Jurnal Edukasi Biologi
Volume 12 No 2, September 2026, 213-223
ISSN: 2986-5484 E-ISSN: 2986-4828
DOI: 10.21831/edubio.v12i2.30113

The effect of project-based learning (PjBL) assisted by ChatGPT on critical thinking skills in climate change material

Ghayatuna Raudhatul Jannah[1], Ahmad Kamal Sudrajat[1*]
[1]Biology Education Study Program, Universitas Negeri Yogyakarta, Indonesia
E-mail: kamalsudrajat@uny.ac.id

Abstract. This study aims to: (1) describe students' critical thinking skills on climate change material after participating in learning using Project-Based Learning (PjBL) assisted by ChatGPT; and (2) determine the effect of implementing Project-Based Learning (PjBL) assisted by ChatGPT on students' critical thinking skills on climate change material at SMAN 1 Pleret. This study uses a quantitative approach with a quasi-experimental method using a Nonequivalent Control Group Design. The study was conducted at SMAN 1 Pleret with a sample of two classes, namely the experimental class and the control class, selected using a purposive sampling technique. The experimental class received ChatGPT-assisted Project-Based Learning (PjBL), while the control class used Project-Based Learning (PjBL) without ChatGPT assistance. The research instrument consisted of an essay test of critical thinking skills based on FRISCO indicators (Focus, Reason, Inference, Situation, Clarity, and Overview) and an observation sheet for learning implementation. Data analysis used descriptive and inferential statistics, including normality tests, homogeneity tests, and Mann–Whitney tests. The results of the study showed that: (1) the critical thinking abilities of students in the experimental class showed varying achievements in each FRISCO indicator, with the Inference indicator obtaining the highest percentage of 68.89% (critical category), followed by Clarity at 62.78% and Focus at 61.67% (critical category), while Reason at 58.89%, Overview at 58.33%, and Situation at 49.44% were included in the fairly critical category. Furthermore, (2) the implementation of Project-Based Learning (PjBL) assisted by ChatGPT did not have a significant effect on students' critical thinking abilities on climate change material, as indicated by the results of the Mann–Whitney posttest value with Asymp. Sig. (2-tailed) of 0.416 ($p > 0.05$). However, descriptively, the experimental class's average posttest score (60.00) was higher than the control class's (56.67). Overall, students' critical thinking skills after participating in learning using Project-Based Learning (PjBL) assisted by ChatGPT were in the fairly critical to critical category. Teachers can use this research as a consideration when using Chatbots in the classroom.
Keywords: ChatGPT, Climate change, Critical thinking skills, Project-Based Learning (PjBL)

Received: 24 August 2026 Revised: 07 September 2026 Accepted: 08 September 2026 Published: 19 September 2026

INTRODUCTION

Critical thinking skills are an essential 21st-century competency that must be developed through the learning process (Diniyyah et al., 2022; Sudrajat et al., 2020). The rapid development of science, technology, and information requires students to analyze, evaluate, and use this information appropriately to support decision-making (Saefi et al., 2025). Critical thinking skills are the ability to systematically analyze and evaluate information based on evidence and reasoning, enabling individuals to make decisions and solve problems appropriately (Redhana, 2024).

Despite this, students in Indonesia still have not developed critical thinking skills optimally. Observations and interviews with biology teachers at SMAN 1 Pleret indicate that students can express opinions and draw simple conclusions but still struggle to provide reasons to support arguments, evaluate information based on evidence, and defend opinions during discussions. These findings align with research by Jabar et al. (2025), which reported that high school students' critical thinking skills were still in the low-to-moderate category, particularly in the evaluation and inference indicators. This suggests that the learning process still needs

strategies that provide meaningful learning experiences so students can develop higher-order thinking skills.

One biology topic with strong potential for developing critical thinking skills is climate change, as it is directly related to real-world environmental phenomena relevant to everyday life, such as weather anomalies and extreme temperatures (Schaeffer et al., 2025). Through observations of ecosystem dynamics, students are not only required to understand the material theoretically. However, they are also encouraged to analyze causal relationships between human activities and environmental damage and to evaluate scientific data objectively. This analytical process enables them to think at the synthesis and evaluation levels when formulating innovative solutions and designing applicable mitigation and adaptation measures, from the school level to the broader community (Hügel & Davies, 2024).

