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Analysis of Students' Critical Thinking Skills Through Active Learning Strategy at Senior High School

Pariabti Palloan[1*], Syamsul Wahid[1], A Sri Astika Wahyuni[1], Jusriana[1]

[1] Department of Physics Education, Universitas Negeri Makassar, Indonesia

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Corresponding Author:
Pariabti Palloan
pariabty.p@unm.ac.id

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Abstract: In the 21st century, critical thinking skills have become a crucial competency in physics education for understanding the concepts behind complex natural phenomena; however, prior research has rarely explored digital-based learning models specifically capable of measuring improvements in these skills among students. This research aims to determine the critical thinking skills of students through the application of active learning strategies at senior high school twenty-two Makassar. The type of research is quantitative research with a descriptive survey method to obtain data. The population in this research was all class eleventh students with a physics interest at senior high school twenty-two Makassar, which consists of ten classes with a total of three hundred fifty-one students. The sampling technique used in this research was purposive sampling. The sample of this research was one hundred thirty-nine students. The variables in this research were critical thinking skills and active learning strategies. The data obtained showed that the critical thinking skills of students were mostly in the low category with a percentage reaching sixty-eight percent. The factors that made the scores of students' critical thinking skills predominantly in the low category were the application of active learning strategies in physics subjects that were not optimal because they are accustomed to memorizing, have little mastery of concepts, and are not trained in critical thinking. These findings indicate that a limited understanding of concepts and a lack of opportunities to practice critical thinking may contribute to students' low critical thinking skills. Implications for physics teachers or curriculum developers regarding the optimization of active learning strategies to enhance critical thinking skills.

Keywords: Active learning strategy; Critical thinking skill; Survey method; Physics learning; Quantitative descriptive research

Introduction

Education has crucial role in shaping the character and abilities of students, both spiritually and physically. Education is defined as a process that provides learning experiences, thus providing knowledge for students, which is expected to eventually develop the skills to solve problems they face. Therefore, it can be concluded that education is a conscious effort undertaken by every human being throughout their life, a never-ending journey to develop themselves and understand everything as preparation for the future. "Critical thinking in physics education serves as the bedrock for socio-scientific reasoning, enabling students to evaluate clean energy transitions and climate data objectively." (Kousa et al., 2022, *Journal of Research in Science Teaching*). "Integrating climate change fluid dynamics into high school physics enhances students' systemic critical thinking skills regarding global environmental challenges." (Baur & Scheuermann, 2024, *International Journal of Science Education*)

Education not only teaches intellectual skills but also teaches how to manage emotions and trains students to think critically and creatively, absorbing and using information from their surroundings to solve problems. The primary goal of education is to develop students' critical thinking skills so they can face life's various challenges. Critical thinking skills are essential in responding to the increasingly dynamic changes of the times, technology, and information. In the 21st

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century, critical thinking skills have become crucial competency in physics education for deciphering complex natural phenomena. However, empirical data from PISA 2022 indicate that the scientific literacy of Indonesian students remains below the OECD average, with a score of 383; notably, approximately 66% of students have yet to grasp fundamental scientific concepts. This deficiency in Higher-Order Thinking Skills aligns with findings from TIMSS and various national studies in physics, which confirm that students generally demonstrate low proficiency in interpretation, evaluation, and inference. The research gap addressed in this study is the lack of integration of innovative, digitally based learning models empirically proven to enhance these critical thinking aspects within the context of abstract physics topics.

