiveness indicates that students with moderate self-regulation are more helped by a project-based approach that allows active and contextual involvement. A similar thing was also found in the low SRL category, with a significance value of 0.000 (less than 0.05) and a t_{count} value of 6.382 (greater than t_{table}). These results strengthen the conclusion that the PjBL model is significantly superior to Discovery Learning in improving the analytical skills of students with low SRL abilities. This means that the PjBL model is more adaptive and supports the needs of students with low self-regulation through learning activities that require active involvement, collaboration, and direct experience in solving real problems. These results indicate that the effectiveness of the learning model on the development of students' analytical skills is highly dependent on the level of self-regulation ability. The PjBL

model shows more prominent advantages in students with moderate and low SRL, while in students with high SRL, both models have equal effectiveness.

DISCUSSION AND CONCLUSION

Based on the results of hypothesis testing, a significance value of $0.000 < 0.05$ was obtained, indicating a significant difference between the Project-Based Learning (PjBL) model and the Discovery Learning model in terms of students' analytical abilities on the excretory system topic. This suggests that the learning model used has a distinct impact on improving students' analytical skills, emphasizing the importance of selecting an appropriate instructional model in developing higher-order thinking skills such as analysis.

The difference in impact between the two models on students' analytical abilities can be explained by the level of student engagement in the learning process. In PjBL, students are more actively involved in designing projects, identifying problems, and planning solutions, which demands intensive analytical activity. In contrast, in Discovery Learning, analytical processes occur more spontaneously and rely on students' exploratory drive. Therefore, PjBL tends to provide a more structured and in-depth stimulation for analysis. These findings are in line with the views of Thomas (2000), Bell (2010), Krajcik & Blumenfeld (2005), who assert that PjBL can enhance higher-order thinking skills because students are required to analyze problems, design solutions, and make independent decisions. In support of this, Alkandari & Alabdulhadi (2023) assert that project-based learning places students at the center of their learning in complex and authentic contexts, enabling them to work autonomously with teacher guidance to achieve meaningful outcomes.

The interaction between learning models and Self-Regulated Learning (SRL) represents two interdependent factors that shape students' analytical abilities. Hypothesis testing results presented in Table 8 reveal a significant interaction effect with a significance value of $0.023 < 0.05$. This indicates that the effectiveness of a particular learning model in improving analytical skills cannot be separated from students' level of self-regulation. In other words, the success of implementing instructional models such as PjBL or Discovery Learning is strongly influenced by how well students can independently manage and regulate their learning process. This finding supports Zimmerman (2002) assertion that SRL plays a crucial role in determining learning success, especially in active learning contexts that require full student participation. In the context of PjBL, for instance, students are expected to plan, gather information, evaluate, and present results—stages that heavily rely on strong self-regulatory skills. In line with this, Alkandari & Alabdulhadi (2023) emphasize that the PBL strategy facilitates the development of metacognitive skills, motivational beliefs, effort regulation, and peer learning—each of which is a core domain of SRL. Therefore, instructional models should be aligned with students' SRL profiles to optimally enhance higher-order thinking skills such as analysis.

Furthermore, Zarouk et al. (2020) argue that students actively engaged in PjBL activities demonstrate improvements in cognitive and metacognitive functions, both individually and

collaboratively. This study contributes to a better understanding of how SRL development can be effectively integrated into project-based learning environments. Movahedzadeh et al. (2012) showed that PjBL can improve critical and analytical thinking skills, especially when combined with self-directed learning strategies. The interaction between learning models and SRL on students' analytical abilities, as shown in Figure 3, demonstrates that the non-parallel lines with different gradients indicate interaction. This phenomenon suggests that the effectiveness of a learning model in enhancing students' analytical skills is influenced by their level of SRL. In other words, learning models and SRL do not operate independently but interactively affect student learning outcomes. This finding is supported by Nawastiti et al. (2018), who stated that interaction between variables can be identified by graph lines that are not parallel or have different gradients. This implies a varied response of the dependent variable (analytical ability) to combinations of treatments from two independent variables (learning model and SRL). Therefore, in the context of this study, the non-parallel nature of the graph lines representing the combinations of learning models and SRL levels reinforces the statistical analysis results showing a significant interaction. This aligns with the opinions of Sugiyono, (2015), Nawastiti et al. (2018), and Santoso & Madiistriyatno (2021), who stated that non-parallel or differently sloped lines in interaction graphs indicate an interactive relationship between two independent variables on the dependent variable.

