Jurnal Pendidikan MIPA
e-ISSN: 2685-5488 | p-ISSN: 1411-2531
URL: https://jpmipa.fkip.unila.ac.id/index.php/jpmipa
Jounal's DOI: http://doi.org/10.23960/jpmipa

Vol. 27, No. 3, 2026
Article ID: 1205
Pages: 1298-1316

Problem-Based Learning and Inquiry-Based Learning Models in Learning Arithmetic Sequences and Series in High School

Hanum Ulfiatus Sufiyah[1], Budi Cahyono[1,*], Nadhifah[1], & Bunga Ihdanorra[1,2]
[1]Department of Mathematics Education, UIN Walisongo, Indonesia
[2]Department of Curriculum and Instructional Technology, Malaya University, Malaysia

*Corresponding email: budi.cahyono@walisongo.ac.id

Received: 07 January 2026 *Accepted: 13 June 2026* *Published: 24 July 2026*

Abstract: This study aims to compare the effectiveness of Problem-Based Learning (PBL) and Inquiry-Based Learning (IBL) models in improving the critical thinking skills of tenth-grade high school students on the topic of Arithmetic Sequences and Series. The research employed a quantitative approach using a Matching Pretest–Posttest Comparison Group Design. The study population consisted of six classes of tenth-grade students at SMAN 16 Semarang that were normally distributed, homogeneous, and had similar average initial abilities. Due to time constraints and the need to ensure consistent implementation of learning treatments, three classes were selected through cluster random sampling. Class X-01 was assigned as Experimental Group I using the PBL model, class X-02 as Experimental Group II using the IBL model, and class X-03 as the control group using a conventional learning model. Data collection was conducted using pretest and posttest instruments designed to measure students' critical thinking skills. The instruments were validated before the implementation. Data analysis was conducted using an independent samples t-test to determine the effectiveness of the PBL and IBL models compared to the conventional model. Furthermore, a paired samples t-test followed by an N-gain analysis was used to compare the effectiveness between the PBL and IBL models. The results indicated that both PBL and IBL models were effective in improving students' critical thinking skills compared to the conventional learning model. However, the N-gain analysis showed that students taught with the PBL model experienced greater improvement in critical thinking skills than those taught with the IBL model. Therefore, it can be concluded that although both learning models are effective, the Problem-Based Learning model is more effective than the Inquiry-Based Learning model in enhancing critical thinking skills of grade X high school students in learning Arithmetic Sequences and Series.

Keywords: inquiry-based learning (IBL), critical thinking skills, problem-based learning (PBL).

Article's DOI: https://doi.org/10.23960/jpmipa.v27i3.pp1298-1316

INTRODUCTION

The rapid dynamics of technology and science demand competent human resources capable of adapting to changing societal and professional landscapes. To meet these challenges, education plays a pivotal role in equipping students not only with factual knowledge but also with essential skills and competencies required in the 21st century (Kalyani, 2024). Among these skills, critical thinking has emerged as one of the most significant, as it enables students to approach problems systematically, evaluate alternatives, and make informed decisions (Dad & Akbar, 2023). Students with well-developed critical thinking skills are able to understand concepts in depth, recognize underlying patterns, analyze complex problems, evaluate multiple solution strategies, and construct coherent and logical arguments (Alsaleh, 2020; Hitchcock, 2017; Jamil et al., 2024).

Critical thinking ability is conceptualized as an intentional, trained intellectual process in which individuals actively and skillfully conceptualize, apply, analyze, synthesize, and evaluate information obtained or generated through observation, experience, reflection, reasoning, or communication. The results of this process are then used as a foundation for forming beliefs and guiding subsequent actions (Ennis, 2016; Hitchcock, 2017). In the context of mathematics learning, critical thinking is not merely an abstract skill; it is a cornerstone for effective learning. It affects not only students' mastery of mathematical concepts but also their ability to plan, evaluate, and execute strategies that create an interactive, reflective, and meaningful learning environment (Rahmadani et al., 2024; Tjahjadi & Seleky, 2022). Students who engage in critical thinking are more likely to question assumptions, connect different mathematical concepts, and apply reasoning to solve non-routine problems, which is essential for higher-order mathematical understanding.

To operationalize critical thinking in educational research, this study employs the FRISCO indicators proposed by Ennis, which comprise Focus, Reason, Inference, Situation, Clarify, and Overview (Cahyono et al., 2022; Ennis, 2011; Mason, 2007; Payan-Carreira et al., 2015). The focus indicator relates to students' ability to identify known and requested information in a problem. The Reason indicator refers to students' ability to provide logical reasons for the chosen strategy or solution steps. The Inference indicator reflects the ability to draw conclusions from the analysis results. The Situation indicator emphasizes students' ability to adapt the solution strategy to the problem context. Furthermore, the Clarify indicator assesses students' clarity in conveying the solution's steps and arguments. In contrast, the Overview indicator reflects students' ability to review and evaluate the correctness of the solution obtained (Amri & Mustika, 2022). In the context of mathematical problem solving, critical thinking skills are reflected through students' ability to identify known and requested information, choose a solution strategy or formula based on logical reasoning, and organize the solution steps in a coherent and systematic manner (Cahyono, 2017). Although these indicators are core competencies in learning, especially in mathematics, students' critical thinking skills in Indonesia have not yet developed to their full potential (Siregar et al., 2018; Tachie, 2019; Vidad & Quimbo, 2021).

In fact, several studies have demonstrated that students' critical thinking skills in Indonesia remain relatively low (Sarwanto et al., 2021; Susetyarini & Fauzi, 2020; Wilde-Larsson et al., 2017). This is further evidenced by Indonesia's performance in the 2022 Program for International Student Assessment (PISA), in which the country ranked 70th out of 82 participating nations (OECD, 2023). Such rankings highlight a concerning trend in which many Indonesian students struggle to solve non-routine problems that require reasoning, analysis, and evaluation of given information. The underlying cause of this low performance is largely attributed to educational practices that emphasize procedural learning and rote memorization, leaving students underprepared to interpret contextual problems, connect mathematical concepts meaningfully, and provide logical justifications for their solutions (Liestari et al., 2024).

Moreover, research on mathematical problem-solving highlights specific cognitive gaps associated with critical thinking indicators. For instance, studies show that students often have difficulty identifying relevant information in complex problems, reflecting weaknesses in the Focus indicator (Putri et al., 2024). Similarly, students struggle to articulate logical reasons for selecting a particular solution strategy, corresponding to the Reason indicator (Cahyono et al., 2019). The ability to organize solution steps coherently and communicate reasoning effectively, as related to the Situation and Clarify indicators, is also frequently underdeveloped among secondary school students (Amri & Mustika, 2022). Finally, many students fail to consistently review and evaluate their solutions, which corresponds to the Overview indicator, indicating a lack of metacognitive reflection and self-monitoring skills (Jamil et al., 2024)

Collectively, these findings from the literature indicate a systematic challenge in developing critical thinking skills in mathematics learning. Students may perform procedural calculations correctly, but they often lack the ability to reason critically, evaluate strategies, and reflect on their own thinking processes. This body of evidence underscores the need for instructional approaches that go beyond rote procedures and emphasize cognitive processes, problem analysis, and evaluative thinking. Implementing such approaches is critical for fostering students' higher-order thinking skills, which are essential for effective mathematics learning and for preparing learners to face complex, real-world challenges in the 21st century (Dad & Akbar, 2023; Ennis, 2016; Hitchcock, 2017).