Science learning should align with its function and purpose to foster a scientific attitude in students. Therefore, the role of teachers in fostering students' scientific attitudes is essential by providing opportunities for students to develop their scientific attitudes. One important aspect of a scientific attitude is critical thinking skills. So far, physics learning in schools has not developed critical thinking skills. Teachers still adhere to the old paradigm, where educators are sources of information and students are recipients of information. The weakness of this paradigm is that interaction in learning occurs only one way, from teacher to student. Students do not have many opportunities to actively participate in teaching and learning activities because learning is more teacher-centered, rather than student-centered. Another weakness is that physics learning is often oriented only toward results, rather than the process of mastering knowledge. Therefore, changes are needed in physics learning methods, towards a direction that emphasizes student activeness and trains thinking skills to solve problems in everyday life. Empirical evidence from recent science education research literature (2024–2026) consistently reveals a significant gap between national curriculum targets and the reality of physics classrooms. Needs analysis studies and field observations indicate that physics instruction at the high school level remains dominated by conventional, teacher-centered approaches. Classroom observation data shows that teaching and learning activities largely consist of one-way lectures and the copying of mathematical formulas from the board, with minimal active student engagement. Consequently, national cognitive assessments indicate that Indonesian students' Higher-Order Thinking Skills (HOTS) in physics fall into the low category. In-depth interviews confirm that most students tend to solve physics problems mechanically relying on the rote memorization of procedural algorithms—without truly grasping the underlying physical concepts. This passive state is exacerbated by limited school assessment tools, which generally measure only rote memorization and low-level application (C1–C3), thereby failing to foster the analytical reasoning, logical evaluation, and self-regulation skills that form the foundation of 21st-century competencies.

According to research has done by (Kurniawan, Hidayah, and Rahman, 2021), who analyzed the critical thinking skills of vocational high school students, it was found that the critical thinking skills of the Cendika Bangsa Vocational High School students he studied were in the low category. This low level of critical thinking skills is caused by the form of learning and teaching activities that are not optimally oriented towards critical thinking skills. The results of other research have done by Permata, Muslim, and Suyana (2019) found that the critical thinking skills of high school students are still relatively low and still need to be trained in learning. Teachers must start thinking creatively and critically to create learning designs that can train students' critical thinking skills. A substantial body of international pedagogical research documents the effectiveness of various active learning models in boosting students' critical thinking skills in science and physics. A study by Kousa et al. (2022), demonstrates that socio-scientific learning enables students to objectively analyze clean energy transition data by strengthening the foundations of critical reasoning. Meanwhile, Sinatra & Hofer (2023), writing in Educational Psychologist, emphasize that in an era of information disruption, science education must integrate active digital literacy; this equips students to apply critical thinking skills to filter information and expose the pseudoscience claims prevalent in the public sphere. The effectiveness of problem-based learning models is also strongly supported by a comprehensive meta-analysis conducted by Jamil, Hafeez, & Muhammad (2024) research that aligns closely with 21st-century physics curricula. They concluded that problem-based learning consistently yields a significant positive impact on students' abilities to analyze, evaluate, and solve conceptual problems, outperforming conventional methods.

Innovations integrating technology into active learning models have also shown a highly positive trend over the past two years. A quasi-experimental study by Baur & Scheuermann (2024) in the International Journal of Science Education found that introducing global climate fluid dynamics through problem-based inquiry learning significantly boosted the systems thinking and critical thinking skills of high school students. Regarding independent learning, a study by Samaila et al. (2024) demonstrated that integrating the flipped classroom model with problem-based learning successfully drove a dramatic increase in cognitive engagement and learning motivation. Through this strategy, students explore theoretical material independently at home before collaborating to solve complex physics problems in class—an approach that research by Kuo & Wu (2025) has proven effective in maturing metacognition and safeguarding students against blind reliance on automated answers generated by artificial intelligence.

At the national level, a similar trend is observed in a study by Merianti (2025) which evaluated the implementation of inquiry-based learning in high school physics classes; the results revealed a sharp increase in indicators of students' scientific argumentation and inference, driven by a cultural shift from teacher-centered instruction to active exploration. Finally, a comprehensive review by Ramdani et al. (2025) clarifies the current state of the literature by demonstrating that integrating digital interactive media into the guided inquiry learning framework yields significantly better cognitive learning outcomes and critical thinking skills compared to conventional active learning approaches that lack technological integration.

