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The relationship between metacognitive and critical thinking abilities across three distinct learning approaches

Yatin Mulyono[1]*, Mujib Ubaidillah[2]
[1]Department of Biology Education, IAIN Palangka Raya, Indonesia
[2]Department of Biology Education, IAIN Syekh Nurjati Cirebon, Indonesia
**Correspondence: yatin.mulyono@iain-palangkaraya.ac.id*

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Abstract

This research explores variations in the correlated regression equations. The findings demonstrate a connection between metacognitive capabilities and critical thinking skills. This study's sample consists of ninety science education students aged between nineteen and twenty-one. The students are divided into three groups, each receiving a different teaching technique. Data on metacognitive and critical thinking abilities were collected for each group. Regression analysis was employed to examine the relationship between metacognitive skills and critical thinking skills at a significance level of 0.05. Results show a significant association between metacognitive abilities and critical thinking skills across the three learning techniques, with distinct regression lines verified using ANOVA. The study suggests that these learning strategies influence the rate and extent of growth in critical thinking abilities in unique ways.

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Introduction

An essential aspect of critical thinking involves engaging in metacognitive processes, enabling individuals to assess the depth of their thoughts, analyze the consequences of their thinking, and derive insights from their learning experiences (Persky et al., 2019; Sjöström & Eilks, 2018). Metacognitive skills are related to critical thinking growth and are a significant factor in increasing pupils' cognitive capacities (Warni et al., 2018). All sub-dimensions of metacognitive beliefs are correlated to students' critical thinking scores (Semerci & Elaldi, 2014). That correlation is positive (Cakici, 2018; Gurcay & Ferah, 2018). Metacognition is the most potent predictor of critical thinking abilities (Gholami et al., 2016). Metacognition, through its reflective elements, is connected to critical thinking. It plays a role in enhancing higher-order thinking skills by actively overseeing various cognitive processes involved in learning (Uzuntiryaki-Kondakci & Capa-Aydin, 2013).

Students must have metacognitive skills to increase their thinking capacity (Dwyer & Walsh, 2020; Kozikoglu, 2019). Metacognitive abilities are required to assist individuals in issue-solving (Mitsea et al., 2022; Tachie & Molepo, 2019). Strengthening metacognitive skills during the learning process can help students become more independent (Marantika, 2021). Metacognition is essential for making learning more meaningful for kids by helping them

comprehend the significance of an idea, and it is an essential component of academic achievement (Dang et al., 2018).

Students equipped with critical thinking skills can employ rational analysis to comprehend knowledge and ready themselves for self-directed learning. Those proficient in critical thinking can evaluate the relevance or insignificance of information. This ability fosters lucid perceptions, perspectives, and coherent communication strategies for conveying explanations (Su et al., 2016). Critical thinking is decisive in academic success (Djumadi, 2021; Goodsett, 2020) since students are capable of identifying objectives and perspectives, evaluating rationales behind particular content, and making decisions through analytical thinking.. Giving pupils thinking skills involves survival skills for their future lives (Mulyono, 2018; Yuliarti et al., 2023). Students who think critically tend to build relevant information for life, increasing their drive to solve everyday difficulties (Lai & Viering, 2012; Mulyono et al., 2023).

High school thinking capabilities, including metacognitive skills (A. M. Amin et al., 2020) and tertiary institutions in Indonesia (Muhlisin et al., 2016) are relatively low. The results of observations in learning show that many students need help to solve problems related to everyday life (Lin, 2019; Simamora & Saragih, 2019). Classroom instruction has yet to prove successful in enhancing students' metacognitive capacities. Students, specifically, exercise critical thinking abilities by solving issues. The capacity of students to solve issues is one of the signs of developing critical thinking abilities (Memduhoğlu & Keleş, 2016). Science education students' understanding of concepts related to critical thinking skills is still lacking, and the average score of critical thinking skills essay tests is still underdeveloped (Amin et al., 2017). Because most students could not supervise their thought processes, their exam outcomes could have been better (Persky et al., 2019). Empowering metacognitive skills is vital for improving critical thinking abilities. Students who are aware of their metacognitive talents can increase their learning and academic performance (Abdelrahman, 2020).

The word 'meta-cognition' was first introduced by Flavell (1976). Metacognition is a person's comprehension of cognition. Metacognitive abilities encompass self-regulation, self-evaluation, monitoring and planning, self-assessment of learning strategies, and problem-solving effectiveness (Rezai et al., 2022; Takarroucht, 2022; Vasu et al., 2020). Metacognitive skills assist students in gaining knowledge and improving their intellectual talents during the learning process and experience (Al-Gaseem et al., 2020; Sutiyatno & Sukarno, 2019). Enhancing metacognitive skills can enhance students' cognitive abilities by reflecting on how they process and apply knowledge during learning (A. M. Amin et al., 2020; Djamahar et al., 2019).