Project-Based Learning (PjBL) is a learning model considered effective in developing critical thinking skills because it places students at the center of learning through investigation, problem-solving, collaboration, and project completion (Dobber et al., 2017). During the learning process, students identify problems, collect and analyze information, develop solutions, and produce products relevant to the issues being studied. Research by Dywan & Airlanda (2020) and Wandari et al. (2024) shows that implementing Project-Based Learning (PjBL) positively impacts students' critical thinking skills because the learning process is active, contextual, and problem-solving-based.

Furthermore, developments in artificial intelligence (AI) technology are opening up new opportunities to support the learning process. One widely used AI technology is ChatGPT, a Generative Pre-trained Transformer-based chatbot that can generate natural language responses and help students find information, develop ideas, and receive feedback during the learning process (Kasneci et al., 2023). ChatGPT can support critical thinking because students can compare information, explore alternative solutions, and verify the information they find (Costa et al., 2024; Nasr et al., 2025). However, ChatGPT-generated information is not always completely accurate, so evaluating the sources used is still necessary.

Integrating ChatGPT into project-based learning is expected to strengthen the learning process because students receive support in seeking information, developing ideas, and evaluating alternative project solutions, while still analyzing and verifying the information they obtain. Amaliah & Putri (2026) stated that using AI in project-based learning can help students obtain initial information and feedback during project completion without eliminating the need for higher-order thinking. Therefore, combining Project-Based Learning (PjBL) and ChatGPT has the potential to create a more effective learning experience for developing critical thinking skills.

Several previous studies have examined the effectiveness of Project-Based Learning (PjBL) and ChatGPT on critical thinking skills. Research by Dywan & Airlanda (2020) and Wandari et al. (2024) showed that Project-Based Learning (PjBL) can improve students' critical thinking skills. Meanwhile, Hadarmawandi et al. (2025) reported that using ChatGPT in Biology learning yielded better results than conventional learning in improving critical thinking skills. However, most studies examined these approaches separately. Research integrating Project-Based Learning (PjBL) with ChatGPT, particularly on climate change at the high school level, remains relatively limited, so the effectiveness of the combination is largely unknown.

Based on this gap, this study offers a novel approach by implementing Project-Based Learning (PjBL) with ChatGPT on climate change and measuring critical thinking skills using the FRISCO indicators (Focus, Reason, Inference, Situation, Clarity, and Overview). This study is expected to provide an overview of students' critical thinking skills after participating in Project-Based Learning (PjBL) with ChatGPT and provide evidence of this model's impact on those skills. Therefore, this study aims to (1) describe students' critical thinking skills on

climate change after participating in learning using Project-Based Learning (PjBL) with ChatGPT and (2) determine the effect of implementing Project-Based Learning (PjBL) with ChatGPT on students' critical thinking skills at SMAN 1 Pleret.

METHOD

This study employed a quantitative approach with a quasi-experimental method and a Nonequivalent Control Group Design (Cohen et al., 2018). The researchers chose this design because the study was conducted in established classes, so they did not randomize subjects into experimental and control groups. The experimental class received instruction using Project-Based Learning (PjBL) with ChatGPT assistance, while the control class received instruction using PjBL without ChatGPT assistance. Before the treatment, both classes took a pretest to determine their initial critical thinking skills. After completing the learning series, the researchers administered a posttest to measure critical thinking skills after the treatment.

The study was conducted in the even semester of the 2025/2026 academic year at SMAN 1 Pleret, Bantul Regency, Yogyakarta Special Region. The study population was all 178 students in Grade X Phase E. The sample was determined using purposive sampling based on equivalence in academic ability, number of students, teachers, and learning schedule. Based on these criteria, class X E1 (36 students) was designated as the experimental class and class X E2 (36 students) as the control class.

The research procedure began with developing learning materials and having an expert lecturer validate the instruments. Next, both classes were given a pretest. Then they received three sessions of learning using Project-Based Learning (PjBL) syntax, which included: (1) defining fundamental questions, (2) developing a project plan, (3) developing a project implementation schedule, (4) monitoring project progress, (5) testing project results, and (6) evaluating the learning experience (Dobber et al., 2017). The experimental class used ChatGPT to support information retrieval, idea development, alternative solution development, and project completion. In contrast, the control class completed all PjBL stages without using ChatGPT. After the learning process, both classes took a posttest, and the researchers observed the process throughout.