Students with high SRL levels exhibited optimal analytical abilities when taught using either the PjBL or Discovery Learning models. However, among students with moderate and low SRL, the PjBL model proved to be more effective in enhancing analytical abilities than the Discovery Learning model. This suggests that PjBL is more adaptive to variations in students' learning autonomy levels. In other words, PjBL is highly suitable for students with high SRL and is a better choice than Discovery Learning for those with moderate or low SRL. This condition highlights the importance of emotional and motivational regulation in supporting sustained engagement and effective learning, especially in self-directed environments like PjBL (Xue et al., 2025). This finding aligns with Zimmerman (2002) view that students with high SRL have the capacity to set learning goals, monitor progress, and evaluate learning outcomes, thereby responding optimally to project-based learning. In the context of biology learning, this is reinforced by research Tasci & Yurdugul (2017) which found that the application of self-regulated learning strategies significantly improves students' cognitive structure and learning outcomes. Knowles (1975) also emphasized that learning that demands active participation, such as PjBL, is more effective when learners are self-directed in managing their learning processes. Furthermore, Vatillah et al. (2020) affirm that the interaction between learning models and student characteristics, including SRL, influences the attainment of higher-order thinking skills such as analysis and critical thinking. According to Sholiha et al. (2022), students with high SRL tend to achieve better learning outcomes.

This study underscores the pivotal role of Self-Regulated Learning (SRL) in shaping the effectiveness of instructional models aimed at enhancing students' analytical thinking skills. The

findings confirm the central thesis that instructional approaches cannot be one-size-fits-all; rather, they must be responsive to individual learner characteristics. Conducted among Grade XI science students at Senior High School 8 Kendari, the research revealed that the Project-Based Learning (PjBL) model led to significantly higher analytical performance compared to Discovery Learning, particularly for students with moderate and low SRL. The interaction between SRL level and instructional model further emphasized that while high-SRL students benefit equally from both models, those with lower self-regulation require more structured, supportive approaches like PjBL to thrive. These insights affirm that instructional design must consider learners' self-regulatory capacities to maximize cognitive development. Teachers are thus encouraged to implement the PjBL model, especially for students who struggle with independent learning, while ensuring adequate scaffolding and time management. This tailored approach not only supports improved academic outcomes but also fosters more inclusive and effective learning environments. Looking forward, future studies should explore how PjBL impacts affective and psychomotor domains, thereby offering a holistic understanding of its contribution to 21st-century education. Through such adaptive and learner-centered strategies, educators can more effectively cultivate critical thinkers who are equipped to face complex real-world challenges.

During the implementation of this study, several challenges were encountered. One major challenge was ensuring consistent application of the Project-Based Learning (PjBL) model, which required intensive preparation, monitoring, and guidance from the teacher. Some students, particularly those with low Self-Regulated Learning (SRL), struggled to manage their time, maintain motivation, and take responsibility for their learning, which occasionally disrupted the flow of project activities. Another challenge was related to balancing the diverse SRL levels among students; while high-SRL students adapted quickly, medium and low-SRL students needed more scaffolding and repeated instructions, which demanded additional effort from the teacher. Technical issues also arose in coordinating group projects, such as unequal participation within groups and difficulty in aligning project tasks with the limited classroom schedule. Furthermore, measuring analytical skills through tests sometimes did not fully capture students' real problem-solving processes during project work.