Critical thinking is reasoning and reflection-based thinking that focuses on deciding what to believe and do (Ennis, 2018). Analyzing and assessing, finding issues, drawing logical conclusions, and comprehending the ramifications of arguments are all critical thinking processes (Erikson & Erikson, 2019; Listiaji et al., 2022). Students' critical thinking abilities must be empowered in classroom learning to feel responsible for their learning, become active learners, and strive to enhance their learning experience and identity (Ku et al., 2017; Pursitasari et al., 2020; Stupple et al., 2017).

Lecturers should consider empowering students' metacognitive capacities by using appropriate learning approaches. Metacognitive skills training raises students' awareness of learning, helps them organize their learning, manages the learning process, fosters critical thinking to evaluate their efficacy as students, and allows them to reflect on their learning, and evaluates their strengths and weaknesses (Mulyono, 2018; Sulistyanto et al., 2022). Ideally, empowering critical thinking abilities is not a particular activity (Amin et al., 2017). There is much evidence that various learning strategies can improve critical thinking skills (Dwyer & Walsh, 2020; Shutaleva et al., 2021). Educators must try to help students think at a higher level through structured assistance (Taki et al., 2018).

Louise's (2019) research revealed a significant connection between metacognitive skills and the process of learning. It was discovered that the problem-based learning approach (PBL) notably enhanced critical thinking capabilities. Kuvac & Koc (2019) investigated that there was a significant effect between PBL and the metacognitive awareness of prospective science teachers. The results of research by Siagan et al. (2019) showed that PBL effectively increases students' metacognitive abilities and problem-solving. Based on the research conducted by Pursitasari et al. (2020), it was found that implementing simulation problem-based learning (S-PBL) during maternity nursing practicum effectively enhances nursing students' metacognitive skills and critical thinking abilities.

Qamariyah et al. (2021) in his research found that the application of the socio-scientific issue (SSI) approach was effective in increasing higher-order thinking skills (HOTs). The results of the research by (Mulyono et al., 2023) show that learning with an interactive socio-scientific inquiry approach is effective in increasing critical thinking in biology learning. While the findings of Yap (2019) state that an approach through the media film with the theme of socio-scientific issue (SSI) can stimulate evidence-based reasoning and ethical thinking about social issues and encourage reflection on values, including the values of faith that are promoted through the use of or misuse of science and technology. The medium of film is also interesting, where students can explore science concepts and consider some pressing issues and ideas of the times. Widespread use of popular entertainment media can help encourage critical thinking and judgment of media content by addressing misconceptions and distinguishing between "good" and "bad" science.

Much research looks into the relationship between factors in various learning processes (Almanthari et al., 2020; Maatuk et al., 2022; Regmi & Jones, 2020). Significant research has yet to explore the relationship between metacognitive abilities and critical thinking skills within Problem-Based Learning (PBL) contexts that incorporate socio-scientific problem approaches and spiritual values.

The relationship between spiritual values and metacognitive abilities or critical thinking skills is complex and multifaceted. Spiritual values, often associated with transcendence and the unseen, have been found to mediate various aspects of well-being, including preventing and treating depressive symptoms (Soósová et al., 2021). On the other hand, metacognitive abilities, which involve the awareness and understanding of one's thought processes, have been recognized as crucial for successful learning outcomes (Marantika, 2021). Additionally, critical thinking skills, encompassing skills like decision-making and problem-solving, are closely linked to academic achievement and success (Ali & Awan, 2021)

Studies have shown that spirituality can influence critical thinking indirectly through factors like spiritual intelligence, which includes dimensions such as transcendental awareness and critical existential thinking (Abbasi & Alavi, 2023). Moreover, critical thinking skills are essential in various fields, including science education, where they are crucial for improving students' abilities to think critically and solve problems effectively (Astalini et al., 2021). The correlation between spiritual values and metacognitive abilities or critical thinking skills is further supported by research highlighting the importance of critical thinking in enhancing learning outcomes and academic achievement (Er, 2024).

In the educational context, efforts to enhance critical thinking skills often involve interventions to improve students' metacognitive awareness (Ramadhanti & Yanda, 2021). That is particularly important as critical thinking skills are considered fundamental in the modern era and are essential for success in various disciplines (Mayarni & Nopiyanti, 2021). Furthermore, the correlation between information literacy and critical thinking skills underscores the interconnected nature of different cognitive abilities in shaping individuals' capacity to think critically and make informed decisions (Supriyanti et al., 2020).

The relationship between spiritual values and metacognitive abilities or critical thinking skills is intricate and multidimensional. While spirituality can influence cognitive processes indirectly through factors like spiritual intelligence, metacognitive abilities, and critical thinking skills remain essential for academic achievement, problem-solving, and decision-making across various domains.

Consequently, there is a need for research to examine how metacognitive skills correlate with critical thinking skills in the implementation of PBL learning strategies, PBL with socio-scientific problem approaches, and incorporating spiritual values. This research can elucidate the appropriate correlation and regression equation, especially regarding the effectiveness of the regression line and its contribution.

Moreover, it is important to acknowledge the disparities in the regression equations for metacognitive abilities and critical thinking skills across different PBL approaches, including PBL with socio-scientific problem techniques and PBL with spiritual values. Understanding the factors influencing the slope and intercept coefficients resulting from the correlation between metacognitive and critical thinking skills in these learning approaches is crucial.