The researchers collected data through testing and observation. The test instrument consisted of six essay questions structured based on the FRISCO critical thinking skill indicators (Focus, Reason, Inference, Situation, Clarity, and Overview) developed by Ennis (1996). Each indicator was represented by one question so the instrument could measure all aspects of critical thinking skills. Students' answers were assessed using a scoring rubric according to the FRISCO indicators. The observation instrument consisted of a learning implementation sheet structured around the PjBL syntax, with a Guttman scale (score 1 = implemented; score 0 = not implemented) to ensure the learning implementation aligned with the research design. A summary of the test instrument grid is presented in Table 1.

Table 1. Critical thinking ability test instrument grid

FRISCO Indicator	Measured indicators:	Essay Question Format
Focus	Analyze climate change issues	Essay
Reason	Provide logical reasons based on evidence	Essay
Inference	Draw informed conclusions	Essay
Situation	Analyze climate change situations and impacts	Essay
Clarity	Explain solutions clearly and systematically	Essay
Overview	Evaluate and reflect on decisions	Essay Question Format

Before use, two expert lecturers validated all instruments. The validation results indicated that the research instruments were valid to highly valid, making them suitable for use after revisions based on validator input.

Data analysis was conducted descriptively and inferentially using IBM SPSS Statistics 25. Descriptive analysis was used to describe critical thinking skills based on the percentage achievement of each FRISCO indicator, as well as the mean, minimum, maximum, and standard deviation values of the pretest and posttest results. Furthermore, prerequisite tests were conducted, including a normality test using the Shapiro–Wilk test and a homogeneity test using the Levene Test with a significance level of 0.05. Because the posttest data did not meet the assumption of normality, hypothesis testing used the Mann–Whitney U test to determine the effect of the ChatGPT-assisted Project-Based Learning (PjBL) implementation on students' critical thinking skills on climate change.

RESULTS AND DISCUSSION

Results

Implementation of learning

The learning implementation was observed to ensure that the Project-Based Learning (PjBL) model in both the experimental and control classes was implemented according to the teaching module. Table 2 presents the results of the learning implementation observations.

Table 2. Learning Implementation

Meeting	Group		Category
	Experiment	Control	
1	92.31%	92.31%	Very Good
2	90.91%	90.91%	Very Good
3	100%	91.67%	Very Good
Average (%)	94.43%	91.63%	

Based on Table 2, learning implementation in both classes fell within the very good category. The average implementation in the experimental class reached 94.43%, while the control class was 91.63%. These percentages indicate that the PjBL syntax can be applied consistently in both classes, so the treatment provided aligns with the research design. The difference in implementation percentages is relatively small and mainly due to several closing activities that were not carried out directly because of time constraints but were still facilitated through reflection, follow-up discussions, and communication through class groups.

Critical thinking skills

Students' critical thinking skills were analyzed using the FRISCO indicators (Focus, Reason, Inference, Situation, Clarity, and Overview) to describe their achievements in each aspect of critical thinking after participating in PjBL-assisted learning with ChatGPT. Table 3 presents the analysis results.

Table 3. Percentage of Achievement of Each Critical Thinking Ability Indicator in the Experimental Class

Indicator	Maximum Score	Score Obtained	Percentage	Category
Focus	180	111	61.67%	Critical
Reason	180	106	58.89%	Moderately Critical
Inference	180	124	68.89%	Critical
Situation	180	89	49.44%	Moderately Critical
Clarity	180	113	62.78%	Critical
Overview	180	105	58.33%	Moderately Critical

Based on Table 3, the Inference indicator achieved the highest score (68.89%) in the critical category, followed by the Clarity indicator (62.78%) and Focus indicator (61.67%). Conversely, the Situation indicator achieved the lowest score (49.44%) and remained in the fairly critical category. These findings indicate that students are better able to draw conclusions and communicate their thinking than to analyze the situation or the problem's context comprehensively. Table 4 presents a descriptive analysis of critical thinking skills based on the pretest and posttest results.