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REFERENCES

- Aktaş, Ö. İ., & Sop, A. (2022). The Relationship Between Preschool Children's Self-Regulation Skills and Their Mothers' Parental Attitudes. *Theory and Practice in Child Development*, 2(2), 72-95. <https://doi.org/10.46303/tpicd.2022.18>
- Alkandari, K., & Alabdulhadi, M. (2023). Promoting Self-Regulation Skills Among Pre-Service Islamic Studies Teachers Through Project-Based Learning Utilizing a Flipped Learning Strategy. *International Journal of Learning, Teaching and Educational Research*, 22(5), 74–100. <https://doi.org/10.26803/IJLTER.22.5.4>
- Anderson, L. W., & Krathwohl, D. R. (2001). A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives. In *Anderson, L. W., & Krathwohl, D. R* (Complete E).
- Fayanto, S., Degeng, I. N. S., Patmanthara, S., & Ulfa, S. (2024). Instructional Process of Design-Based Learning Integration on Computational Thinking: A Framework for Effective Teaching in Course of Physics Experiment Design. *Science Education International*, 35(4), 394-407. <https://doi.org/10.33828/sei.v35.i4.10>
- Fernández, A. G. E., López-Banet, L., & Ruiz-Vidal, A. (2022). Students' performance in the scientific skills during secondary education. *Eurasia Journal of Mathematics, Science and Technology Education*, 18(10), em2165. <https://doi.org/10.29333/ejmste/12444>
- Bell, S. (2010). Project-Based Learning for the 21st Century: Skills for the Future. *The Clearing House*, 83(2), 39–43. <https://doi.org/10.1080/00098650903505415>
- Botes, W., & Philip, A. (2025). Enhancing Pedagogical Development of Natural Science Teachers Through a Key Concepts in Science Project: A Social Constructivist Perspective. *Research in Social Sciences and Technology*, 10(1), 191-208. <https://doi.org/10.46303/ressat.2025.11>
- Chiang, C. L., & Lee, H. (2016). The Effect of Project-Based Learning on Learning Motivation and Problem-Solving Ability of Vocational High School Students. *International Journal of Information and Education Technology*, 6(9), 709–712. <https://doi.org/10.7763/IJiet.2016.V6.779>
- Coyne, J., Hollas, T., & Potter, J. P. (2016). Jumping In: Redefining Teaching and Learning in Physical Education Through Project-Based Learning: Column Editor: Anthony Parish. *Strategies*, 29(1), 43–46. <https://doi.org/10.1080/08924562.2016.1113910>
- Donker, A. S., De Boer, H., Kostons, D., Dignath Van Ewijk, C. C., & Van Der Werf, M. P. C. (2014). Effectiveness of learning strategy instruction on academic performance: A meta-analysis. *Educational Research Review*, 11, 1–26. <https://doi.org/10.1016/j.edurev.2013.11.002>
- Dwyer, C. P., Hogan, M. J., & Stewart, I. (2014). An integrated critical thinking framework for the 21st century. *Thinking Skills and Creativity*, 12, 43–52. <https://doi.org/10.1016/j.tsc.2013.12.004>