To address these challenges, several previous studies have compared various constructivist learning models in mathematics education. Comparative studies between Problem-Based Learning (PBL), Inquiry-Based Learning (IBL), Discovery Learning, and other student-centered approaches generally indicate positive effects on students' higher-order thinking skills. For example, Indah and Nuraeni found that PBL improved students' mathematical deductive reasoning more effectively than IBL, with PBL achieving a medium N-Gain category. At the same time, IBL remained in the low category (Indah & Nuraeni, 2021). In another study, Sutarsa and Puspitasari reported that the Group Investigation (GI) model outperformed PBL in improving students' critical thinking skills (Sutarsa & Puspitasari, 2021). Furthermore, research by Sugeng demonstrated that IBL was significantly more effective than conventional learning models in enhancing students' conceptual understanding and inquiry abilities (Istni et al., 2022). Other studies have also confirmed PBL's positive contribution to students' mathematical critical thinking and problem-solving skills across various mathematical topics (Nufus et al., 2021).

Although these studies indicate that constructivist learning models have significant potential for improving higher-order thinking skills, direct comparative studies between PBL and IBL focusing specifically on students' mathematical critical thinking skills are still limited, particularly in the topic of arithmetic sequences and series at the senior high school level. Therefore, this study seeks to fill this gap by comparing the effectiveness of PBL and IBL in improving students' mathematical critical thinking skills within a specific curriculum context.

Among these models, instructional models such as Problem-Based Learning (PBL) and Inquiry-Based Learning (IBL) are highly relevant. Problem-Based Learning (PBL) is a relevant learning model for developing students' critical thinking skills. This model emphasizes using contextual problems from real situations as a starting point for learning, providing a meaningful context for students to develop critical thinking and problem-solving skills. (Ali, 2019; Hutsalo & Ordanovska, 2024). The PBL learning model is known to be effective in improving critical thinking skills (Cahyono et al., 2022; P. Chen & Chang, 2021; Dakabesi et al., 2019; Nadeak & Naibaho, 2020; Nufus et al., 2021; Yih et al., 2011). The problem-oriented stage in this model confronts students with real-life contextual problems. This stage aligns with constructivism theory, which emphasizes that knowledge is built through meaningful learning experiences. The problems presented also encourage students to identify important information, formulate problems, and activate prior knowledge, thereby training critical thinking skills in the analytical and problem-focused aspects (Qablan et al., 2024; Saleem & Deeba, 2021; Shah, 2019).

Another well-known model for developing students' critical thinking skills is Inquiry-Based Learning (IBL) (Duran & Dökme, 2016; Kartika & Rakhmawati, 2022; Prayogi et al., 2018). Based on the level of teacher guidance in the learning process, the Inquiry-Based Learning approach is divided into several types, namely the Guided Inquiry Approach, the Free Inquiry Approach, and the Modified Free Inquiry Approach (Dobber et al., 2017; Lazonder & Harmsen, 2016). In this study, the approach used was the Guided Inquiry Approach, namely providing guidance and instructions from the teacher to students in carrying out investigative activities (Sulistyani et al., 2022). This approach is considered appropriate for students who are not yet accustomed to inquiry-based learning, so that students can still develop critical thinking skills without experiencing difficulties in designing and implementing the investigation process independently.

Although many studies have shown that Problem-Based Learning (PBL) and Inquiry-Based Learning (IBL) are effective in improving students' critical thinking skills, no study has directly compared the two models to see which is better in improving critical thinking skills in high school mathematics learning (Nufus et al., 2021; Prasekti & Marsigit, 2017; Sulistyani et al., 2022). Furthermore, this study not only analyzes overall critical thinking skills but also examines improvements in each indicator of students' critical thinking, considering the distinct learning mechanisms embedded in each model. PBL emphasizes problem orientation, collaborative problem-solving, and structured reflection, which may foster higher-level critical-thinking indicators such as analysis and evaluation. In contrast, IBL focuses on inquiry processes such as hypothesis formulation, exploration, and discovery, which may influence students' inference and reasoning in different ways. The selection of arithmetic sequences and series as the focus of this study is based on the cognitive characteristics of the topic, which strongly support the development of students' critical thinking skills. Unlike procedural mathematical topics that primarily emphasize formula application, arithmetic sequences and series require students to recognize numerical patterns, analyze relationships between terms, formulate generalizations, and apply logical reasoning systematically. Students are expected not only to determine numerical results but also to justify the reasoning used to derive formulas and solve contextual problems.

In solving problems related to arithmetic sequences and series, students must identify relevant information and determine the underlying pattern of the sequence (Focus), provide logical arguments for selecting formulas or strategies (Reason), draw conclusions based on mathematical relationships obtained from the analysis process (Inference), and apply appropriate concepts according to the problem context (Situation). In addition, students are required to explain their solution procedures coherently (Clarify) and to evaluate the correctness of their solutions by rechecking or using alternative strategies (Overview). Therefore, the topic of arithmetic sequences and series provides an appropriate mathematical context for evaluating and developing students' critical-thinking skills aligned with the FRISCO indicators. To fill this gap, this study aims to compare the effectiveness of Problem-Based Learning (PBL) and Inquiry-Based Learning (IBL) models on students' critical thinking skills in learning arithmetic sequences and series in grade 10 of senior high school. Accordingly, this study is guided by the following research questions:

1. Are the Problem-Based Learning (PBL) and Inquiry-Based Learning (IBL) models effective in improving students' critical thinking skills in

learning arithmetic sequences and series in grade 10 of senior high school?
2. Which learning model, PBL or IBL, is more effective in improving students' critical thinking skills in the topic of arithmetic sequences and series?

METHOD

Participants

This study involved grade X students of SMA Negeri 16 Semarang in the 2025/2026 academic year as research subjects. The research population comprised all Grade X students across 6 classes. Each class consisted of 36 students. The research sample was selected using a cluster random sampling technique; each class has an equal chance of being a sample, so class selection is probabilistic (Sugiyono, 2019). From the sampling process, three classes were obtained as research samples: two experimental classes and one control class. Class X-02 as experimental class I, class X-01 as experimental class II, and class X-03 as control class.

Research Design and Procedure

This study used a quantitative approach with a quasi-experimental design, namely the Matching Pretest–Posttest Comparison Group Design. This design was chosen because it allows researchers to compare the effectiveness of two learning models, namely Problem-Based Learning (PBL) and Inquiry-Based Learning (IBL), on students' critical thinking skills (Sugiyono, 2019).

Table 1 shows that before the treatment was administered, all sample classes took a pretest to assess students' critical thinking skills. Three sample classes were then selected, each given treatment according to a predetermined learning model. In the experimental class, I implemented the Problem-Based Learning (PBL) model, while the experimental class II implemented the Inquiry-Based Learning (IBL) model with a Guided Inquiry approach. The control class implemented learning using a conventional learning model through the lecture method.