Only a limited number of studies have delved into the correlation between metacognitive abilities and critical thinking skills within the context of PBL, PBL integrated with socio-scientific problem approaches, and PBL integrated with socio-scientific problem approaches alongside spiritual values, particularly within microbiology classes. Metacognitive skills offer insights into how students apply problem-solving thinking processes to align with their knowledge and learning experiences. These abilities are required for pupils to become autonomous learners capable of meeting the difficulties of 21st-century advances. As a result, it is critical to uncover the relationship between the two and apply it to the regression equation.

This study intends to uncover the link between metacognitive and critical thinking skills in the four learning styles based on the following problems: (1) What is the relationship between metacognitive skills and critical thinking skills in applying the three learning strategies? (2) How important is the difference in the correlation regression equation between metacognitive skills and critical thinking skills in the three learning strategies?

Method

Purposes

This study aimed to discover the association between metacognitive abilities and critical thinking skills in three PBL strategies: PBL with the SSI method, PBL with the SSI approach, and PBL with the SSI approach and spiritual values. This research also tries to uncover discrepancies in the correlated regression equations.

Research Design

This study employs a quantitative correlational research design to investigate the relationship between metacognitive and critical thinking abilities.

Sample

The participants in this study were undergraduate students majoring in science education at Muhammadiyah University in Surakarta, Central Java, Indonesia. Specifically, the sample comprised 90 fourth-semester students enrolled in microbiology courses. Through a random selection process, these students were divided into three equal groups, each consisting of 30 participants. The grouping was determined after conducting a similarity test among the students. Subsequently, each group was exposed to a distinct learning technique: Group 1 underwent Problem-Based Learning (PBL), Group 2 experienced PBL integrated with Socio-Scientific Issues (SSI), and Group 3 engaged in PBL integrated with SSI and spiritual values. This division examined how different learning approaches influenced the development of metacognitive and critical thinking abilities among the students.

Data Collection

Data collection for this study encompassed the assessment of each group's metacognitive and critical thinking abilities, guided by specific learning strategies. The Problem-Based Learning (PBL) group followed a structured approach comprising orientation, organization, investigations, problem-solving, and analysis evaluation. Meanwhile, the PBL group integrated with Socio-Scientific Issues (SSI) adopted procedures involving SSI problem identification, exploration, discussion investigations, reports and presentations, and reflection. Additionally, the PBL group integrated with SSI and spiritual values and incorporated further reflective practices grounded in spiritual values, including caring for environmental problems, observing bioprocesses, seeking truth, sharing and conveying truth, fostering mutual respect, and engaging in self-introspection. Through these tailored procedures, the study aimed to capture nuanced variations in metacognitive and critical thinking abilities across distinct learning approaches, providing a comprehensive understanding of their interplay in educational contexts.

Instrument Validation

The instruments for testing metacognitive and critical thinking skills were validated before deployment. Expert validation was conducted by three experts in educational research instruments, biology education, and microbiology, ensuring content and construct validity. Empirical validation included 120 biology students selected from Muhammadiyah University Surakarta, Indonesia, and IAIN Palangka Raya, Indonesia. The instruments were evaluated for validity and reliability, and the results confirmed that they were valid and reliable.

Assessment of Abilities

Metacognitive abilities are evaluated through a meticulous process involving validated essay questions and a metacognitive skills rubric featuring seven scales ranging from 0 to 7. This rubric meticulously assesses student responses for each item, allowing for a comprehensive evaluation. Drawing from Green's classification system (2002), metacognitive abilities are categorized into six levels: Super, Acceptable, Developing, Very Unable, Dangerous, and Yet. Additionally, scores are derived using Corebima's algorithm (2009), ensuring accurate and standardized assessment.

On the other hand, critical thinking abilities are assessed using validated essay questions and a structured framework developed by Asy'ari et al. (2019). This framework, derived from the Illinois Critical Thinking Essay Test, encompasses focus, rationale, organization, adherence to conventions, and integration. Each dimension is evaluated on a scale ranging from 0 to 5. Critical thinking proficiency is then classified into two categories: Emerging or Lagging for scores between 1 and 3 and Well-Established for scores ranging from 4 to 5. Data on metacognitive and critical thinking abilities are collected before and after the intervention, providing a comprehensive understanding of the impact of different learning approaches on these cognitive skills.

Data Analysis

Data analysis involved two main stages. Initially, a pre-analysis phase was conducted where the normal distribution of data was assessed using the One-Sample Kolmogorov-Smirnov test. This step ensured that the data met the normality assumption, a prerequisite for many statistical analyses. Subsequently, the primary analysis explored the relationship between metacognitive and critical thinking skills. Regression analysis, a powerful statistical technique, was employed for this purpose. The study aimed to uncover any significant correlations by examining the associations between these variables. A significance level of 0.05 was predetermined, guiding the determination of statistical significance. This rigorous analytical approach aimed to provide robust insights into the intricate interplay between metacognitive abilities and critical thinking skills across different learning approaches.