Table 4. Results of the Critical Thinking Ability Essay Test of Students

Statistical Values	Critical Thinking Skills Pretest		Critical Thinking Skills Posttest	
	Experiment	Control	Experiment	Control
Number of Students	36	36	36	36
Average	40,65	40,83	60	56,67
Highest Score	50	50	80	80
Lowest Score	30	10	50	3,33
Median	40	43,33	60	56,67
Mode	40	43,33	60	53,33
Standard Deviation	4,49	8,99	8,54	13,80

Table 4 shows that the two classes had relatively similar initial abilities, as indicated by pretest averages of 40.65 in the experimental class and 40.83 in the control class. After the learning process, average scores increased to 60.00 in the experimental class and 56.67 in the control class. Furthermore, the median and mode also increased, indicating a shift toward improved critical thinking skills. The standard deviation in the experimental class was lower than in the control class, indicating that student learning outcomes in the experimental class were more homogeneous.

According to Table 5, before the learning process, most students in both classes were in the very poor category. After the learning process, the distribution of critical thinking skills shifted toward the higher category. In the experimental class, no students remained in the very poor category, while in the control class, three students remained in that category. Furthermore, students in the good category began to emerge in both classes, indicating an increase in critical thinking skills after the learning process.

Table 5. Frequency Distribution of Critical Thinking Ability Scores

Category	Value Range	*Pretest*				*Posttest*			
		Experiment		Control		Experiment		Control	
		f	%	f	%	f	%	f	%
Excellent	$81.25 < x \leq 100$	0	0.00	0	0.00	0	0.00	0	0.00
Good	$71.50 < x \leq 81.25$	0	0.00	0	0.00	4	11.11	4	11.11
Fair	$62.50 < x \leq 71.50$	0	0.00	0	0.00	6	16.67	9	25
Poor	$43.75 < x \leq 62.50$	7	19.44	13	36.11	26	72.22	20	55.56
Very Poor	$0 < x \leq 43.75$	29	80.56	23	63.89	0	0.00	3	8.33

Based on Table 5, before the treatment, most students in both classes were in the very poor category. After the treatment, the distribution of critical thinking skills shifted toward higher categories. In the experimental class, no students remained in the very poor category, while in the control class, three students remained in that category. Furthermore, students in the good

category began to emerge in both classes, indicating increased critical thinking skills after the treatment.

Prerequisite test

Prerequisite tests include normality and homogeneity tests as the basis for determining inferential analysis techniques. Table 6 shows the normality test results.

Table 6. Results of the Normality Test of Critical Thinking Ability Data

Class	Data	Sig	Category
Experiment	*Pretest*	0.098	Normal
	Posttest	0.001	Abnormal
Control	*Pretest*	0.000	Abnormal
	Posttest	0.001	Abnormal

The normality test results in Table 6 indicate that not all data are normally distributed because the posttest significance value for both classes is less than 0.05. Therefore, the hypothesis analysis used a nonparametric test. Table 7 shows the results of the homogeneity test for the critical thinking skills test.

Table 7. Results of the Homogeneity Test of the Critical Thinking Ability Test

Data	Class	Sig.	Description
Pretest	Experiment Control	0.013	Not Homogeneous
Posttest	Experiment Control	0.064	Homogeneous

Based on Table 7, the posttest data have homogeneous variance (Sig. = 0.064 > 0.05), while the pretest data do not. We used the Mann–Whitney test because the data did not meet the normality assumption. Table 8 shows the test results.

Table 8. Mann-Whitney Posttest Results

Test Statistic		Description
	Critical Thinking Test	
Mann-Whitney U	576.500	There is no significant difference
Wilcoxon W	1242.500	
Z	-0.813	
Asymp. Sig. (2-tailed)	0.416	

Based on Table 8, the pretest significance value of 0.229 (>0.05) indicates that students in both classes did not differ significantly in initial critical thinking skills. After treatment, the posttest significance value was 0.416 (>0.05), indicating no significant difference in critical thinking skills between the experimental and control classes. However, descriptively, the experimental class's average posttest score (60.00) was higher than the control class's (56.67), indicating a tendency toward increased critical thinking skills in the class that received PjBL learning assisted by ChatGPT, although this increase was not statistically significant.

Discussion

Students' Critical Thinking Skills After Participating in Project-Based Learning (PjBL)

The results show that students' critical thinking skills after participating in Project-Based Learning (PjBL) with ChatGPT assistance ranged from moderately critical to critical. Critical thinking achievement varied across each FRISCO indicator. The Inference indicator had the highest percentage, followed by Clarity and Focus, while Situation had the lowest achievement. This variation indicates that critical thinking skills are not developing evenly across all aspects

of thinking.

