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# The Effect of an Augmented Reality-Assisted Problem-Based Learning Model on the Critical Thinking Skills of 11th-Grade Students

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**Abstract:** The purpose of this study is to characterize the impact and extent of the PBL model with AR assistance on the critical thinking abilities of eleventh-grade dynamics students. The low degree of critical thinking abilities is the study's backdrop and students' difficulty in understanding complex physics concepts that require conceptual analysis. This study employed a quasi-experimental research design using a nonequivalent control group design with purposive sampling to select one experimental class and one control class. The experimental group received PBL assisted by AR, whereas the control group received PBL without AR assistance. Both groups completed a pretest before the learning intervention and a posttest after the intervention. An essay test based on Ennis's critical thinking indicators measured students' critical thinking skills. The instrument showed high reliability, with a Cronbach's alpha coefficient of 0.894. The study collected data through pretests and posttests and analyzed the data using the Mann–Whitney U test. The results showed a statistically significant difference between the two groups, with the experimental class obtaining an average posttest score of 53.38, higher than the control group's 43.42. An effect size of 0.278 indicates an effect in the small-to-moderate range. These results imply that the combination of PBL and AR promotes the growth of critical thinking abilities via contextual problem-solving and concrete visualization of concepts. Thus, AR-assisted PBL effectively enhances students' critical thinking skills. Future research should evaluate the effectiveness of AR-assisted PBL across different physics topics, educational levels, and larger samples.

**Keywords**: Problem-Based Learning; Augmented Reality; Critical Thinking Skills; Physics Education; Dynamics of Motion.

**Abstrak**: Tujuan penelitian ini adalah untuk mengkarakterisasi dampak dan sejauh mana model PBL dengan bantuan AR terhadap kemampuan berpikir kritis siswa kelas sebelas jurusan dinamika. Rendahnya kemampuan berpikir kritis merupakan latar belakang penelitian ini, serta kesulitan siswa dalam memahami konsep fisika kompleks yang membutuhkan analisis konseptual. Penelitian ini menggunakan desain penelitian kuasi-eksperimental dengan desain kelompok kontrol non-ekuivalen dengan pengambilan sampel bertujuan untuk memilih satu kelas eksperimen dan satu kelas kontrol. Kelompok eksperimen menerima PBL dengan bantuan AR, sedangkan kelompok kontrol menerima PBL tanpa bantuan AR. Kedua kelompok menyelesaikan pretest sebelum intervensi pembelajaran dan posttest setelah intervensi. Tes esai berdasarkan indikator berpikir kritis Ennis mengukur kemampuan berpikir kritis siswa. Instrumen menunjukkan reliabilitas tinggi, dengan koefisien alpha Cronbach sebesar 0,894. Penelitian ini mengumpulkan data melalui pretest dan posttest dan menganalisis data menggunakan uji Mann–Whitney U. Hasil penelitian menunjukkan perbedaan yang signifikan secara statistik antara kedua kelompok, dengan kelas eksperimen memperoleh skor posttest rata-rata 53,38, lebih tinggi daripada kelompok kontrol yang memperoleh 43,42. Ukuran efek sebesar 0,278 menunjukkan efek dalam kisaran kecil hingga sedang. Hasil ini menyiratkan bahwa kombinasi PBL dan AR mendorong pertumbuhan kemampuan berpikir kritis melalui pemecahan masalah kontekstual dan visualisasi konsep yang konkret. Dengan demikian, PBL yang dibantu AR secara efektif meningkatkan keterampilan berpikir kritis siswa. Penelitian selanjutnya harus mengevaluasi efektivitas PBL yang dibantu AR di berbagai topik fisika, tingkat pendidikan, dan sampel yang lebih besar.

**Kata kunci**: Pembelajaran Berbasis Masalah; Realitas Tertambah; Keterampilan Berpikir Kritis; Pendidikan Fisika; Dinamika Gerak.

## INTRODUCTION

The ability to think critically is a fundamental ability that 21st-century pupils need to grasp to address and resolve challenging issues (Thornhill et al., 2025; Ramírez et al., 2022). These skills encompass the process of deeply analyzing information, sorting relevant data, evaluating evidence, drawing conclusions and making decisions logically in problem-solving (Adhikari et al., 2025). Ennis (1991) describes critical thinking as a methodical, introspective process that is concentrated on decision-making. Critical thinking skills involve organized processes of interpretation, analysis, evaluation, and inference and constitute a crucial component of education throughout the learning process (Verma et al., 2022). Therefore, Critical thinking abilities are a crucial component of education that must be methodically cultivated.

Although critical thinking skills play a vital role, various studies indicate that students' critical thinking skills have not yet developed optimally (Neswary & Prahani, 2022; Aji et al., 2023). The findings of the Program for International Student Assessment support this. (PISA), which show that only 31% of 15-year-old Indonesian students achieve creative thinking proficiency, a finding influenced by a lack of exploration, expression, and support for critical thinking (OECD, 2024). Furthermore, students at the secondary level still struggle with solving problems that require higher-order thinking skills (Kurniawan et al., 2020). These findings indicate that the current learning process has not completely aided in the growth of pupils' critical thinking abilities, thus necessitating a more innovative and student-centered learning model.

Innovative It has been demonstrated that learning paradigms like Problem-Based Learning (PBL) are successful in enhancing students' critical cognitive abilities (Jannah & Atmojo, 2022; Ayu et al., 2023). Furthermore, PBL has also been demonstrated to improve comprehension of physics topics (Siregar et al., 2023). However, in its implementation, students often struggle to identify and understand relevant real-world problems, thus requiring more structured learning support (Kardoyo et al., 2020). Differences in ability among students can also affect the effectiveness of PBL implementation, thus requiring learning media capable of supporting a more Contextual and interactive education process (Suardika et al., 2025). One technology with potential to support a more contextual implementation of PBL is Augmented Reality (AR).