Results and Discussion

The Relationship between Metacognitive Skills and Critical Thinking Skills in PBL Application

The findings of the correlation regression analysis regarding the relationship between metacognitive skills and critical thinking skills in PBL are presented in Tables 1 through 3.

Table 1. Overview of Regression Analysis in PBL

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.9978	0.9956	0.9611	5.0867

Table 2. Results of the ANOVA Test in the PBL

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	168257.6363	1	168257.6363	6502.808492	1.06177E-34
	Residual	750.3637018	29	25.87461041		
	Total	169008	30			

Table 3. PBL Regression Equation Coefficient Analysis

Model		Coefficients	Std. Error	T Stat	P-value	Sig.
1	Intercept	0	#N/A	#N/A	#N/A	.000
	PBL	0.908126275	0.01126149	80.63999313	1.13419E-35	.000

The related regression equation graph is presented in Figure 1.

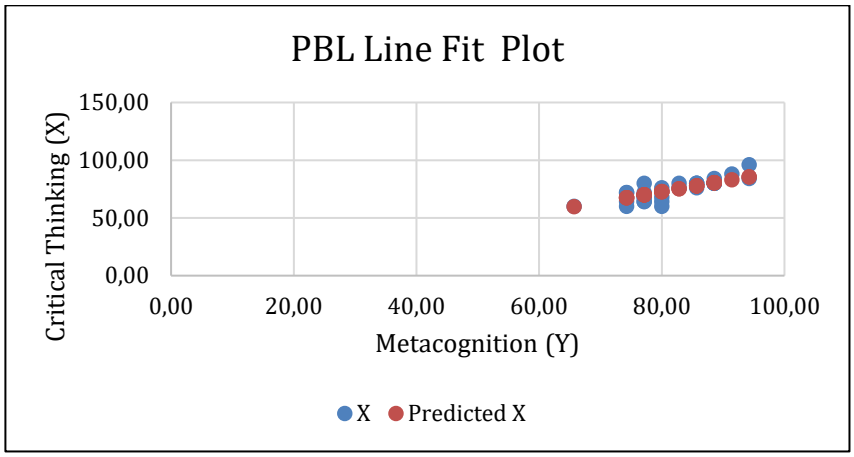

Figure 1. Displays the PBL Graph Illustrating the Regression Equation.

Tables 1-3 reveal a highly significant correlation of 0.9978 (R) and 6502.808492 (F) between metacognitive skills and students' critical thinking skills. That indicates that within the framework of PBL, a relationship exists between metacognitive and critical thinking abilities. The derived regression equation is y = 0x + 0.908126275, with an R^2 value of 0.9956, signifying that metacognitive skills contribute 99.56% to critical thinking skills, while other factors contribute the remaining 0.44%.

The Correlation between Metacognitive Abilities and Critical Thinking Abilities in PBL Learning Strategies Utilizing the SSI Approach

Tables 4-6 present the outcomes of the correlation regression analysis between metacognitive skills and critical thinking skills within the PBL learning strategy employing the SSI approach.

Table 4. Summarizes the Regression Analysis Findings in PBL Utilizing the SSI Approach.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.8392	0.7043	0.6937	3.2930

Table 5. Results of ANOVA Test in the PBL with SSI Approach

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	723.0369468	1	723.0369468	66.67672229	6.87912E-09
	Residual	303.6297199	28	10.84391857		
	Total	1026.666667	29			

Table 6. PBL Regression Equation Coefficient Analysis Using the SSI Approach

Model		Coefficients	Std. Error	T Stat	P-value	Sig.
1	Intercept	2.1949	9.6289	0.2279	0.8213	.000
	PBL with SSI approach	0.8996	0.1102	8.1656	6.87912E-09	.000

The related regression equation graph is presented in Figure 2.

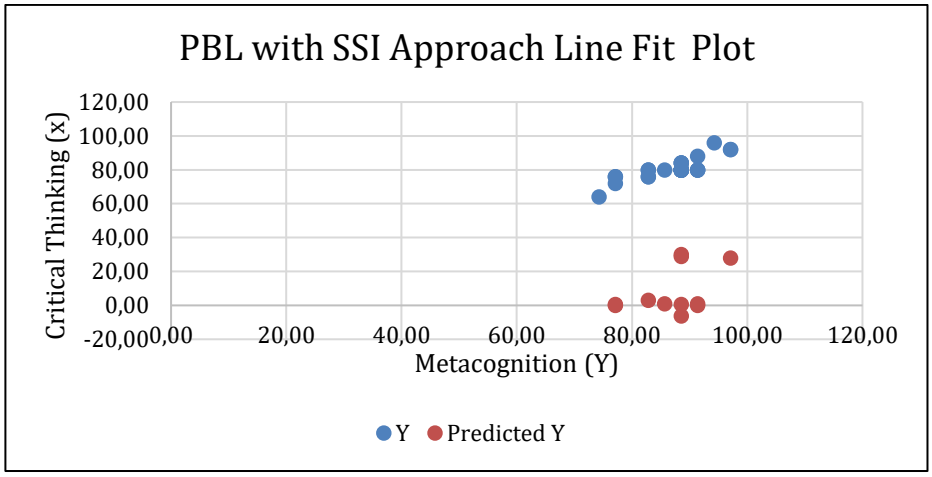

Figure 2. PBL regression equation graph using the SSI technique.