All sample classes were taught by the same teacher, the researcher, using the same material, namely arithmetic sequences and series, in three meetings with the same time allocation, namely 2 lesson hours (2 x 45 minutes) per meeting. After the entire series of treatments was completed, students were given a final test (posttest) to measure their critical thinking skills following the learning.

Table 1. Research design

Group	Pretest	Treatment	Posttest
Experimental 1	O_1	X_1 (PBL)	O_4
Experimental 2	O_2	X_2 (IBL)	O_5
Control	O_3	X_3 (Conventional Learning)	O_6

Instruments

The research instrument consisted of a critical thinking ability test structured in five descriptive questions to be completed within 2 lesson hours (2 x 45 minutes). The critical thinking ability indicators in this test are based on Ennis indicators, including Focus, Reason, Inference, Situation, Clarify, and Overview (FRISCO). Each test item was designed to accommodate all six indicators through different aspects of students' written responses. An example of the critical thinking test item is as follows: "Four positive numbers form an arithmetic sequence. If the product of the first and fourth terms is 46, and the product of the second and third terms is 144, determine the sum of the four numbers." The items presented a problem related to arithmetic sequences, in which students were required to identify relevant information and formulate the core problem (Focus), provide logical reasoning for the chosen solution strategy (Reason), draw appropriate conclusions based on the obtained results (Inference), select and apply relevant mathematical concepts according to the given situation (Situation), explain each step of the solution clearly and mathematically (Clarify), and recheck the correctness of the solution using an alternative approach or justification (Overview). Students' responses were assessed holistically using a scoring rubric developed based on the FRISCO indicators. The detailed scoring rubric for each indicator is provided in the supplementary material.

Before being used in the research, the test instrument was first consulted with the mathematics education lecturer and the 10th-grade mathematics teacher, and then a trial was conducted. The instrument was trialed on students outside the research sample class. Based on the trial results, an analysis of the item validity, reliability, difficulty level, and discriminating power was conducted to ensure that the instrument was suitable for use in collecting research data. Item validity was tested using the Pearson Product Moment correlation by comparing the value of r_{count} with r_{table} at a significance level of 0.05. The results showed that all items had r_{count} values greater than $r_{table} = 0{,}349$, indicating that all items were valid. Instrument reliability was assessed using Cronbach's Alpha, yielding a coefficient of 0.906, indicating high internal consistency. Therefore, the instrument was considered valid and reliable for measuring students' critical thinking skills. The mathematical critical-thinking ability test was administered twice: before the treatment (pretest) and after all learning treatments were completed (posttest). The results of the pretest and posttest were used to assess improvements in students' critical thinking skills and to provide a basis for comparative analysis of the effectiveness of implementing the Problem-Based Learning (PBL) and Inquiry-Based Learning (IBL) learning models.

Data Analysis

Data analysis techniques were conducted using descriptive analysis and inferential statistics of the data obtained. Descriptive analysis was conducted by finding the average, standard deviation, variance, minimum score, and maximum score of the data obtained, both for pre-treatment and post-treatment data. Analysis was also conducted to determine the percentage of indicator achievement according to the criteria.

Inferential statistical analysis of data before treatment using ONE WAY ANOVA with a significance value criterion of 0.05, which shows that there is no difference in the average between the two classes before the treatment is given (Khudriyah, 2021). Meanwhile, the post-treatment data will undergo the independent-samples t-test, paired t-test, and N-Gain testing stages. The independent-samples t-test was conducted at a significance level of 0.05 to determine whether the PBL and IBL methods are effective in developing critical thinking skills (Sugiyono, 2019). A paired t-test at the 0.05 significance level will show a significant difference in the average between the PBL and IBL classes (Anwar, 2009). The test was then continued with the N-Gain test to demonstrate that the PBL method is more effective than the IBL method in developing critical thinking skills (Wahab et al., 2021). The data obtained were then classified according to the criteria in Tables 2 and 3 for the scale of ability improvement.

Table 2. N-Gain category

N-gain value	Information
$g \geq 0.7$	High
$0.3 \leq g < 0.7$	Medium
$g \leq 0.3$	Low

Table 3. N-Gain effectiveness category

Percentage (%)	Information
<40	Ineffective
40-55	Less Effective
56-75	Quite Effective
>76	Effective

RESULT AND DISCUSSION

Normality and Homogeneity of Data

Before conducting the hypothesis test, the research data were first tested for normality and homogeneity to meet the prerequisites for parametric analysis. The normality test was conducted using the Lilliefors test to determine whether the pretest and posttest data on students' critical thinking skills were normally distributed. Based on Tables 5 and 6, the results of the right-tailed test at a significance level of 5%, the data showed that $L_{count} < L_{table}$, then H_0 accepted, meaning that each research group, both before and after treatment, was normally distributed, thus fulfilling the requirements for parametric statistical analysis.

Table 4. Results of normality test before treatment

Class	l_{count}	l_{table}
Class X-01	0.1497	0.1566
Class X-02	0.1401	0.1498
Class X-03	0.1502	0.1591
Class X-04	0.1144	0.1618
Class X-05	0.1097	0.1566
Class X-06	0.1225	0.1591

Table 5. Results of normality test after treatment

Class	l_{count}	l_{table}
Experimental Class I (PBL)	0.1342	0.1618
Experimental Class II (IBL)	0.1474	0.1591
Control Class	0.1461	0.1566

Next, a homogeneity of variance test was conducted using the Bartlett test to determine whether all groups had equal variances. Referring to Table 7, the test results with the right-tailed test at a significance level of 5% showed that $x^2_{count} < x^2_{table}$, then H_0 it was accepted, meaning that the data variance between groups before and after treatment was homogeneous or had the same variance. By fulfilling the assumptions of normality and homogeneity, the research data were deemed to meet the prerequisites for hypothesis testing using the ANOVA and t-tests.

Table 6. Results of the homogeneity test

	Before	After
x^2count	8.49	3.53
x^2table	11.07	5.99

After it is known that the data is homogeneous, it is necessary to conduct a One-Way ANOVA test on the data before treatment. The results of the One-Way ANOVA test on the data before treatment show that the value of = 0.45 and = 2.26. These results indicate that there was no difference in the average between the six classes before the treatment. In other words, the average initial abilities of students in the six classes were the same based on the aspects measured.

The Effectiveness of Problem-Based Learning (PBL) Models on Students' Critical Thinking Skills

The results of the descriptive statistical analysis of critical thinking skills show that there is a difference in the average score of students' critical thinking skills before and after learning in each group.

There was a decrease in the number of participants from pretest to posttest across all groups: Experimental Class I (PBL), from 35 to 30 students; Experimental Class II (IBL), from 32 to 31 students; and Control Class, from 35 to 32 students. This decrease was due to several students being absent from the posttest for health reasons or with personal permission. Despite the decrease, the analysis showed that the distribution of initial characteristics (pretest) between students who remained in the posttest and those who did not remain was relatively balanced. Therefore, the impact of the decrease on the research findings is estimated to be minimal.