Critical thinking skills are the ability to reflect on thoughts and solve problems systematically and structurally. These skills are crucial for students to develop analytical, creative, and innovative abilities when dealing with complex problems. Physics learning is one of the subjects that supports the development of science, not just a collection of theories and facts, but also discoveries. Physics learning uses an empirical approach to seeking natural explanations for phenomena observed in the universe. This is why students' critical thinking skills in physics are so crucial. Peter A. Facione's theory defines critical thinking as a self-regulatory process of making judgments that result in interpretation, analysis, evaluation, and inference. In physics research, this theory is applied through six key indicators. Students employ interpretation skills to accurately decipher the meaning of graphs or physical phenomena. Through analysis, they identify cause-and-effect relationships between variables within complex physical systems. Evaluation skills are used to assess the validity of theories or verify the accuracy of scientific claims. Meanwhile, inference plays a crucial role when students formulate hypotheses and draw conclusions based on experimental data. The ability to provide explanations requires students to present their physical reasoning coherently, supported by robust scientific arguments. Finally, the self-regulation aspect measures students' metacognitive awareness, enabling them to independently monitor, examine, and correct their own misconceptions regarding physics.

People who can think critically are able to conclude what they know, know how to use information to solve a problem, and are able to find relevant sources of information to support problem solving. Critical thinking is a high-level thinking skill that is crucial for students. However, students' critical thinking skills are often suboptimal and require quality learning (Azka, Masrukan, & Tri, 2025) Critical thinking skills mean the ability to evaluate information critically and objectively, with the goal of making informed decisions. These skills are crucial in everyday life, especially in the workplace and in education (Ariadila et al., 2023)

Physics lessons are placed as one of the important subjects and must be taught as well as possible so that students can master the concepts and principles of physics and have critical thinking skills. As emphasized by BSNP (2007) which states that, the learning process in educational units is held interactively, inspiring, fun, challenging, empowering students to participate actively, providing sufficient space for creative initiatives, independence according to the talents, interests, and physical and psychological development of students so that they can understand the knowledge, concepts and principles of physics, have scientific skills, and critical thinking skills. High school education has a crucial role in shaping students' cognitive foundations. Developing critical thinking skills is crucial in preparing the younger generation to face the complex demands of life in the era of globalization. This includes students' ability to critique, analyze, and evaluate information in a systematic and reflective manner.

Critical thinking can be developed by enriching students with meaningful experiences. These experiences can include opportunities to express opinions verbally or in writing like a scientist. Discussions arising from divergent questions or ill-structured problems, as well as practical activities that require observation of symptoms or phenomena, will challenge students' thinking skills. She describes an ill-structured problem as one that "cannot be explained with a high degree of comprehensiveness; cannot be solved even with a high degree of confidence, where experts often disagree on the best solution, even when the problem can be completely solved".

Based on result of the observations that have been done by researchers at senior high school 22 Makassar, it was found that students' learning experiences were not yet successful. This is evident in the low physics exam scores. The average student score is still below the minimum completion criteria. These low physics learning outcomes indicate students' low critical thinking skills in receiving learning. Based on these assumptions, it is necessary to conduct an analysis of critical thinking skills through active learning strategies of students at senior high school 22 Makassar to provide an in-depth picture of the extent to which critical thinking skills have been formed in students at the high school.

Based on the research background, the problem formulation raised in this research is how are students' critical thinking skills through active learning strategies at senior high school 22 Makassar?

The problem-solving approach in this research is to use active learning strategies. Using active learning strategies, it is hoped that students' critical thinking skills will improve. The active learning strategy used is an approach that actively involves students in the learning process. This strategy aims to hone students' understanding and skills, especially critical thinking skills.

The state-of-the-art and novelty of this research compared to other research is from the learning method where in this research using active learning strategy to see the critical thinking ability of students at senior high school 22 Makassar while in the research has done by Nurul (2024) at senior high school 1 Gowa, South Sulawesi did not apply a specific method only taking data on students' critical thinking ability and then analyzing it. So, in this case the instrument made by Nurul Aziza Wulandari to measure students' critical thinking ability is only general while in this research the statements in the instrument already refer to active learning strategy.

Method

Research Design

This research is quantitative descriptive research using a survey method to obtain data. The researcher did not administer any treatment to the respondents, so this research only reveals a describing of critical thinking skills in students through active learning strategies at senior high school 22 Makassar. Survey research is a quantitative research method for obtaining data on the beliefs, opinions, characteristics, or behaviors of a representative sample of a population (Sugiyono, 2018). According to Creswell (2003) researchers collect data from a population sample at a specific point in time. The data is gathered simultaneously to describe the situation at that moment as Form of Survey research. According to Cohen et al. (2018), survey research is a non-experimental design that collects data from a population sample to describe, compare, or explain specific attitudes, opinions, behaviors, and characteristics in a structured manner.