The analysis findings in Tables 4-6 reveal a correlation coefficient (R) of 0.8392 and an F-value of 66.6767, indicating a significant relationship between metacognitive skills and students' critical thinking abilities. Specifically, a notable correlation of 0.00 exists between these skills when implementing PBL using the SSI approach. The regression equation derived from this analysis is y = 2.1949x + 0.8995, with an R-squared value of 0.7043, suggesting that metacognitive abilities contribute to 70.43% of the variance in critical thinking abilities, leaving 29.57% to be influenced by other factors.

Metacognitive and Critical Thinking Abilities in SSI Approach PBL Learning Strategies and Spiritual Values

The results of the correlation regression analysis investigating the relationship between metacognitive skills and critical thinking abilities in PBL learning methodologies employing the SSI approach alongside spiritual values are displayed in Tables 7-9.

Table 7. Regression Analysis Summary for the PBL Correlation with SSI and Spiritual Values Approach

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.8156	0.6652	0.6532	3.0608

Table 8. Results of ANOVA Test in the PBL with SSI and Spiritual Values Approach

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	521.1473	1	521.1473389	55.62733641	4.0117E-08
	Residual	262.3193	28	9.368547419		
	Total	783.4666	29			

Table 9. Regression Equation Coefficient Analysis in the PBL with SSI and Spiritual Values Approach

Model		Coefficients	Std. Error	t Stat	P-value	Sig.
1	Intercept	-6.2269	12.1281	-0.5134	0.6117	.000
	PBL with SSI and Spiritual Values approach	1.0029	0.1344	7.4584	4.0117E-08	.000

The related regression equation graph is presented in Figure 3.

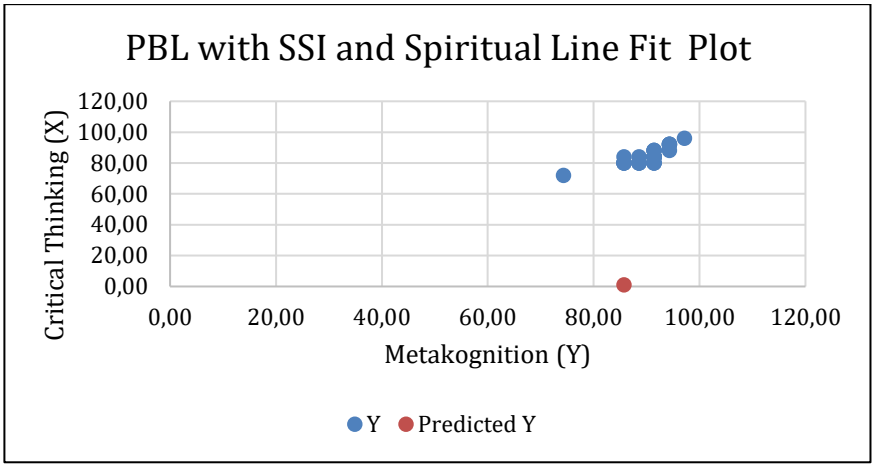

Figure 3. Graph of Regression Equation in the PBL with SSI and Spiritual Values Approach.

Table 7-9 displays a notable correlation of 0.00 between metacognitive skills and students' critical thinking abilities, with R = 0.8156 and F = 55.6273. That implies that a connection exists between metacognitive skills and critical thinking abilities in implementing PBL utilizing the SSI approach and spiritual principles. The regression equation derived is y = 1.0029 - 6.229x with an R2 value of 0.6652, indicating that metacognitive skills account for 66.52% of critical thinking skills, while other factors contribute to the remaining 34.48%.

Metacognitive and Critical Thinking Abilities in PBL Strategy, SSI-approach PBL, and SSI-approach PBL and Spiritual Values

Tables 10–12 present the results of the correlation regression analysis regarding the relationship between metacognitive skills and critical thinking skills within the contexts of Problem-Based Learning (PBL), PBL integrated with the SSI (Socio-Scientific Issues) method, and PBL combined with the SSI approach alongside spiritual values.

Table 10. Summarizes the correlation regression analysis across PBL, PBL with the SSI approach, and PBL with the SSI and Spiritual Values Approach.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.8742	0.7642	0.7615	3.8664

Table 11. Results of ANOVA Test in the PBL with SSI and Spiritual Values Approach

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4264.027599	1	4264.027599	285.2348	2.37355E-29
	Residual	1315.527956	88	14.94918132		
	Total	5579.555556	89			

Table 12. Analyses the Regression Equation Coefficients Relating to the Connection between Metacognitive Abilities and Critical Thinking Abilities in PBL, PBL with SSI Approach, and PBL with SSI and Spiritual Values Approach

Model		*Coefficients*	Std. Error	t Stat	P-value	Sig.
1	Intercept	-12.6016	5.4850	-2.2975	0.0240	.000
	PBL, PBL with SSI Approach, and PBL with SSI and Spiritual Values Approach	1.0674	0.0632	16.8889	2.37355E-29	.000

Figure 4 depicts the relevant regression equation graph.