The high achievement in the Inference indicator indicates that students can draw conclusions and determine solutions based on the information they obtain during the learning process. This finding can be explained by PjBL's characteristics, which position students as problem solvers. During the project, students identify the causes of climate change, analyze their impacts, compare alternative solutions, and select the most appropriate one (Feigin et al., 2023). This process aligns with constructivist theory, which states that knowledge is built through active learning experiences and problem-solving, enabling students to gradually develop reasoning skills (Muhali & Asy'ari, 2026).

ChatGPT supports this process by quickly providing alternative information and solutions. However, students do not use the generated information as a direct basis for decision-making. Students are still directed to verify information through textbooks, group discussions, and other scientific sources before concluding. Thus, ChatGPT functions as cognitive support that expands access to information without replacing students' thinking processes (Bai et al., 2023). This finding aligns with Pelealu et al. (2026), who stated that ChatGPT can support reasoning skills when used critically and accompanied by an information verification process. This study also supports Sholeh et al. (2024), who found that PjBL can improve students' ability to analyze problems and develop evidence-based solutions.

The Clarity and Focus indicators also fall into the critical category. These achievements indicate that students can identify key issues and communicate ideas systematically. These results relate to group discussions, project presentations, and feedback, which are part of the PjBL syntax. Through these activities, students not only develop an understanding of climate change but also learn to present arguments coherently. This finding supports Rahayu et al. (2025), which showed that PjBL can develop scientific communication skills, collaboration, and effective idea delivery.

Conversely, the Reason, Overview, and Situation indicators remain in the moderately critical category. Low achievement in the Reason indicator indicates that some students cannot adequately develop arguments supported by scientific evidence. In the Overview indicator, students are also not yet accustomed to evaluating their decisions. Meanwhile, low achievement in the Situation indicator indicates that students still struggle to connect climate change to the real-world context of their surroundings (Aprilianti & Suratsih, 2023). These results suggest that argumentation, reflection, and contextual analysis skills develop more slowly than the ability to conclude. This finding aligns with research by Anisa et al. (2025) and Nuraeni et al. (2025), which state that providing evidence-based reasoning and understanding authentic contexts requires continuous practice through case analysis, reflection, and problem-solving activities relevant to students' lives.

The Effect of Project-Based Learning (PjBL) Assisted by ChatGPT on Critical Thinking Skills

The inferential analysis results indicate that implementing ChatGPT-assisted PjBL did not significantly affect students' critical thinking skills on climate change. Although the experimental class had a higher average posttest score than the control class, the Mann–Whitney test showed a significance value of 0.416 ($p > 0.05$). Therefore, the hypothesis that using ChatGPT significantly impacts critical thinking skills cannot be accepted.

This insignificant difference is understandable because both groups received learning using the PjBL model. According to PjBL theory, identifying problems, designing solutions, working collaboratively, producing products, and reflecting are processes that intrinsically train critical thinking skills. Therefore, both the experimental and control classes received relatively similar learning experiences in developing higher-order thinking skills. The main difference was the use of ChatGPT as a supplementary learning resource, so this technology

did not contribute enough to produce a statistically significant difference (Baidoo-anu & Ansah, 2023). These results are consistent with research by Tassya et al. (2025), which showed that improvements in critical thinking skills were primarily influenced by the application of PjBL syntax, not solely by the media or technology used.

These findings also indicate that ChatGPT's effectiveness depends significantly on how it is used in the learning process. Throughout the study, students used ChatGPT to search for information, explore alternative solutions, and assist with project design. However, students still had to verify information from textbooks and other scientific sources. Thus, ChatGPT serves as a learning support tool, not a substitute for students' thinking processes. This finding aligns with the views of Amaliah & Putri (2026) and Naurah & Dewantara (2025), who stated that the benefits of generative artificial intelligence in education depend on the quality of the learning design, students' ability to evaluate information, the quality of prompts, and teacher guidance during the learning process.

Furthermore, the three-session treatment duration may have influenced the study results. Critical thinking is a higher-order thinking skill that develops through continuous practice (Sudrajat et al., 2023). Therefore, integrating ChatGPT into learning likely requires a longer implementation period for its impact on critical thinking skills to become more visible. In other words, the insignificant results of this study do not mean that ChatGPT is useless, but rather indicate that the use of technology alone is insufficient to improve critical thinking skills without the support of a learning design that provides opportunities for students to analyze, evaluate, and reflect on information in depth (Yu, 2023).