Population and Sample

This research was conducted in senior high school 22 Makassar during the even semester of the 2024/2025 academic year. The population in this research was all class XI students with a physics interest at senior high school 22 Makassar, which consists of 10 classes with a total of 351 students. The sampling technique used in this research was purposive sampling. Purposive sampling technique is a technique for taking samples of data sources with certain considerations. Purposive sampling was selected because this study required subjects meeting specific characteristics not shared by the entire population. The primary reason was to control for confounding variables such as differences in teaching styles or variations in curriculum implementation by selecting classes taught by the same physics teacher and possessing equivalent levels of prerequisite knowledge. The sample of this research was 139 students spread across class eleven with a physics interest that consist of class XI-2, XI-3, XI-8, XI-9, and XI-10. Determining the sample size involved combining Slovin's formula with purposive sampling to obtain a representative group of subjects that also met specific criteria. Slovin's formula was used initially to mathematically calculate the minimum sample quota based on the total population, assuming a five percent margin of error. Once the minimum quantity target derived from Slovin's formula was met, purposive sampling was applied to screen subjects within that quota against inclusion criteria—such as comparable baseline physics proficiency and teacher homogeneity. This approach ensured that the research sample was not only quantitatively valid but also qualitatively relevant in terms of the cognitive attributes required to measure critical thinking indicators.

Variables of Research

The variable in this research was critical thinking skills. Critical thinking skills are the ability to analyze information objectively and rationally, evaluate arguments, and make logical decisions. Students' critical thinking skills were measured using a critical thinking measurement instrument. This instrument consisted of multiple-choice physics essay questions developed based on critical thinking indicators: interpretation, analysis, evaluation, and inference.

Procedure of Research

This research procedure is divided into several stages, as follows: (1) Preparation Stage, this preparation stage includes: (a) The researcher selects the research location; (b) Communicating and requesting permission from the school; (c) Initial observations; (d) Arranging the research permit; (e) Developing a research proposal; (f) Developing a critical thinking skills test instrument; (f) Validating the research instrument with a validator to determine whether the test items are valid or not. (2) Implementation Stage, the implementation stage includes administering a critical thinking skills test to students. (3) Final Stage, in the final stage of this research, the researcher analyzes the data obtained to determine the results and the extent to which the research objectives have been met.

Data collection technique

This research was to administer a critical thinking skills test to predetermined research subjects, namely students at Class XI. The instrument was structured in the form of essay questions covering indicators of critical thinking skills, including interpretation, analysis, evaluation, and inference. Data collection was conducted by setting a 90 minute test duration under controlled and standardized conditions, and by employing a question randomization method to minimize the risk of experimental bias. Based on the critical thinking skills test data, students were categorized based on critical thinking grouping criteria. Research instruments are the tools or facilities used by researchers to collect data. The instrument used in this research was a critical thinking skills test, a series of 15 essay-based questions or exercises covering aspects of competency and knowledge based on critical thinking skills, referring to critical thinking indicators, which were then used to measure the level of critical thinking skills in students. Duration/Time Allocation: The time allocated for students to complete the entire 15-item critical thinking essay test was 90 minutes (calculated based on standard assessment pacing for high school physics surveys). Scoring Rubric: Each essay item was evaluated using a tiered descriptive rubric with a maximum score of 3 points per question (0 = incorrect/no answer, 1 = incomplete physical identification, 2 = correct identification with faulty reasoning, 3 = fully correct identification and scientific reasoning). Across the 15 items, this rubric yielded a minimum possible score of 0 and a maximum theoretical score of 45. Content Validity (Gregory Index)0.93 is High content relevance and expert agreement. Instrument Reliability is 0.78 (Reliable internal consistency), total Invalid Items is 15 questions.