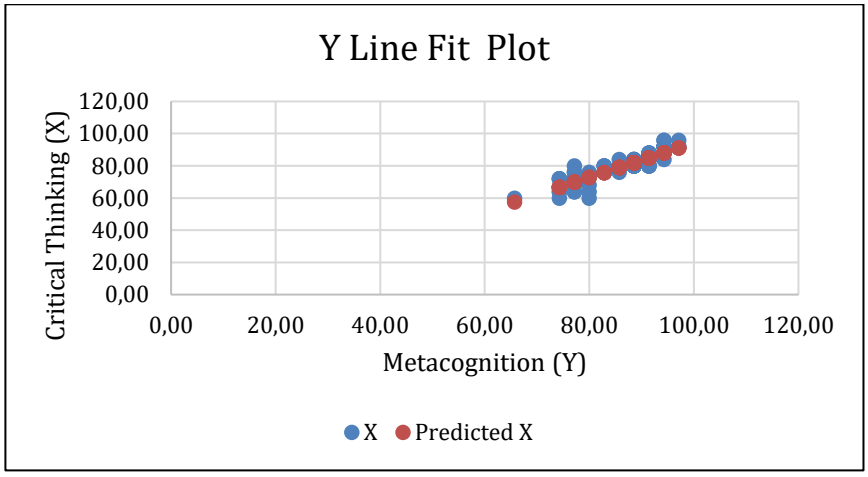

Figure 4. PBL Regression Equation Graph with SSI and Spiritual Values Approach

The data analysis presented in Tables 10-12 reveals a correlation coefficient (R) of 0.8742 and a regression coefficient (F) of 285.2348 regarding the relationship between metacognitive skills and students' critical thinking abilities. The associated p-value is 0.00, indicating statistical significance. In other words, employing the three models demonstrates a clear correlation between metacognitive skills and critical thinking abilities. The derived regression equation is y = 1.0674 - 12.6016x, with an R-squared value of 0.7642. That suggests that metacognitive skills account for 76.42% of the variation in critical thinking skills, leaving the remaining 23.58% influenced by other factors.

The results of correlation regression analysis examining the relationship between metacognitive abilities and critical thinking abilities across three distinct learning methodologies indicate a significant finding, with each approach displaying a significance value of less than 0.05. This study underscores the assertion that metacognitive abilities are intricately linked with critical thinking abilities across all three learning modes. Enhancing metacognitive prowess is shown to directly correspond with improving critical thinking abilities. Conversely, a decline in metacognitive abilities is paralleled by decreased critical thinking capabilities.

These findings align with previous research by Akcaoğlu et al. (2023) and Yassin (2024), highlighting the intimate connection between an individual's capacity to regulate cognitive activities, metacognitive ability, and proficiency in critical thinking. Metacognition encompasses the higher-level mental processes regularly employed to devise study strategies, assess learning progress, and forecast performance. Learners must possess positive attitudes and procedural metacognition to formulate effective plans or strategies for engaging in cognitive thought processes. Success in controlling one's thoughts significantly influences perspectives, expectations, and judgments of mental processes and outcomes.

The insights gleaned from this research resonate deeply with the foundational work of Michalsky in (2024), serving to illuminate the intricate web of connections between an individual's cognitive regulation, metacognitive acumen, and proficiency in critical thinking. Delving deeper into this nexus, one finds that metacognition constitutes the higher-order cognitive processes that individuals routinely employ to strategize their approach to learning, monitor their progress, and anticipate their performance outcomes.

At its essence, metacognition is the compass guiding learners through the vast terrain of knowledge acquisition and application. It encompasses the awareness of one's cognitive processes and the strategic deployment of this awareness to enhance learning outcomes. Learners with a robust repertoire of metacognitive strategies are better equipped to adapt to varying learning contexts, capitalize on their strengths, and address their weaknesses (Simonovic et al., 2023).

Positive attitudes toward learning and a keen understanding of procedural metacognition—the ability to develop and execute tailored plans to tackle cognitive tasks are central to cultivating effective metacognitive practices (Mansueto et al., 2022). These attitudes and abilities empower learners to engage in metacognitive regulation, allowing them to orchestrate their cognitive resources judiciously, set realistic goals, and persist in facing challenges.

Moreover, the significance of metacognitive regulation extends beyond individual learning endeavors to shape broader perspectives, expectations, and judgments concerning mental processes and outcomes. Those who excel in metacognitive regulation are adept learners and astute evaluators of their own cognitive functioning (Le & Chong, 2024; Littrell et al., 2024). They possess the insight to recognize the efficacy of different learning strategies, the flexibility to adapt their approaches as needed, and the resilience to persevere through setbacks (Albalhareth & Alasmari, 2023; Tsamago & Bayaga, 2023). In essence, the mastery of metacognition represents a cornerstone of effective learning and critical thinking. By fostering an awareness of one's cognitive processes, cultivating strategic approaches to learning, and

nurturing a positive mindset, individuals can unlock their full potential as learners and thinkers, paving the way for success in academic pursuits and beyond (Mohammadi et al., 2023; Yüce et al., 2023).