- English, M. C., & Kitsantas, A. (2013). Supporting Student Self-Regulated Learning in Problem- and Project-Based Learning. *Interdisciplinary Journal of Problem-Based Learning*, 7(2), 128–150. <https://doi.org/10.7771/1541-5015.1339>
- Günzel, H., & Brehm, L. (2024, June 18). A Roadbook for the Professionalization of Project-based Learning Courses. *10th International Conference on Higher Education Advances (HEAd'24)*. Tenth International Conference on Higher Education Advances. <https://doi.org/10.4995/HEAd24.2024.17194>
- Jagantara, I. M. W., Adnyana, P. B., & Widiyanti, N. L. P. M. (2014). Pengaruh Model Pembelajaran Berbasis Proyek (Project Based Learning) Terhadap Hasil Belajar Biologi Ditinjau dari Gaya Belajar Siswa SMA. *Jurnal Pendidikan Dan Pembelajaran IPA Indonesia*, 4(1).
- Kalyuga, S. (2007). Expertise Reversal Effect and Its Implications for Learner-Tailored Instruction. *Educational Psychology Review*, 19(4), 509–539. <https://doi.org/10.1007/s10648-007-9054-3>
- Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The Expertise Reversal Effect. *Educational Psychologist*, 38(1), 23–31. https://doi.org/10.1207/S15326985EP3801_4
- Kayacan, K., & Sonmez-Ektem, I. (2019). The Effects of Biology Laboratory Practices Supported with Self-regulated Learning Strategies on Students' Self-directed Learning Readiness and Their Attitudes towards Science Experiments. *European Journal of Educational Research*, volume–8–2019(volume8-issue1.html), 313–299. <https://doi.org/10.12973/eu-jer.8.1.313>
- Kim, D., Coenraad, M., & Park, H. R. (2021). Digital storytelling as a tool for reflection in virtual reality projects. *Journal of Curriculum Studies Research*, 3(1), 101–121. <https://doi.org/10.46303/jcsr.2021.9>
- Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. *Educational Psychologist*, 41(2), 75–86. https://doi.org/10.1207/s15326985ep4102_1
- Knowles, M. S. (1975). *Self-Directed Learning: A Guide for Learners and Teachers*. Association Press.
- Krajcik, J. S., & Blumenfeld, P. C. (2005). Project-Based Learning. In *The Cambridge Handbook of the Learning Sciences*. Cambridge University Press. <https://doi.org/10.1017/CBO9780511816833.020>
- Loyens, S. M. M., Van Meerten, J. E., Schaap, L., & Wijnia, L. (2023). Situating Higher-Order, Critical, and Critical-Analytic Thinking in Problem- and Project-Based Learning Environments: A Systematic Review. *Educational Psychology Review*, 35(2), 39. <https://doi.org/10.1007/s10648-023-09757-x>
- Nurfadilah, D. S., Maruto, G., & Fayanto, S. (2020). Effectiveness of Using Discovery Learning Model Assisted Tracker on Improvement of Physics Learning Outcomes Observed From

- Students Initial Knowledge. *International Journal of Scientific and Research Publications*, 1-8. <http://dx.doi.org/10.29322/IJSRP.10.01.2020.p9755>
- Movahedzadeh, F., Patwell, R., Rieker, J. E., & Gonzalez, T. (2012). Project-Based Learning to Promote Effective Learning in Biotechnology Courses. *Education Research International*, 2012(1), 536024. <https://doi.org/10.1155/2012/536024>
- Muliawan, W., Nahar, W. S., Sebastian, C. E., Yuliza, E., & Khairurrijal. (2016). Implementing Project-based Learning in making a weight meter. *Journal of Physics: Conference Series*, 739, 012139. <https://doi.org/10.1088/1742-6596/739/1/012139>
- Nawastiti, N., Suyono, S., & Rahayu, W. (2018). Pengaruh Model Pembelajaran Accelerated Learning Terhadap Kemampuan Penalaran Matematis Siswa Ditinjau Dari Self Regulated Learning. *Journal of Mathematics Learning*, 1(1), 1–12. <https://doi.org/10.30653/004.201811.1>
- Rafni, A., Suryanef, Fansurya, A.H., Juwita, S., & Azizah, C. N. (2024). Understanding the Formation Mechanism of Students' Preparedness in Political Course Learning: The Moderating Role of Information Literacy, *Journal of Social Studies Education Research*, 15(3), 47-87. <https://jsse.org/index.php/jsse/article/view/5563/680>
- Rahayuningsih, S., Ikram, M., & Indrawati, N. (2023). Learning To Promote Students' Mathematical Curiosity and Creativity. *Uniciencia*, 37(1), 1–13. <https://doi.org/10.15359/ru.37-1.6>
- Ratnayake, A., Bansal, A., Wong, N., Saseetharan, T., Prompiengchai, S., Jenne, A., Thiagavel, J., & Ashok, A. (2024). All “wrapped” up in reflection: Supporting metacognitive awareness to promote students' self-regulated learning. *Journal of Microbiology & Biology Education*, 25(1), e00103-23. <https://doi.org/10.1128/jmbe.00103-23>
- Santoso, I., & Madiistriyatno, H. (2021). *Metodologi Penelitian Kuantitatif*. Indigo Media.
- Shao, J., Chen, Y., Wei, X., Li, X., & Li, Y. (2023). Effects of regulated learning scaffolding on regulation strategies and academic performance: A meta-analysis. *Frontiers in Psychology*, 14, 1110086. <https://doi.org/10.3389/fpsyg.2023.1110086>
- Sholiha, T. A., Kurniati, N., Tyaningsih, R. Y., & Prayitno, S. (2022). Pengaruh Self-Regulated Learning (SRL) terhadap Hasil Belajar Matematika Siswa Kelas XI SMAN 1 Masbagik. *Jurnal Ilmiah Profesi Pendidikan*, 7(3), 1355–1362. <https://doi.org/10.29303/JIPP.V7I3.745>
- Simonsmeier, B. A., Flaig, M., Deiglmayr, A., Schalk, L., & Schneider, M. (2022). Domain-specific prior knowledge and learning: A meta-analysis. *Educational Psychologist*, 57(1), 31–54. <https://doi.org/10.1080/00461520.2021.1939700>
- Splichal, J. M., Oshima, J., & Oshima, R. (2018). Regulation of collaboration in project-based learning mediated by CSCL scripting reflection. *Computers & Education*, 125, 132–145. <https://doi.org/10.1016/j.compedu.2018.06.003>
- Sugiyono. (2015). *Metode penelitian pendidikan: Pendekatan kuantitatif, kualitatif, dan R&D*. Alfabeta.