Data Analysis

The test instrument used was reviewed by two experts, and the results were analyzed by the researchers. This was followed by a validity analysis, which was used to analyze the data from the experts. Gregory testing stated that the data analysis was used to determine validity by two validators, namely by using the Gregory test. After calculating the consistency of the instrument that has been checked by experts, the instrument is then tested on students to determine its validity and reliability. For validation calculations using the correlation point biserial and calculating the item reliability, the Alpha Cronbach formula is used. If Cronbach's alpha value is ≥ 0.70, the instrument is reliable but if Cronbach's alpha value is < 0.70, the instrument is unreliable. The data analysis of students' critical thinking skills used statistical analysis techniques, namely descriptive statistics. This analysis will provide a description of students' critical thinking skills in solving physics problems for each item and the indicators of critical thinking skills. The results of this analysis are displayed in the form of the highest score, lowest score, average score, and standard deviation. After calculating the critical thinking skills score in solving physics problems, categorization is carried out based on criteria. All data screening, descriptive analysis, and instrument psychometric validations in this study were processed using IBM SPSS Statistics (Statistical Product and Service Solutions) version 26.0. This computing software was utilized to calculate point-biserial correlations for item validity, compute Cronbach's Alpha for internal consistency, and extract descriptive baseline metrics including the mean, minimum, maximum, and standard deviation.

Result and Discussion

This research presents data on critical thinking skills in Physics learning. Descriptive statistical processing is used to state the scores of critical thinking skills tests with indicators of interpretation, analysis, evaluation, and inference possessed by students in the Physics subject of class XI at senior high school 22 Makassar. The results of the critical thinking ability test in physics for class XI students at senior high school 22 Makassar are grouped into 5 categories and presented in a frequency distribution table, as shown in Table 1.

Table 1. Descriptive Statistics Table

Descriptive Statistical Metrics	Score Value
Sample Size (N)	139
Minimum Score	6
Maximum Score	45
Mean Score (μ)	18,45
Standard Deviation (σ)	4,91

Table 2. Frequency distribution of score

Score Interval	Category	Frequency	∑ Score Percentage (%)
38 - 45	Very high	2	1
30 – 37	High	2	1
22 - 29	Medium	32	23
14 - 21	Low	94	68
6 – 13	Very low	9	7
Total		139	100

Based on Table 2 above, the level of critical thinking skills is still relatively low. This is clearly seen in Figure 1.

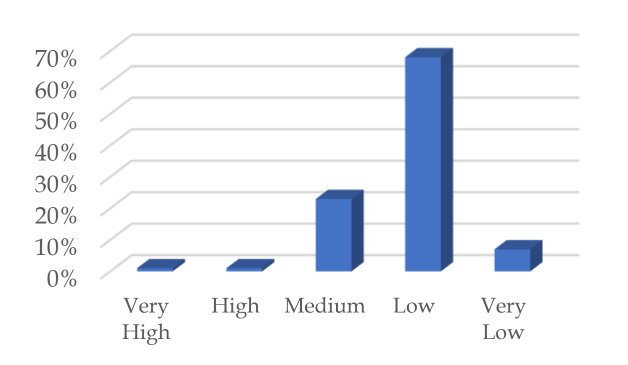

Figure 1: Diagram bar of critical thinking skill scores

The data obtained indicates that the critical thinking skills students' class XI at senior high school 22 Makassar are in the low category. This is evident in the analysis the data, which shows that the overall average critical thinking skills are in the low category. This is caused by several factors, including a lack of thoroughness, lack of practice, and a lack of motivation and interest, which can hinder the development of students' critical thinking skills in completing the 15-question test. Critical thinking skills. The results of the descriptive analysis of students' critical thinking skills for each indicator are outlined below.

The interpretation indicator requires students to be able to write down the meaning or significance of the problem correctly, which can be seen from whether they are able to write down what is known and asked in the question. Interpretation indicators with achievement in the sufficient category indicate that students can understand and explain basic physics concepts but often struggle with applying the concepts to more complex situations. Students are also able to clearly identify physics problems but are unable to formulate problems from more complex or less structured situations.