The findings suggest that ChatGPT is better positioned as a supporting tool in project-based learning than as the primary driver of improved critical thinking skills (Sudrajat et al., 2025). Integrating ChatGPT with PjBL still has the potential to enrich the learning experience by providing faster, more diverse access to information. However, its success depends on teachers' ability to design activities that require students to verify information, develop evidence-based arguments, and reflect on the decision-making process (Lo et al., 2026). Thus, developing critical thinking skills depends not only on the presence of technology but also on the quality of learning design that encourages higher-order thinking processes on an ongoing basis.

CONCLUSION

This study shows that implementing Project-Based Learning (PjBL) with ChatGPT did not significantly improve students' critical thinking skills on climate change compared with PjBL without ChatGPT. This finding indicates that the presence of ChatGPT as a supporting technology does not automatically improve critical thinking skills. The quality of the learning process better determines the development of these skills, as it encourages students to analyze, evaluate, verify information, and reflect on their thinking during project completion. Nevertheless, learning using PjBL with ChatGPT can facilitate the development of students' critical thinking skills, ranging from moderately critical to critical. The highest achievement was in the ability to draw conclusions (inference), while the ability to understand the problem context (situation) still requires strengthening.

The results imply that generative artificial intelligence in learning should be positioned as a supporting tool (learning support tool) integrated with active learning strategies, not as a substitute for students' thinking processes. Teachers play a crucial role in guiding students to verify information, construct scientific arguments, and evaluate decisions so that using ChatGPT truly supports the development of higher-order thinking skills. Further research is recommended to implement learning over a longer duration, involve a wider sample size, and develop more structured ChatGPT utilization strategies, such as prompt engineering training, information evaluation sheets, or integration with other learning models.

REFERENCES

Amaliah, A. R., & Putri, N. (2026). Pengaruh penggunaan ChatGPT dan kecerdasan buatan (AI) terhadap kemampuan berpikir kritis siswa dalam pembelajaran Bahasa Indonesia. *MUARA PENDIDIKAN: Jurnal Ilmiah Ilmu Pendidikan & Sosial Humaniora*, 2(2), 15-27. https://doi.org/10.64365/muradik.v2i2.304

Anisa, A., Fitriani, W. R., Mellinda, C., Noviani, D., Juniati, F., & Afgani, M. W. (2025). Peran Pembuktian Matematis terhadap Pengembangan Kemampuan Berpikir Kritis Siswa Sekolah Menengah Atas (SMA). *De Fermat: Jurnal Pendidikan Matematika*, 8(2), 801–809. https://doi.org/10.36277/defermat.v8i2.2360

Aprilianti, A. N. M., & Suratsih. (2023). Pengaruh Implementasi Program Adiwiyata Terhadap Literasi Lingkungan Peserta Didik SMA Negeri 10 Yogyakarta. *Jurnal Edukasi Biologi*, 9(1), 46–62. https://doi.org/10.21831/edubio.v9i1.18759

Bai, L., Liu, X., & Su, J. (2023). ChatGPT: The cognitive effects on learning and memory. *Brain-X*, 1(3), e30. https://doi.org/https://doi.org/10.1002/brx2.30

Baidoo-anu, D., & Owusu Ansah, L. (2023). Education in the Era of Generative Artificial Intelligence (AI): Understanding the Potential Benefits of ChatGPT in Promoting Teaching and Learning TT - Education in the Era of Generative Artificial Intelligence (AI): Understanding the Potential Benefits. *Journal of AI*, 7(1), 52–62. https://doi.org/10.61969/jai.1337500

Cohen, L., Manion, L., & Morrison, K. (2018). *Research Methods in Education* (8th ed.). Routledge. https://doi.org/10.4324/9781315456539

Costa, A. R., Lima, N., Viegas, C., & Caldeira, A. (2024). Critical minds: enhancing education with ChatGPT. *Cogent Education*, 11(1), 2415286. https://doi.org/10.1080/2331186X.2024.2415286

Diniyyah, M., Susilo, H., Balqis, B., & Sudrajat, A. K. (2022). Improving critical thinking and problem- solving skills through POGIL combined with digital mind map. *Jurnal Pendidikan Biologi Indonesia*, 8(3), 275–286. https://doi.org/10.22219/jpbi.v8i3.18992