Table 7. Description of critical thinking skills data results

Class	Information	Pretest	Posttest
Experimental Class I (PBL)	N	35	30
	Mean	28.03	60.15
	Minimum	3.33	27.78
	Maximum	52.22	92.22
	Std	13.39	21.08
	t_{count}	6.4587	
	t_{table}	1.6706	
Experimental Class II (IBL)	N	32	31
	Mean	30.17	45.02
	Minimum	1.11	22.22
	Maximum	64.44	88.89
	Std	12.67	17.40
	t_{count}	3.6232	
	t_{table}	1.6702	
Control Class	N	35	32
	Mean	30.14	30.28
	Minimum	5.56	5.56
	Maximum	51.11	68.89
	Std	9.61	15

Table 7 shows the results of the analysis of students' critical thinking skills. The Problem-Based Learning (PBL) model demonstrated effectiveness in improving students' critical thinking skills. This is evident from the increase in the average score for students' critical thinking skills from 28.03 on the pretest to 60.15 on the posttest. Furthermore, based on the results of the independent-samples t-test for the PBL class, the t-statistic was t = 6.4587, which exceeds the critical t-value of 1.6706. The maximum posttest score in the PBL class, at 92.22, also indicates that some students achieved a very high level of critical thinking after participating in the learning. Therefore, the PBL method is effective in improving students' critical thinking skills.

Through the implementation of PBL, students are encouraged to actively seek and formulate solutions to problems related to everyday life through the collaborative application of learned material concepts (Ali, 2019; C. Chen & Kuo, 2019). Furthermore, the PBL learning process provides opportunities for students to explore, analyze, and find solutions independently, thereby effectively stimulating student learning. In PBL, students are no longer positioned as passive learning objects, but rather as active subjects directly involved in the learning process (Almulla, 2020). The substantial improvement in students' posttest scores indicates that such engagement contributes meaningfully to the development of critical thinking skills. These findings are consistent with previous studies reporting that PBL promotes higher-order cognitive activities, including analysis, evaluation, and solution formulation, both individually and collaboratively (P. Chen & Chang, 2021; Yew & Goh, 2016).

Unlike conventional learning approaches that emphasize procedural mastery, PBL places problem-solving at the core of the learning process. Students are consistently confronted with contextual and non-routine problems that require them to analyze problem situations, formulate relevant questions, evaluate alternative strategies, and justify their solutions. This learning orientation aligns with the arguments of Sholihah & Lastariwati (2020) and Yih et al. (2011), who emphasized that critical thinking develops when students are actively engaged in reasoning processes rather than passively receiving information. The significant gains observed in this study suggest that sustained involvement in such cognitive activities can transform students' thinking patterns toward more analytical and reflective modes.

Nevertheless, compared to studies reporting only moderate improvements in critical thinking through PBL, the relatively high posttest scores in this study suggest that the effectiveness of PBL is closely related to how learning activities are designed and implemented. Learning problems that are connected to real-life contexts and supported by collaborative discussion appear to intensify students' cognitive engagement. This finding extends the work of Ceker & Ozdamli (2016) by demonstrating that the strength of PBL lies not only in its problem-oriented nature, but also in the quality of problem design and opportunities for meaningful student interaction. Improvements in students' valid argumentation techniques after learning with the PBL method indicate that students' critical thinking skills have improved (Cahyono et al., 2021).

Furthermore, while Almulla (2020) emphasized student activeness as a defining feature of PBL, the present findings indicate that activeness alone is insufficient to foster critical thinking. Critical thinking develops more effectively when student participation is accompanied by structured opportunities for reasoning, argumentation, and reflection. Overall, this study strengthens the existing literature by demonstrating that PBL is not merely a student-centered learning model but a problem-solving-oriented instructional approach that, when properly implemented, can substantially enhance students' critical thinking skills in mathematics. These findings provide empirical support for the use of PBL as a robust framework for developing higher-order thinking skills in secondary education.

The Effectiveness of Inquiry-Based Learning (IBL) Models on Students' Critical Thinking Skills

As shown in Table 7, the Inquiry-Based Learning (IBL) model was also effective in improving students' critical thinking skills. The average score for students' critical thinking skills increased from 30.17 in the pretest to 45.02 in the posttest. The results of the independent-samples t-test for the IBL class showed that the t-statistic (3.6232) is greater than the critical value (1.6702). So, it can be said that the IBL method is effective for students' critical thinking skills.

According to Dobber et al. (2017) and Lazonder & Harmsen (2016), IBL positions students as active and independent subjects during the learning process, both in thinking activities and in the search for concepts or expected final results, while still being grounded in teacher direction and guidance. In its application, IBL emphasizes the scientific inquiry process, in which students actively seek, collect, and analyze information to answer questions or solve given problems (Gholam, 2019). In this model, students are asked to formulate hypotheses, test hypotheses, and draw conclusions based on data obtained before and during the learning process by linking new information obtained with cognitive structures and prior knowledge that students already have, so that the learning process takes place meaningfully, as stated in Ausubel's learning theory. (Blown & Bryce, 2024; Jasper Abowei & Ebikiemo, 2023; Qablan et al., 2024). In addition, students are involved in discussions, group work, and teacher guidance, which aligns with Vygotsky's learning theory, in which students' cognitive development occurs through social interactions and collaborative processes (Gunawardena & Wilson, 2021; Luong, 2022; Morgan & Skaggs, 2016). IBL also actively engages students during investigative activities, which include asking questions and exploring various sources of information, such as books and other references (Mellita & Rosita, 2019). So that students are always accustomed to solving problems systematically, thereby improving their critical thinking skills.

Analysis of Student's Answer Sheets

To strengthen the quantitative findings, a simple qualitative analysis was conducted on students' written responses from both the Problem-Based Learning (PBL) and Inquiry-Based Learning (IBL) classes. The analysis focused on identifying students' problem-solving patterns, common errors, and the manifestation of the FRISCO indicators (Focus, Reason, Inference, Situation, Clarify, and Overview) in students' written work. Several representative answer sheets were selected and analyzed anonymously to provide empirical evidence supporting the differences in students' critical thinking performance between the two learning models.

The qualitative analysis revealed noticeable differences between students' responses in the PBL and IBL classes. Students in the PBL class generally demonstrated more systematic and structured solution processes. Most of them began by identifying the known and required information before determining appropriate mathematical strategies. In addition, they tended to explain the reasoning behind the formulas they used and to recheck their final answers by substitution or alternative calculations. These characteristics are reflected in stronger performance across the Focus, Clarify, and Overview indicators.

Meanwhile, students in the IBL class were generally able to identify relationships between terms and formulate mathematical expressions correctly. However, several students provided incomplete explanations and did not consistently justify their strategies. Some students directly performed calculations without explicitly explaining their reasoning processes or verifying the correctness of their answers. This finding suggests that inquiry activities successfully stimulated students' reasoning abilities, but the reflective and evaluative aspects of critical thinking were less developed.

Table 8. Qualitative analysis of students' answer sheets in IBL and PBL classes

Analysis Aspect	PBL	IBL
Focus	Students identified known and asked for information completely and systematically. The solution process began with problem interpretation and concept identification.	Students were able to identify known and asked information, but several answers were incomplete and less organized. Some students directly performed calculations without clearly explaining the mathematical situation.
Reason	Students selected appropriate mathematical concepts and accurately connected several of them, such as arithmetic series formulas, nth-term formulas, and algebraic modeling.	Students applied arithmetic sequence and Pythagorean concepts correctly in several parts, but some algebraic manipulations were inconsistent.
Inference	Students arranged their reasoning systematically, from variable assumptions and substitutions to calculations and conclusions.	The solution process generally led to the correct answer, but several steps lacked detailed explanations.