- Sukma, D. T., Suwono, H., & Fachrunnisa, R. (2021). *Student's rationality in decision making on infusion of analytical thinking skill's framework in biology learning*. 030022. <https://doi.org/10.1063/5.0043262>
- Tasci, G., & Yurdugul, H. (2017). Biology teaching through self-regulated learning and cognitive structure: An analysis of the effect of learning strategies for cognitive development via latent growth model. *Journal of Baltic Science Education*, 16(1), 20–31. <https://doi.org/10.33225/JBSE/17.16.20>
- Thomas, J. W. (2000). *A Review of Research on Project-Based Learning*. Autodesk Foundation.
- Vatillah, V., Ambarwati, L., & Hakim, L. El. (2020). Pengaruh Model Problem Based Learning Terhadap Kemampuan Penalaran Matematis dan Self-Regulated Ditinjau dari Kemampuan Awal Matematika Siswa. *Jurnal Penelitian Dan Pembelajaran Matematika*, 13(2), 313–329. <https://doi.org/10.30870/JPPM.V13I2.6995>
- Wekesa, N. W., & Ongunya, R. O. (2016). Project Based Learning on Students' Performance in the Concept of Classification of Organisms among Secondary Schools in Kenya. *Journal of Education and Practice*, 7(16), 25–31.
- Xue, Y., Khalid, F. B., & Karim, A. B. A. (2025). Emerging Trends in Self-Regulated Learning: A Bibliometric Analysis of MOOCs and AI-Enhanced Online Learning (2014–2024). *International Journal of Learning, Teaching and Educational Research*, 24(1), 420–442. <https://doi.org/10.26803/IJLTER.24.1.21>
- Zarouk, M. Y., Olivera, E., & Khaldi, M. (2020). The Impact of Flipped Project-Based Learning on Self-Regulation in Higher Education. *International Journal of Emerging Technologies in Learning (IJET)*, 15(17), 127–147. <https://doi.org/10.3991/IJET.V15I17.14135>
- Zhang, L., & Ma, Y. (2023). A study of the impact of project-based learning on student learning effects: A meta-analysis study. *Frontiers in Psychology*, 14, 1202728. <https://doi.org/10.3389/fpsyg.2023.1202728>
- Zheng, L. (2016). The effectiveness of self-regulated learning scaffolds on academic performance in computer-based learning environments: A meta-analysis. *Asia Pacific Education Review*, 17(2), 187–202. <https://doi.org/10.1007/s12564-016-9426-9>
- Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory into Practice*, 41(2), 64–70. https://doi.org/10.1207/s15430421tip4102_2