Dobber, M., Zwart, R., Tanis, M., & van Oers, B. (2017). Literature review: The role of the teacher in inquiry-based education. *Educational Research Review*, 22, 194–214. https://doi.org/https://doi.org/10.1016/j.edurev.2017.09.002

Dywan, A. A., & Airlanda, G. S. (2020). Efektivitas model pembelajaran project based learning berbasis STEM dan tidak berbasis STEM terhadap kemampuan berpikir kritis siswa. *Jurnal Basicedu*, 4(2), 344–354. https://doi.org/10.31004/basicedu.v4i2.353

Ennis, R. H. (1996). *Critical Thinking*. The New York Times Company. https://philpapers.org/rec/ENNCT-4

Feigin, S. V, Wiebers, D. O., Lueddeke, G., Morand, S., Lee, K., Knight, A., Brainin, M., Feigin, V. L., Whitfort, A., Marcum, J., Shackelford, T. K., Skerratt, L. F., & Winkler, A. S. (2023). Proposed solutions to anthropogenic climate change: A systematic literature review and a new way forward. *Heliyon*, 9(10), e20544. https://doi.org/https://doi.org/10.1016/j.heliyon.2023.e20544

Hadarmawandi, H., Rompegading, A. B., Sir, P., Anita , Y., & Irfandi, R. (2025). Pengaruh Penerapan ChatGPT dalam Pembelajaran Biologi terhadap Kemampuan Berpikir Kritis Siswa. *Venn: Journal of Sustainable Innovation on Education, Mathematics and Natural Sciences*, 4(3), 131-138. https://doi.org/10.53696/venn.v4i3.279

Hügel, S., & Davies, A. R. (2024). Expanding adaptive capacity: Innovations in education for place-based climate change adaptation planning. *Geoforum*, 150, 103978. https://doi.org/https://doi.org/10.1016/j.geoforum.2024.103978

Jabar, M. B. A., Rasyid, A., & Suryaningsih, Y. (2025). Analisis Kemampuan Berpikir Kritis Sekolah Menengah Atas: Literatur Review. *Papanda Journal of Mathematics and*

Science Research, 4(1), 104–111. https://ejournal.papanda.org/index.php/pjmsr/article/view/2513

Kasneci Seßler, K., Küchemann, S., E., Bannert, M., Dementieva, D., Fischer ..., F., & Kasneci, G. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and Individual Differences*, 103, 102274. https://doi.org/10.1016/j.lindif.2023.102274

Lo, J., Wong, C., Ng, A., Wong, P., Cheung, D., & Lai, P. (2026). Stretching AI's reach: Assessing an AI-driven feedback system for extended academic writing. *Computers and Education: Artificial Intelligence*, 10, 100511. https://doi.org/https://doi.org/10.1016/j.caeai.2025.100511

Muhali, & Asy'ari, M. (2026). Conceptual problem-based learning model: Promising intervention to enhance prospective science teachers' critical thinking skills. *Social Sciences & Humanities Open*, 13, 102509. https://doi.org/https://doi.org/10.1016/j.ssaho.2026.102509

Nasr, N. R., Tu, C.-H., Werner, J., Bauer, T., Yen, C.-J., & Sujo-Montes, L. (2025). Exploring the Impact of Generative AI ChatGPT on Critical Thinking in Higher Education: Passive AI-Directed Use or Human–AI Supported Collaboration? *Education Sciences*, 15(9). https://doi.org/10.3390/educsci15091198

Naurah, E. S., & Dewantara, B. A. (2025). Efektivitas ChatGPT Sebagai Alat Bantu Dalam Menyelesaikan Tugas Akademik Mahasiswa Teknologi Pendidikan Universitas Lambung Mangkurat. *Journal of Instructional Technology*, 6(2), 127-134. https://doi.org/10.20527/j-instech.v6i2.15633

Nuraeni, Y., Tuzzami, U., Pratama, M. A., & Anggraeni, A. (2025). Strategi Pembelajaran Berbasis Masalah (Problem-Based Learning) dalam Meningkatkan Kemampuan Berpikir Kritis Peserta Didik. *Jurnal Bersama Ilmu Pendidikan (DIDIK)*, 1(3), 146–152. https://jurnal.literasisains.id/index.php/didik/article/view/292