Clarify	Students provided clearer explanations and included reasons for using specific formulas or procedures.	Mathematical explanations were often brief, and some operations were written without justification.
Overview	Students reviewed their solutions by matching their answers to the problem conditions.	Students rarely rechecked their final answers, resulting in unnoticed computational errors.
Common Errors	Only minor computational inaccuracies were found, while conceptual understanding remained strong.	Algebraic manipulation errors, incomplete conclusions, and lack of explanation in intermediate steps.

Based on the analysis of students' answer sheets, there were clear differences in the characteristics of students' critical thinking performance between the PBL and IBL classes. In the IBL class, students generally understood the problems and identified relevant mathematical concepts. However, many solutions remained relatively procedural and brief. Several students immediately substituted values into formulas without explaining why particular concepts were selected. In addition, some algebraic inconsistencies and incomplete conclusions were identified in the responses.

For example, in problems involving arithmetic sequences and right triangles, students in the IBL class were able to recognize arithmetic patterns and apply the Pythagorean theorem appropriately. Nevertheless, some intermediate reasoning processes were omitted, making the logical flow of the solutions less explicit. This indicates that the Clarify and Overview indicators were not fully developed in several responses.

In contrast, students in the PBL class demonstrated more organized and reflective problem-solving processes. Students began by identifying known and required information, then constructed mathematical models, performed substitutions, and drew conclusions consistent with the problem context.

One representative answer sheet from the PBL class showed that the student successfully connected the arithmetic series formula with the nth-term concept to determine unknown variables before obtaining the final solution. The student also provided written justifications for each mathematical step and rechecked the obtained results according to the conditions presented in the problem. These characteristics indicate stronger critical thinking performance, particularly in the Focus, Reason, Clarify, Overview indicator.

Overall, the qualitative findings support the quantitative results, indicating that students taught through the PBL model demonstrated better critical thinking performance than those taught through the IBL model. Through problem-based learning activities, students appeared to become more accustomed to analyzing contextual problems systematically, constructing mathematical arguments, and evaluating their own solutions critically.

Comparison of Students' Critical Thinking Skills Using the Problem-Based Learning (PBL) Model and the Inquiry-Based Learning (IBL) Model

To determine the difference in effectiveness between the Problem-Based Learning (PBL) and Inquiry-Based Learning (IBL) models in improving students' critical thinking skills, an Independent Samples t-test was conducted on the students' post-test scores. The statistical analysis results are presented in Table 9.

Table 9. Independent sample t-test results of students' critical thinking skills

	PBL	**IBL**
Mean	60.15	45.02
Variance	444.42	302.87
Observations	30	31
Hypothesized Mean Difference	0	
df	56	
t Stat	3.05	
P(T<=t) one-tail	0.0017	
t Critical one-tail	1.67	
P(T<=t) two-tail	0.003	
t Critical two-tail	2.003	

Based on the Independent Samples t-test results in Table 8, the calculated t-value (t_{count} = 3.052) is greater than the critical t-value (t_{table} = 2.003) at a 0.05 significance level. Furthermore, the p-value ($P(T \leq t\}$ = 0.003) is much smaller than 0.05 ($p < 0.05$). This statistically demonstrates a significant difference in critical thinking skills between students taught with the PBL model and those taught with the IBL model.

The mean score of the PBL class ($M = 60.15$) is higher than that of the IBL class (M = 45.02). This result is also supported by the N-Gain test, in which the PBL class achieved an N-Gain score of 0.448 (45%, moderate category), while the IBL class obtained only 0.2185 (22%, low category). Therefore, it can be concluded mathematically and statistically that the Problem-Based Learning (PBL) model is significantly more effective than the Inquiry-Based Learning (IBL) model in improving students' critical thinking skills.

In Problem-Based Learning (PBL), students are presented with problems that require them to apply the mathematical concepts they have learned. The problems presented in PBL classes not only serve as learning triggers but also serve as the core of the entire learning process (Hung, 2016). Through student activity sheets (LAS), students are required to analyze problems, find or select relevant concepts, and directly apply the concepts or solutions obtained to solve the problem as a whole. Thus, students gain more intense experience in integrating conceptual knowledge with problem-solving skills. This differs from Inquiry-Based Learning (IBL), which places more emphasis on the process of investigation and concept discovery through observation, data collection, and drawing conclusions (Lazonder & Harmsen, 2016). Although students also use LAS and are actively involved in the exploration process, the main focus of IBL tends to stop at the concept discovery stage, so that the application of concepts in diverse problem-solving contexts is not a primary emphasis. As a result, students' opportunities to practice critical thinking skills during the solution implementation and evaluation stages are less intensive than in PBL learning.

In PBL, students begin by addressing problems and developing questions that lead to the search for solutions (Ceker & Ozdamli, 2016; Yih et al., 2011). The initial step of PBL is student orientation to the problem (Sari et al., 2021). encourages students to think critically from the beginning of learning through to the evaluation stage of the results of the solution. This process trains students not only to understand concepts but also to apply them logically and systematically to solve real-life problems. This is in line with the opinion of Yew & Goh (2016), who stated that one of the main characteristics of IBL is learning that focuses on problem-solving. This difference in characteristics leads to critical thinking indicators such as focus, inference, situation, and overview developing more in PBL learning than in IBL. Therefore, PBL is considered more effective than IBL in improving students' critical thinking skills because PBL not only guides students to discover concepts but also emphasizes the direct application of these concepts in problem solving, so that all critical thinking indicators, starting from focus, reason, inference, situation, clarification, and overview, can develop more optimally.