Furthermore, the body of research conducted by Michalsky (2024) and Simonovic et al. (2023) delves into the intricate interplay between metacognitive aptitude and critical thinking prowess, shedding light on the robust correlation between these cognitive faculties. Their studies underscore the symbiotic nature of these cognitive functions, revealing how proficiency in one domain invariably influences and enhances the capabilities in the other.

In parallel, the work of Corebima and Rohman (2016) bolsters this connection, providing empirical evidence of a compelling positive association between metacognitive proficiency and critical thinking abilities among students. Their findings illuminate the symbiotic relationship between these cognitive processes, elucidating how the cultivation of metacognitive strategies can significantly augment the capacity for critical analysis, logical reasoning, and problem-solving. Through meticulous examination and empirical validation, these studies collectively underscore the pivotal role of metacognition in nurturing and amplifying critical thinking abilities (Li & Yuan, 2022; Mizumoto, 2023; Rombout et al., 2021). They provide compelling evidence of how the deliberate cultivation of metacognitive abilities enhances individual learning outcomes and cultivates the analytical acumen and intellectual agility necessary for navigating complex challenges in academic, professional, and everyday contexts.

Delving into the regression equations, scrutinizing the relationship between metacognitive and critical thinking abilities within PBL techniques yields profound insights. PBL, as a pedagogical approach, not only cultivates a deep comprehension of fundamental concepts but hones problem-solving strategies (Bulut Ates & Aktamis, 2024; Santos-Meneses et al., 2023). In the context of PBL, metacognitive strategies such as data organization, logical reasoning, and critical thinking are not just auxiliary tools but integral components intricately woven into the fabric of the problem-solving process.

The literature resoundingly affirms the symbiotic relationship between problem-solving abilities and critical thinking (Maor et al., 2023). Engaging in problem-solving tasks necessitates activating and applying critical thinking abilities. Within the dynamic environment of PBL, learners are not merely passive recipients of information; they actively grapple with authentic problems, employing metacognitive strategies to dissect, analyze, and synthesize information in pursuit of viable solutions (Hidajat, 2023; Maskur et al., 2020).

Moreover, the recursive nature of PBL compels learners to constantly reflect on their problem-solving approaches, fostering metacognitive awareness and iterative improvement in critical thinking abilities. Through iterative cycles of problem-solving and reflection, learners refine their metacognitive toolkit, fine-tuning their ability to assess the effectiveness of different problem-solving strategies and adjust their approaches accordingly (Moslemi Nezhad Arani et al., 2023; Santos-Meneses et al., 2023). Integrating metacognitive strategies and critical thinking within the framework of PBL transcends mere academic exercise; it equips learners with the cognitive flexibility and adaptability necessary to navigate complex real-world challenges. By immersing learners in authentic problem-solving scenarios and scaffolding their metacognitive development, PBL lays the groundwork for fostering lifelong learners adept at

tackling novel problems with ingenuity and analytical rigor (Kong et al., 2024; Urban & Urban, 2023).

Furthermore, integrating the SSI approach into PBL significantly enhances students' critical thinking abilities. SSI-based learning encourages holistic problem analysis, decision-making, and communication, fostering metacognitive control and conceptual understanding (Kinskey & Zeidler, 2021; Kumar et al., 2024; Yalaki, 2016). Similarly, incorporating spiritual values into PBL with the SSI approach enriches students' learning experiences, promoting metacognitive awareness and critical thinking abilities.

The results of the ANOVA tests, which compare regression equations across various learning approaches, serve as robust evidence affirming the effectiveness of PBL in bolstering critical thinking capacities when juxtaposed with alternative methodologies. This statistical validation underscores the potency of PBL as a pedagogical framework capable of nurturing the analytical acumen and cognitive agility indispensable for navigating complex real-world scenarios (S. Amin et al., 2020; Triyanti, 2022).

Furthermore, it elucidates educators' pivotal role in sculpting learning environments conducive to student-centered pedagogies, particularly those rooted in constructivist principles. By relinquishing the traditional role of the "sage on the stage" and assuming the mantle of facilitators, educators catalyze active engagement and deep comprehension among learners. Through carefully curated PBL modules and activities, they orchestrate opportunities for students to grapple with authentic, ill-structured problems, instigating cognitive dissonance and prompting critical inquiry (Kardoyo et al., 2020; Yustina et al., 2022). Indeed, the essence of PBL lies not merely in acquiring factual knowledge but in cultivating meta-cognitive strategies and epistemic virtues. Students immersed in PBL frameworks are challenged to deconstruct complex issues, synthesize disparate information, and cogently articulate their reasoning—a process engenders resilience, adaptability, and intellectual autonomy (Acharya et al., 2021; Srikan et al., 2021).