Pelealu, F., Umboh, P., & Kainde, H. V. F. (2026). Peran ChatGPT sebagai Asisten Pembelajran dalam Meningkatkan Efektivitas Pembelajaran Daring Mahasiswa Teknik Informatika. *Jejak Digital: Jurnal Ilmiah Multidisiplin*, 2(4), 6728–6743. https://indojurnal.com/index.php/jejakdigital/article/view/3618

Rahayu, S., Markhamah, M., & Fathoni, A. (2025). Analisis keterampilan berpikir kritis siswa dalam pembelajaran berbasis proyek di sekolah dasar. *Metodik Didaktik*, 20(2), 122–135. https://ejournal.upi.edu/index.php/MetodikDidaktik/article/view/72360

Redhana, I. W. (2024). *Berpikir Kritis pada Era Digital: Pedoman untuk Pemikiran Modern*. Sumatera Barat: Mafy Media Literasi Indonesia.

Saefi, M., Suwono, H., Fachrunnisa, R., Adi, W. C., Susilo, H., & Sudrajat, A. K. (2025). Raising Information Literacy of Biology Pre-Service Teachers: Study on Three Problem Solving Methods. *Australian Journal of Teacher Education*, 50(2), 20–40. https://doi.org/10.14221/1835-517X.6442

Schaeffer, R., Schipper, E. L. F., Ospina, D., Mirazo, P., Alencar, A., Anvari, M., Artaxo, P., Biresselioglu, M. E., Blome, T., Boeckmann, M., Brink, E., Broadgate, W., Bustamante, M., Cai, W., Canadell, J. G., Cardinale, R., Chidichimo, M. P., Ditlevsen, P., Eicker, U., … Ziervogel, G. (2025). Ten new insights in climate science 2024. *One Earth*, 8(6), 101285. https://doi.org/https://doi.org/10.1016/j.oneear.2025.101285

Sholeh, M. I., 'Azah, N., Tasya, D. A., Sokip, Syafi'i, A., Sahri, Rosyidi, H., Arifin, Z., & Ab Rahman, S. F. binti. (2024). PENERAPAN PEMBELAJARAN BERBASIS PROYEK (PJBL) DALAM MENINGKATKAN KEMAMPUAN BERPIKIR KRITIS SISWA. Jurnal Tinta, 6(2 SE-Articles), 158–176. https://doi.org/10.35897/jurnaltinta.v6i2.1484

Sudrajat, A. K., Andriningrum, H., Supartinah, S., & Anggrella, D. P. (2023). Accelerating pre-service elementary school teacher students' problem-solving skills through online case study discussion. *International Journal of Innovation and Learning*, 34(4), 398–413. https://doi.org/10.1504/IJIL.2023.134749

Sudrajat, A. K., Subiantoro, A. W., & Ghazi, M. I. Al. (2025). Biology teachers' preferences and key factors in adopting learning technology. *Jurnal Pendidikan Biologi Indonesia*, 11(1), 37–48. https://doi.org/10.22219/jpbi.v11i1.39636

Sudrajat, A. K., Susilo, H., & Rohman, F. (2020). Student perspective on the importance of developing critical thinking and collaboration skills for prospective teacher students. *AIP Conference Proceedings*, 2215. https://doi.org/10.1063/5.0000558

Tassya, T. O., & Jufri & Mahrus, A. W. (2025). Efektivitas Model PjBL (Project-Based Learning) dalam Meningkatkan Kemampuan Berpikir Tingkat Tinggi Siswa. *Teaching: Jurnal Inovasi Keguruan dan Ilmu Pendidikan*, 5(3), 33-46. https://edubio.ftk.uinjambi.ac.id/index.php/edubio/article/view/174

Wandari, W., Nursamsu , N., & Wahyuni, A. (2024). Peningkatan Kemampuan Berpikir Kritis Siswa Biologi Dengan Menggunakan Model PjBL Berbasis STEM (Science, Technology, Engineering, Mathematics). *BIODIK*, 10(4), 743-754. https://doi.org/10.22437/biodik.v10i4.38431

Yu, H. (2023). Reflection on whether Chat GPT should be banned by academia from the perspective of education and teaching. *Frontiers in Psychology*, 14. https://doi.org/10.3389/fpsyg.2023.1181712