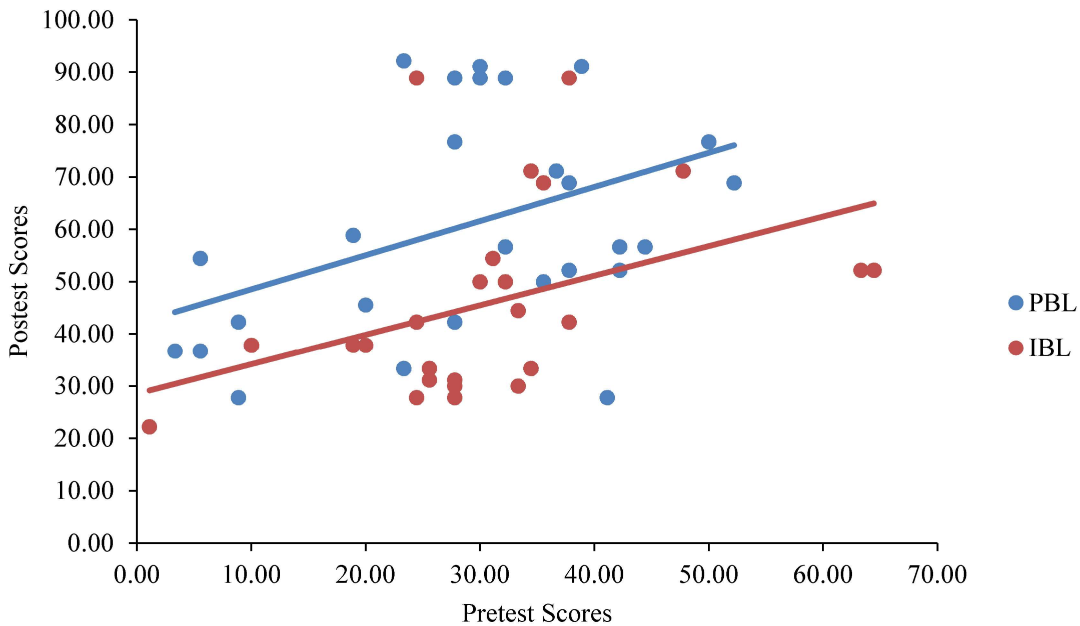

Figure 1. Pretest posttest scatter plot

Figure 1 presents a scatter plot of students' pretest and posttest scores, illustrating the overall improvement in critical thinking skills following the implementation of the learning models. The upward distribution of data points indicates that most students experienced gains from pretest to posttest, although the magnitude of improvement varied among individuals. This variation suggests that the learning models influenced students' cognitive development differently depending on the specific cognitive processes emphasized during instruction. The indicator-level analysis shows that the highest improvement in the PBL class occurred in the *focus* indicator. This finding can be explained from a cognitive learning perspective by examining the initial stages of PBL implementation. In PBL, students are directly confronted with contextual problems that must be understood and analyzed before a solution strategy is determined. Cognitively, this process requires students to identify relevant information, distinguish between known and unknown elements, and define the problem's core. Such activities engage selective attention and problem representation processes, which are central to the focus component of critical thinking. Therefore, although the scatter plot in Figure 1 reflects overall improvement, the indicator analysis clarifies that PBL particularly strengthens students' ability to focus on essential information during problem analysis (Hutsalo & Ordanovska, 2024).

In contrast, the reason indicator showed the greatest improvement in the IBL class. This result is consistent with the characteristics of Inquiry-Based Learning, where students are actively involved in scientific reasoning processes such as formulating hypotheses, testing assumptions, and providing logical explanations for their conclusions. From a cognitive perspective, these activities directly support the development of reasoning skills, as students are required to justify relationships between evidence and conclusions (Pratama et al., 2020). The PBL activities primarily emphasized finding and applying solutions to given problems, while explicit requirements for students to articulate, justify, or reflect on their solutions were limited. As a result, students may have engaged in internal reasoning processes without being encouraged to express their arguments explicitly. This suggests that the lower improvement in clarification is attributable to task design that did not sufficiently prompt students to verbalize or write their reasoning, rather than a weakness of the PBL model itself.

Similarly, the lowest improvement in the IBL class was found in the inference indicator. Although IBL effectively engages students in data collection and analysis, students were not consistently guided to integrate their analytical results into comprehensive conclusions. This indicates that drawing well-structured inferences requires explicit instructional support, which may not have been optimally emphasized during the inquiry process in this study. Overall, the scatter plot in Figure 1 confirms the general effectiveness of PBL and IBL in improving students' critical thinking skills. At the same time, the indicator-level analysis provides deeper insight into the specific cognitive processes supported by each model. PBL is more effective in strengthening focus through intensive problem analysis, whereas IBL is more effective in developing reasoning skills through structured inquiry activities. These findings demonstrate that improvements in critical thinking are indicator-specific and highly dependent on how learning tasks are designed to support particular cognitive processes.

RESEARCH LIMITATIONS

Although this research has been carried out with maximum effort, the author acknowledges that several shortcomings and errors were encountered due to limitations, as follows: (1) Limited Sample. The research involved only three classes from one high school, so the results cannot be generalized to other school contexts with different characteristics. Future research is recommended to involve a larger sample size and schools with diverse backgrounds. (2) Material Limitations: This research focused only on arithmetic sequences and series. Therefore, the effectiveness of the Problem-Based Learning (PBL) and Inquiry-Based Learning (IBL) models on other mathematics materials cannot be concluded. Further research can examine the application of these two models to different topics and educational levels.

CONCLUSION

Based on the findings of this study, two main conclusions can be drawn. First, the PBL and IBL methods effectively improve students' critical thinking skills when learning arithmetic sequences and series in senior high school grade X. This finding indicates that problem-based and inquiry-based learning can help students build conceptual understanding through a systematic process of exploration, analysis, and teacher guidance. Second, the PBL method is more effective than the IBL method on students' critical thinking skills in learning arithmetic sequences and series for senior high school grade X. This difference in effectiveness indicates that the characteristics of PBL, which emphasize collaborative contextual problem-solving, provide a wider space for students to develop analytical, reasoning, and evaluation skills in the mathematics learning process. Nevertheless, both learning models still have practical significance in supporting the development of students' critical thinking skills. The results of this study have implications for classroom practice: teachers are encouraged to apply PBL and IBL learning models as a basis for problem-based learning and, where possible, use the PBL learning model. Future research should extend the duration of implementation, involve diverse school contexts, and explore other problem-based learning models to better understand the synergy between cognitive and social aspects of learning.

DECLARATION OF GENERATIVE AI USAGE IN THE WRITING PROCESS

During the writing of this manuscript, the author(s) employed ChatGPT (OpenAI) to assist with language refinement and academic writing support. The author(s) have reviewed, revised, and edited all content generated by this tool and assume full responsibility for the accuracy, originality, and integrity of the published article.

REFERENCES

Ali, S. S. (2019). Problem-based learning/ : a student-centered approach. *English Language Teaching*, *12*(5), 73–78. https://doi.org/10.5539/elt.v12n5p73

Almulla, M. A. (2020). The effectiveness of the project-based learning (PBL) approach as a way to engage students in learning. *SAGE Open*. https://doi.org/10.1177/2158244020938702

Alsaleh, N. J. (2020). Teaching critical thinking skills/ : Literature review. *Turkish Online Journal of Educational Technology*, *19*(1), 21–39. https://eric.ed.gov/?id=EJ1239945

Amri, A. A. U., & Mustika, J. (2022). *FRISCO criteria: Analysis of student's mathematic critical thinking ability on HOTS test*. https://s.id/3HKWg

Anwar, A. (2009). *Statistika untuk penelitian pendidikan dan aplikasinya dengan SPSS dan Excel*. IAIT Press.

Blown, & Bryce. (2024). Ausubel's meaningful learning re-visited. *Current Psychology*, *43*, 4579–4598. https://doi.org/10.1007/s12144-023-04440-4

Cahyono, B. (2017). Analisis ketrampilan berfikir kritis dalam memecahkan masalah ditinjau perbedaan gender. *Aksioma*, *8*(1), 50. https://doi.org/10.26877/aks.v8i1.1510

Cahyono, B., Kartono, K., Waluya, B., Mulyono, M., & Setyawati, R. D. (2021). Problem-based learning supported by arguments scaffolding that affect critical thinking teacher candidates. *Cypriot Journal of Educational Sciences*, *16*(6), 2956–2969. https://doi.org/10.18844/cjes.v16i6.6480

Cahyono, B., Kartono, Waluyo, B., & Mulyono. (2019). Analysis critical thinking skills in solving problems algebra in terms of cognitive style and gender. *Journal of Physics: Conference Series*, *1321*(2). https://doi.org/10.1088/1742-6596/1321/2/022115

Cahyono, B., Rohman, A. A., Setyawati, R. D., & Mustaghfiroh, U. (2022). Critical thinking of prospective teachers in solving math problems in terms of learning styles. *Jurnal Pendidikan Matematika*, *12*(2), 226–241.