The level of students' critical thinking skills in the analysis indicator. The reason for students' low analytical skills is that students are more often given problems with numbers and are only asked to solve problems using mathematical formulas. Students also more often solve problems that have clear formulas. In addition, in the learning process, teachers deliver material without explaining the relationship between equations that have been previously learned. This is in accordance with research which states that teachers in delivering learning as if each equation has no relationship so that students view an equation as a formula without meaning (Arizkah, 2019).

The level of critical thinking ability of students in the inference indicator can be interpreted as being able to identify and obtain the elements needed to make a reasonable conclusion by paying attention to statements, principles, evidence, opinions, beliefs, and other forms of representation. An inference indicator with achievement in the adequate category means students can connect basic concepts to physics theory but may not fully explore or apply these relationships in more complex or varied contexts. Therefore, students can draw conclusions from data, but these conclusions often only cover obvious relationships without exploring more complex relationships or long-term implications.

The level of critical thinking ability of students in the evaluation indicator can be interpreted as students being able to evaluate indicators with achievements in the low category can be interpreted as students being less able to evaluate events that occur around them and relate them to physics concepts to make a reasonable conclusion, but many students tend to draw conclusions outside the main problem, which are weak and not well structured.

Students' critical thinking skills are still low because they are accustomed to memorizing, have little mastery of concepts, and are not trained in critical thinking. Students also lack basic knowledge, making it difficult to solve problems and find alternative solutions. This aligns with the research findings of Arini and Juliadi (2022) who also stated that students' critical thinking skills were low. Furthermore, based on student interviews, the study revealed that students were unfamiliar with questions that indicated critical thinking skills, making them reluctant to solve problems when they encounter obstacles. Research by Sarip, Kaharuddin, & Pariabti (2022) also states that factors contributing to students' low critical thinking skills include lack of training in critical thinking when answering questions, as the questions do not use critical thinking indicators. In the learning process, teachers are accustomed to using questions with a low cognitive level. Consequently, students rely solely on memorization when answering questions, resulting in underdeveloped critical thinking skills.

Conclusion

Based on the descriptive statistical analysis, this research concludes that the critical thinking skills of eleventh-grade physics students at Senior High School 22 Makassar are predominantly in the low category, with a percentage reaching sixty-eight percent. When analysed by indicator, students' abilities in inference and evaluation are categorized as low, whereas their skills in interpretation and analysis fall into the sufficient category. This empirical reality demonstrates that while active learning strategies were structurally present, their implementation in physics classrooms was not yet optimal because students remain heavily conditioned to rote memorization, possess limited conceptual mastery, and lack systematic training in high-level reasoning.

Scientific Contribution & Novelty

The novel scientific contribution of this study lies in its targeted evaluation of critical thinking components that are structurally mapped onto an active learning instrument, contrasting with prior localized studies that evaluated critical thinking only in a general, unstructured context. Conceptually, this research advances the science education literature by providing empirical evidence of how a passive classroom culture disrupts the cognitive transition from basic conceptual understanding (interpretation) to high-level execution (inference and evaluation). It serves as a diagnostic baseline confirming that introducing active learning frameworks without shifting foundational assessment habits yields sub-optimal cognitive engagement in abstract physics learning.

Practical Implications

For Physics Teachers: Teachers must urgently shift away from conventional, formula-centric lecturing and move toward optimizing active learning strategies by integrating ill-structured, real-world problems and digital collaborative tools. Physics instruction should emphasize physical reasoning, contextual meaning, and cause-and-effect relationships rather than mechanical rote memorization of mathematical algorithms.

For Schools: School administrators need to systematically upgrade internal assessment designs—moving past low-level cognitive testing (C1–C3)—and design teacher professional development programs that focus heavily on teaching and evaluating Higher-Order Thinking Skills (HOTS).

For Curriculum Developers: Developers should design physics curricula that explicitly embed systematic metacognitive pathways, inquiry-based frameworks, and socio-scientific reasoning tasks. This ensuring that technology and active engagement are balanced to build strong conceptual defence mechanisms against misinformation.

Research Limitations

This study possesses objective limitations, primarily its reliance on a descriptive survey design without a controlled, longitudinal experimental intervention to measure actual, real-time growth over an extended period. Additionally, the sample was bounded within a single geographical location (Senior High School 22 Makassar) using a purposive sampling method, which limits the immediate statistical generalizability of these findings to broader, highly diverse national demographics. Future research should utilize quasi-experimental methodologies paired with digital interactive tools to expand, track, and validate robust interventions for these critical thinking deficiencies.