Moreover, the efficacy of PBL extends beyond the confines of academic discourse, permeating into lifelong learning and professional practice. Armed with a robust foundation in critical thinking nurtured through PBL, individuals are better equipped to navigate the myriad challenges of the contemporary world, make informed decisions, and effect positive change in their communities (Boye & Agyei, 2023; Bulut Ates & Aktamis, 2024).

In essence, the findings underscore the superiority of PBL in fostering critical thinking and the transformative potential of student-centered pedagogies in nurturing the next generation of agile, discerning thinkers and problem solvers (N. Ali et al., 2024; Chueh & Kao, 2024). As such, educators are called upon to embrace innovative instructional approaches that prioritize active learning, collaboration, and authentic problem-solving, propelling learners toward intellectual empowerment and lifelong success.

The relationship between metacognitive skills and critical thinking skills is crucial in various educational approaches, particularly Problem-Based Learning (PBL), PBL integrated with Socio-scientific Issues (SSI), and PBL integrated with SSI and spiritual values. Metacognitive skills involve the awareness and regulation of one's cognitive processes, while critical thinking skills encompass the ability to analyze, evaluate, and synthesize information effectively.

Research indicates that PBL enhances metacognitive awareness and fosters the development of critical thinking skills among students (Leasa, 2024). PBL encourages active learning, collaboration in group discussions, and knowledge building, promoting metacognitive skills and critical thinking abilities (Leasa, 2023). The collaborative nature of PBL allows students to apply metacognitive strategies, such as planning and monitoring, influencing their capacity to evaluate arguments effectively, an essential aspect of critical thinking (Teng & Yue, 2022).

Integrating SSI into PBL has significantly impacted students' critical thinking development and cognitive learning outcomes (Fita et al., 2021). Using SSI problems as learning contexts, students are challenged to think critically, analyze complex issues, and make informed decisions, strengthening their critical thinking abilities (Fita et al., 2021).

Furthermore, integrating spiritual values into PBL and SSI can enhance the development of metacognitive and critical thinking skills. While the direct relationship between spiritual values and cognitive skills is not extensively studied, the mediating role of spirituality in well-being and cognitive processes suggests a potential influence on metacognitive and critical thinking abilities. By infusing spiritual values into the learning environment, students may reflect on ethical considerations, moral dilemmas, and broader perspectives, enhancing their metacognitive and critical thinking capacities.

Integrating metacognitive skills and critical thinking skills in PBL, PBL integrated with SSI, and PBL integrated with SSI and spiritual values promotes active learning, collaborative problem-solving, and real-world application of knowledge. These approaches empower students to think critically, evaluate information effectively, and develop a deeper understanding of complex issues. Challenges arise in assessing and measuring the impact of spiritual values on cognitive skills and ensuring the effective implementation of metacognitive and critical thinking skills across diverse educational settings.

The integration of metacognitive skills and critical thinking skills in PBL, PBL integrated with SSI, and PBL integrated with SSI and spiritual values offers a holistic approach to fostering cognitive development and enhancing students' abilities to think critically, solve problems, and make informed decisions in diverse contexts. This study highlights the integral relationship between metacognitive abilities and critical thinking abilities across various learning methodologies. By understanding and harnessing these cognitive processes, educators can create enriching learning environments conducive to nurturing students' critical thinking abilities and promoting academic success.

Conclusion

Based on the data analysis and discussion findings, it is possible to conclude that (1) there is a significant relationship between metacognitive skills and critical thinking skills in the application of the three learning strategies (PBL, PBL with the SSI approach, and PBL with the SSI approach and spiritual values), and (2) regression line parallels do not coincide and intersect in the regression equation tested using ANOVA. This study suggests that the three learning strategies impact the rate and amount of growth in critical thinking abilities in distinct ways.

Empowering metacognitive skills in the learning process must be done optimally and continuously at all levels of schooling. This empowerment will have an impact on students'

critical thinking skills and independence. These skills are necessary for students to be competitive and motivated in today's fast-paced and digital development period. Professors and lecturers can use innovative learning techniques such as PBL, PBL using the SSI approach, and PBL utilising the SSI approach and spiritual values as an option to develop students' metacognitive abilities and critical thinking skills.

The correlation study of metacognitive and critical thinking abilities in applying the three learning methods indicates that the PBL strategy has the most excellent dependability value, followed by the PBL with the SSI approach and spiritual values and the PBL with the SSI approach. As a result, lecturers and teachers are encouraged to use PBL learning approaches to help students build metacognitive and critical thinking skills. More research is needed to determine the relationship between metacognitive abilities and critical thinking skills in the same or different classes, subjects, and dependent variables when three learning techniques are used (PBL, PBL with the SSI approach, and PBL with the SSI approach and spiritual values).

Credit Authorship Contribution Statement

Yatin Mulyono: Conceptualization, Methodology, Software, Visualization, Formal analysis, Writing – original draft. **Mujib Ubaidillah**: Conceptualization, Methodology, Formal analysis, Resources, Writing – review & editing.

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