Ceker, E., & Ozdamli, F. (2016). Features and characteristics of problem based learning. *Cypriot Journal of Educational Sciences*, *11*(4), 195–202. https://eric.ed.gov/?id=EJ1140792

Chen, C., & Kuo, C. (2019). An optimized group formation scheme to promote collaborative problem-based learning. *Computers & Education*, *133*(64), 94–115. https://doi.org/10.1016/j.compedu.2019.01.011

Chen, P., & Chang, Y. C. (2021). Enhancing creative problem solving in postgraduate Courses of education management using project-based learning. *International Journal of Higher Education*, *10*(6). https://doi.org/10.5430/ijhe.v10n6p11

Dad, H., & Akbar, R. A. (2023). Critical thinking as a twenty first century skill. *Journal of Educational Research & Social Sciences Review*, *3*(1), 8–15. https://s.id/QiCdF

Dakabesi, D., Supiah, I., & Luoise, Y. (2019). The effectiveness of problem-based learning model to increase the students' critical thinking skills. *Journal of Education and Learning*, *13*(4), 543–549. https://doi.org/10.11591/edulearn.v13i4.12940

Dobber, M., Zwart, R., Tanis, M., & Oers, B. Van. (2017). Literature review: The role of the teacher in inquiry-based education. *Educational Research Review*. https://doi.org/10.1016/j.edurev.2017.09.002

Duran, M., & Dökme, Ý. (2016). *The effect of the inquiry-based learning approach on student's critical-thinking*. *12*(12), 2887–2908. https://doi.org/10.12973/eurasia.2016.02311a

Ennis, R. H. (2016). Critical thinking across the curriculum/ : A vision. *Topoi*, *2011*. https://doi.org/10.1007/s11245-016-9401-4

Gholam, A. P. (2019). Inquiry-based learning/ : student teachers' challenges and perceptions. *Journal of Inquiry and Action in Education*, *10*(2), 112–133. https://digitalcommons.buffalostate.edu/jiae/vol10/iss2/6/

Gunawardena, M., & Wilson, K. (2021). Scaffolding students' critical thinking/ : A process not an end game. *Thinking Skills and Creativity*, *41*, 100848. https://doi.org/10.1016/j.tsc.2021.100848

Hitchcock, D. (2017). Critical thinking as an educational ideal. In *On reasoning and argument: Essays in informal logic and on critical thinking* (pp. 477–497). Cham: Springer International Publishing.

Hung, W. (2016). *All PBL starts here/ : The problem*. *10*(2). https://doi.org/10.7771/1541-5015.1604

Hutsalo, L., & Ordanovska, O. (2024). *Strategies for developing critical thinking and problem-based learning in the modern educational environment*. https://doi.org/10.31893/multiscience.2024ss0209

Indah, P., & Nuraeni, R. (2021). *Perbandingan kemampuan penalaran deduktif matematis melalui model PBL dan IBL berdasarkan KAM* [Comparison of mathematical deductive reasoning abilities through PBL and IBL models based on KAM]. *Mosharafa: Jurnal Pendidikan Matematika*, *10*(1), 165–176. https://doi.org/10.31980/mosharafa.v10i1.931

Istni, T., Utomo, D. H., & Utaya, S. (2022). *Pengaruh model problem based learning (PBL) berbantuan LKPD terhadap kemampuan berpikir kritis mata pelajaran geografi siswa kelas XI IPS MA bilingual Batu* [The influence of the problem based learning (PBL) model assisted by LKPD on the critical thinking skills of geography students of class XI IPS MA bilingual Batu]. *Jurnal Integrasi Dan Harmoni Inovatif Ilmu-Ilmu Sosial (JIHI3S)*, *2*(2), 194–203. https://doi.org/10.17977/um063v2i2p194-203

Jamil, M., Bokhari, T. B., & Zia, Q. (2024). *Qualitative content analysis for critical thinking and skill development/ : A case of chemistry curriculum*. *13*(1), 147–155. https://doi.org/10.62345/jads.2024.13.1.12

Jasper Abowei, & Ebikiemo, F. (2023). *Contextual learning approach/ : A tool for enhancing critical thinking skills amongst learners*. *4*(5). https://doi.org/10.17605/OSF.IO/GB2SR

Kalyani, L. K. (2024). *The role of technology in education/ : Enhancing learning outcomes and 21 st century skills*. *3*(4), 5–10. https://ijsrmst.com/index.php/ijsrmst/article/view/199

Kartika, Y. K., & Rakhmawati, F. (2022). *Peningkatan kemampuan berpikir kritis matematis siswa menggunakan model inquiry learning* [Improving students' critical mathematical thinking skills using the inquiry learning model]. *Jurnal Cendekia/ : Jurnal Pendidikan Matematika*, *6*(3), 2515–2525. https://doi.org/10.31004/cendekia.v6i3.1627

Khudriyah. (2021). *Metodologi penelitian dan statistik pendidikan*. https://eprints.walisongo.ac.id/id/eprint/9459/1/Nur_Khoiri_Metodoogi_Penelitian_Pendidikan.pdf

Lazonder, A. W., & Harmsen, R. (2016). *Meta-analysis of inquiry-based learning/ : Effects of guidance*. *20*(10), 1–38. https://doi.org/10.3102/0034654315627366

Liestari, S. P., Arsiah, Z., & Patria, R. R. (2024). *How Indonesia students perform in mathematics: Learn from PISA 2022* (Issue October). https://doi.org/10.37517/978-1-74286-792-2_32

Luong, P. A. (2022). Applying the concepts of "community" and "social interaction" from Vygotsky's sociocultural theory of cognitive development in math teaching to develop learner's math communication competencies. *Journal of Contemporary Educational Policies and Practices*, 209–215.