Based on the research conducted, the researcher makes several suggestions, such as it is hoped that students' thinking skills will be improved. Efforts to improve these skills can be fostered and honed through learning activities that train critical thinking skills. Students should practice developing their critical thinking skills effectively and for the future researchers are expected to develop better indicators and instruments for critical thinking skills to obtain more accurate results and strengthen the findings of this research.

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Author Contributions

Conceptualization, PP. and SW; methodology, ASAW. and J; validation, SW, PP, and ASAW; formal analysis, SW.; investigation, J.; resources, PP, SW, ASAW, and J; data curation, SW; writing—original draft, SW.; writing—review and editing, PP, SW, ASAW, and J; visualization, J.; All authors have read and approved the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

References

Ariadila, N., S., Yessi, F., Firda, H., dkk. (2020). Analisis Pentingnya Keterampilan Berpikir Kritis Terhadap Pembelajaran bagi Siswa. *Jurnal Ilmiah Wahana Pendidikan*, 9(20), 664-669 https://doi.org/10.5281/zenodo.8436970

Arini, W. & Juliadi, F. (2018) Analisis kemampuan berpikir kritis pada mata pelajaran fisika untuk pokok bahasan Vektor siswa kelas X SMA Negeri 4 Lubuklinggau, Sumatera Selatan. *Berkala Fisika Indonesia,* 10(1), 1-11.

Arizkah, N. (2019). Penerapan Pembelajaran Berbasis Masalah terhadap Keterampilan Berpikir Kritis Peserta Didik SMAN 5 Soppeng. *Jurnal Sains dan Pendidikan Fisika*, 14(3), 56-63. https://doi.org/10.35580/jspf.v14i3.10123

Azka, Z., M., Masrukan, M. & Tri, S., N., A. (2024). Kemampuan Berpikir Kritis Siswa Model Problem

Based Learning dengan Asesmen Dinamis Berpendekatan Pembelajaran Berdiferensiasi Ditinjau dari Kemandirian Belajar. *Jurnal Cendikia: Jurnal Pendidikan Matematika*. 8(2), 1259-1272. https://doi.org/10.31004/cendekia.v8i2.3255

Baur, M., & Scheuermann, T. (2024). Integrating climate change fluid dynamics into high school physics enhances students' systemic critical thinking skills regarding global environmental challenges. *International Journal of Science Education*, 46(2), 241–263.

BSNP. (2017). Kurikulum Tingkat Satuan Pendidikan. Jakarta: BSNP

Cohen, L., Manion, L., & Morrison, K. (2018). Research methods in education (8th ed.). Routledge.

Creswell, J. W., & Creswell, J. D. (2023). Research design: Qualitative, Quantitative, and Mixed Methods Approaches (6th ed.). SAGE Publications

Dhina, M., A & Mubaroq, S., R. (2017). Efektifitas Model Pembelajaran Investigasi Kelompok Untuk Meningkatkan Keterampilan Proses Sains dan Keterampil Berpikir Kritis Siswa SMA. *Jurnal Pendidikan Fisika*, 5(2), 1-19. https://doi.org/10.26618/jpf.v5i2.605

Jamil, M., Hafeez, F. A., & Muhammad, N. (2024). Critical thinking development for 21st century: Analysis of physics curriculum. *Journal of Physics Education Trends*, 12(1), 45-56.

Kuo, Y. H., & Wu, L. T. (2025). Evaluating AI-generated physics solutions requires high-level critical thinking and epistemological understanding, preventing reliance on automated misinformation. *Computers & Education*, 198 (1), 104-118.

Kousa, P., et al. (2022). Critical thinking in physics education serves as the bedrock for socio-scientific reasoning, enabling students to evaluate clean energy transitions and climate data objectively. *Journal of Research in Science Teaching*, 59(4), 512–535.