Mellita, S. A., & Rosita, L. (2019). *Pengaruh model pembelajaran inquiry based learning terhadap kemampuan berpikir kritis siswa pada mata pelajaran matematika* [The influence of the inquiry-based learning model on students' critical thinking skills in mathematics subjects]. *Primary/ : Jurnal Keilmuan dan Kependidikan Dasar*, *11*(2), 133. https://doi.org/10.32678/primary.v11i02.2323

Morgan, D., & Skaggs, P. (2016). *Collaboration in the zone of proximal development*. *September*. https://shorturl.at/CGiQW

Nadeak, B., & Naibaho, L. (2020). *The effectiveness of problem-based learning on students' critical thinking*. *13*(1), 1–7. https://doi.org/10.33541/jdp.v13i1

Nufus, H., Herizal, H., & Sahputri, L. D. (2021). *Pengaruh model pembelajaran problem based learning (PBL) terhadap kemampuan berpikir kritis matematis siswa pada materi sistem persamaan linear dua variabel* [The influence of the problem based learning (PBL) learning model on students' mathematical critical thinking skills on the material of two-variable linear equation systems]. *Jurnal Pembelajaran Dan Matematika Sigma (Jpms)*, *7*(1), 12–19. https://doi.org/10.36987/jpms.v7i1.1943

OECD. (2023). *PISA 2022 Results (Vol. I): The state of learning and equity in education. I*. OECD Publishing. https://doi.org/10.1787/53f23881-en

Prasekti, E. D., & Marsigit, M. (2017). *Perbandingan keefektifan metode problem-based learning dan project-based learning pada pembelajaran statistika SMA* [Comparison of the effectiveness of problem-based learning and project-based learning methods in high school statistics learning]. *PYTHAGORAS Jurnal Pendidikan Matematika*, *12*(2), 161–172. https://doi.org/10.21831/pg.v12i2.17714

Pratama, Y., Dwirahayu, G., & Satriawati, G. (2020). *Analisis penerapan model inquiry dalam pembelajaran matematika di SLB 4 Jakarta*. *2*(1), 15–28.

Prayogi, Yuanita, & Wasis. (2018). *Critical inquiry based learning/ : Model of learning to promote critical thinking ability of pre-service teachers*. https://

doi.org/10.1088/1742-6596/947/1/012013

Putri, N. I., Fadillah, M. R., Putri, A. L., Nurhasanah, A., & Hidayat, A. R. (2024). *Analisis kemampuan berpikir kritis siswa kelas XII IPA 3 di SMAN 7 Kota Serang pada mata pelajaran sejarah demokrasi liberal* [Analysis of critical thinking skills of class XII IPA 3 students at SMAN 7 Kota Serang in the subject of liberal democratic history]. *JEJAK: Jurnal Pendidikan Sejarah & Sejarah*, *4*(1), 60-73.

Qablan, A., Alkaabi, A., Aljanahi, M. H., & Almaamari, S. A. (2024). *Inquiry-based learning/ : encouraging exploration and curiosity in the classroom* (pp. 1–12). https://doi.org/10.4018/979-8-3693-0880-6.ch001

Rahmadani, A., Khoiroh, F., Harahap, S., Ulkaira, N., Azhari, Y., Hasibuan, S., Wiliam Iskandar, J., Percut, K., Tuan, S., & Serdang, K. D. (2024). *Efektivitas penggunaan strategi pembelajaran dalam meningkatkan hasil belajar siswa di SD Negeri 060822 Medan* [The effectiveness of using learning strategies in improving student learning outcomes at SD Negeri 060822 Medan]. *Jurnal Pendidikan Berkarakter*, *2*(1), 54–71. https://doi.org/10.51903/pendekar.v2i1.566

Saleem, A., & Deeba, F. (2021). *Social constructivism/ : a new paradigm in teaching and learning environmen*. *2*(2), 403–421. https://doi.org/10.52700/pjh.v2i2.86 Social

Sari, Y. I., Sumarmi, Utomo, D. H., & Astina, I. K. (2021). The effect of problem based learning on problem solving and scientific writing skills. *International Journal of Instruction*, *14*(2), 11–26. https://doi.org/10.29333/iji.2021.1422a

Sarwanto, Fajari, L. E. W., & Chumdari. (2021). *Critical thinking skills and their impacts on elementary school students*. *2*(2), 161–187. https://doi.org/10.32890/mjli2021.18.2.6

Shah, R. K. (2019). Effective constructivist teaching learning in the classroom. *International Journal of Education*. *7*(4), 1-13https://doi.org/10.34293/education.v7i4.600

Sholihah, T. M., & Lastariwati, B. (2020). Problem based learning to increase competence of critical thinking and problem solving. *Journal of Education and Learning (EduLearn)*, *14*(1), 148–154.

Siregar, B. H., Dewi, I., & Andriani, A. (2018, March). Error analysis of mathematics students who are taught by using the book of mathematics learning strategy in solving pedagogical problems based on Polya's four-step approach. In *Journal of Physics: Conference Series* (Vol. 970, No. 1, p. 012004). IOP Publishing.

Sugiyono. (2019). *Metode penelitian kualitatif, kuantitatif dan RnD*. Alfabeta. https://shorturl.at/xisYz

Sulistyani, K., Indana, S., & Sudibyo, E. (2022). Analysis effectiveness of guided inquiry implementation to improve students' science process skills. *Ijorer International Journal of Recent Educational Research*, *3*(6), 672–687. https://doi.org/10.46245/ijorer.v3i6.258 ABSTRACT

Susetyarini, E., & Fauzi, A. (2020). Trend of critical thinking skill researches in biology education journals across indonesia: from research design to data analysis. *International Journal of Instruction*, *13*(1), 535–550.

Sutarsa, D. A., & Puspitasari, N. (2021). *Perbandingan kemampuan berpikir kritis matematis siswa antara model* *pembelajaran GI dan PBL* [Comparison of students' mathematical critical thinking abilities between the GI and PBL learning models]. *Plusminus: Jurnal Pendidikan Matematika*, *1*(1), 169–182. https://doi.org/10.31980/plusminus.v1i1.1035

Tachie, S. A. (2019). Meta-cognitive skills and strategies application/ : How this helps learners in mathematics problem-solving. *EURASIA Journal of Mathematics, Science and Technology Education*, *15*(5). https://doi.org/10.29333/ejmste/105364

Tjahjadi, E. H., & Seleky, J. S. (2022). *Peran guru dalam membangun lingkungan belajar efektif pada pembelajaran matematika* [The role of teachers in building an effective learning environment in mathematics learning]. *Seminar Nasional Matematika Dan Pendidikan Matematika (7th Senatik) Program Studi Pendidikan Matematika FPMIPATI-Universitas PGRI Sema rang*, 350–357. https://shorturl.at/B119A

Vidad, D. C., & Quimbo, M. A. T. (2021). *Students' problem-solving difficulties and coping strategies in mathematics:a model-building study* (Vol. 20, Issue 9). https://doi.org/10.26803/ijlter.20.9.9

Wahab, A., Junaedi, & Muh. Azhar. (2021). *Efektivitas pembelajaran statistika pendidikan menggunakan uji peningkatan n-gain di PGMI* [The effectiveness of educational statistics learning using the n-gain improvement test in PGMI]. *Jurnal Basicedu*, *5*(5), 524–532. https://journal.uii.ac.id/ajie/article/view/971

Wilde-Larsson, B., Aiyub, I., Hermansyah, H., Hov, R., Høye, S., Valen Gillund, M., ... & Nordström, G. (2018). Critical thinking, research utilization and barriers to this among nursing students in Scandinavia and Indonesia. *Nordic Journal of Nursing Research*, *38*(1), 28–37.

Yew, E. H. J., & Goh, K. (2016). Problem-based learning/ : an overview of its process and impact on learning. *Health Professions Education*, *2*(2), 75–79. https://doi.org/10.1016/j.hpe.2016.01.004

Yih, M., Kek, C. A., & Huijser, H. (2011). The power of problem based learning in developing critical thinking skills: preparing students for tomorrow's digital futures in today's classrooms. *Higher Education Research & Development*, *30*(3), 37–41. https://doi.org/10.1080/07294360.2010.501074