Kurniawan, N., A., Hidayah, N., & Rahman, D., H. (2021). Analisis Kemampuan Berpikir Kritis Siswa SMK. *Jurnal Pendidikan: Teori, Penelitian, Dan Pengembangan*, 6(3), 334-338. http://dx.doi.org/10.17977/jptpp.v6i3.14579

Lubis, A., et al. (2025). Enhancing critical thinking in physics education through AI: A systematic literature review of trends and pedagogical implications. *Jurnal Pendidikan dan Ilmu Fisika*, *5*(2), 343-354.

Merianti, M. (2025). Implementasi model inquiry-based learning dalam pembelajaran fisika untuk meningkatkan keterampilan berpikir kritis. *Satedik: Jurnal Sains, Teknik, Ekonomi, dan Pendidikan*, 1(1), 27–35.

Nurdin, M., & Utama, S. (2026). Identification of generative AI usage profiles and implications for students' critical thinking skills in physics learning. *JPPS (Jurnal Penelitian Pendidikan Sains)*, *15*(2), 112-125

Nurul A., W. (2024). *Analisis kemampuan Berpikir Kritis Peserta Didik di SMAN 1 Gowa.* Universitas Negeri Makassar.

Permata, A., R., Muslim, M., & Suyana, I. (2019). Analisis Kemampuan Berpikir Kritis Siswa SMA pada Materi Momentum Dan Impuls. *In Prosiding Seminar Nasional Fisika (E-Journal)*, 8(1), SNF2019-PE.

Rahma. (2017). *Analisis Berpikir Kritis Peserta didik Dengan Pembelajaran Socrates Konstektual di SMP Negeri 1 Padangratu Lampung Tengah*. Lampung: Universitas Islam Negeri Raden Intan Lampung

Rahman, F., & Hakim, L. (2026). False understanding in AI-assisted physics problem solving: Theoretical framework on epistemic outsourcing and cognitive short-circuiting. *Physics Education Journal*, *61*(4), 104-115

Ramdani, A., et al. (2025). Analisis problematika pembelajaran fisika konvensional terhadap rendahnya keterampilan berpikir tingkat tinggi (HOTS) siswa SMA. *Jurnal Inovasi Pembelajaran Fisika*, 15(3), 294–300.

Samaila, J., et al. (2024). Flipped classroom model combined with problem-based learning: Fostering deeper learning and critical analytical skills. *International Journal of Educational Research Trends*, 9(1), 158–172.

Sarip, N., Kaharuddin, A., & Pariabti, P. (2022). Analisis Keterampilan Berpikir Kritis Peserta Didik Kelas X di SMAN 10 Makassar. *Jurnal Sains Dan Pendidikan Fisika (JSPF)*, 18(3), 291-299. https://doi.org/10.35580/jspf.v18i3.31668

Sinatra, G. M., & Hofer, B. K. (2023). Physics education must shift toward digital scientific literacy: Critical thinking helps students debunk pseudo-scientific claims rampant on digital platforms. *Educational Psychologist*, 58(2), 93–105.

Sugiyono. (2018). *Metode Penelitian Kuantitatif, Kualitatif, dan R&D*. Bandung: Alfabeta.

Sugiyono. (2016). *Metode Penelitian, Pendekatan Kuantitatif, Kualitatif, dan R&D*. Bandung: Alfabeta.

Sutrisno, E., dkk. (2026). Probing AI-generated physics solutions and preparing students to critique automated reasoning. *Journal of Research in Science Teaching*, *63*(3), 415-429

Tan, K. L., & Chen, J. H. (2026). Investigating the influence of generative AI integration within a Problem-Based Learning framework on physics undergraduate critical thinking. *Journal of Technology and Science Education*, *16*(1), 78-92

Wahid, S. (2025). Analisis Hasil Belajar Mahasiswa pada Mata Kuliah Praktikum Fisika Dasar. *Jurnal Ilmiah ECOSYSTEM*, 25(2), 499-510. https://doi.org/10.35965/eco.v25i2.7030

Zulva, R., Ristanto, S., & Khoiri, A. (2026). Efektivitas model pembelajaran inovatif berbasis digital dalam mereduksi pembelajaran berpusat pada guru pada kelas fisika abad ke-21. *Educational Science and Physics Review*, 6(2), 6100–6112