AR-based learning media have been proven to be valid and successful in improving pupils' physics critical thinking abilities education (Nusroh et al., 2022). Furthermore, AR is capable of providing enhancing student participation in the educational process and providing an immersive learning environment (Hyder et al., 2021; Aryani et al., 2023). Students benefit from using AR as well, visualize abstract concepts more concretely, thereby facilitating their comprehension of the subject matter (Harun et al., 2020). Through interactive simulations, AR allows students to independently explore physics concepts according to their individual learning needs (Rizki et al., 2023). Thus, The efficacy of PBL may be increased by including AR into instruction.

The integration of AR-assisted PBL has been shown to help pupils strengthen their critical thinking abilities. while also helping to present physical phenomena that are difficult to observe directly through interactive digital visualizations (Langi, 2025; Suharti et al., 2024; Khairunnisa & Faradillah, 2023). Muliana and Nufus (2024) shown that using AR-assisted PBL may improve students' active participation in the learning process. In line with these conclusions, Lespita et al. (2023) said that the integration of PBL and AR supports the creation of a more participatory learning environment through student participation in the educational process. Furthermore, the integration of PBL and AR supports problem-solving activities by presenting phenomena that are more contextual and engaging for students (Ansori et al., 2025). These various studies indicate that AR-assisted PBL is a relevant approach for fostering the development of Critical thinking abilities of pupils.

Although PBL has been the subject of various research and AR, research specifically integrating both into physics instruction Regarding the subject of motion dynamics—particularly to improve the critical thinking abilities of high school pupils in the eleventh grade remains limited. A bibliometric analysis using VOSviewer on 1,057 articles acquired using Publish or Perish from Scopus together with Google Scholar from 2021 to 2025 indicates that research on PBL, AR, and critical thinking skills is still largely conducted separately; consequently, the integration of these three elements in physics education is rarely reported in the scientific literature. This gap highlights the need for further investigation into the effectiveness of AR-assisted PBL integration to improve students' critical thinking skills in physics learning. The novelty of this study lies in integrating an AR-assisted PBL model to improve the critical thinking skills of eleventh-grade students in the topic of motion dynamics, an approach that has rarely been investigated in previous studies. Based on the aforementioned, the purpose of this study is to characterize how the AR-assisted PBL learning model affects the critical thinking abilities of the subject's eleventh-grade pupils of dynamics, as well as the magnitude of the effect produced. In line with this objective, the hypothesis tested in this study is that pupils who take part in physics instruction using the AR-assisted PBL model have significantly higher critical thinking skills than those who participate in physics instruction using the PBL model without AR.

## RESEARCH METHODS

A quasi-experimental design was used in this investigation. A study technique called a quasi-experimental design is used to examine how a therapy affects a patient under carefully monitored circumstances (Sugiono, 2019). Two groups—an experimental group and a control group—are involved in the nonequivalent control group study design without subject randomization (Table 1). The experimental group's pupils participated in AR-assisted PBL learning, while the control group engaged in PBL without AR.

**Table 1.** Nonequivalent-Group Research Design

| Class | Pretest | Treatment | Posttest |
|---|---|---|---|
| Experiment | O1 | X1 | O2 |
| Control | O3 | X2 | O4 |

Description:
$O_1$ = stands for the experimental group's pretest
$O_2$ = for their posttest
$O_3$ = for the control group's pretest
$O_4$ = is the control group's posttest.
$X_1$ = AR-assisted PBL treatment
$X_2$ = PBL treatment without AR

Students in the eleventh grade make up the study's population. taking physics classes at State Senior High School (SMAN) 08 and SMAN 10 in Bengkulu City. Purposive sampling was the method used to determine the research sample based on specific considerations tailored to the research needs. These considerations included curriculum uniformity, student characteristic equivalence, ease of obtaining research permission, and the willingness of physics teachers to participate in this study. The control and experimental groups were determined purposively by considering the suitability of the research implementation and the availability of classes that could be involved in the study. Thirty-two pupils from Class made composed the experimental group XI 5 at SMAN 08 in Bengkulu City, whereas 33 pupils from Class made constituted the control group XI G at SMAN 10 in Bengkulu City.

The research procedure consists of (Figure 1) the initial stage (planning), implementation, and the final stage (conclusion). In the planning stage, the researcher determined the research location, developed instructional materials in the form of learning objective sequences, teaching modules, and student worksheets, and developed and validated the research instruments. In the implementation stage, the researcher administered a pretest to both groups, then implemented AR-assisted PBL PBL without AR in the control group and PBL in the experimental group, followed by a posttest. In the final stage, the researcher processed and analyzed the pretest and posttest data, drew conclusions, and prepared an article for publication.

The research tool is an essay-based examination of critical thinking abilities accompanied by a scoring rubric. Each test item refers to learning outcomes, learning objectives, and critical thinking indicators according to Ennis. The test item blueprint is organized centered on the connection between learning and critical thinking indications objectives, which include the competencies of identifying types of forces, calculating force and acceleration, deducing the relationship between friction, explaining the interconnection of force concepts, and evaluating calculation strategies using Kepler's Laws and Newton's law of gravity.

Ennis's five indications of critical thinking abilities served as the foundation for the instrument's development, which were broken down into 12 sub-indicators (see Table 2). All test items underwent content and construct validation by validators (two physics lecturers and a physics teacher), were then consulted with the two supervising lecturers (authors 2 and 3) to obtain feedback, and were revised based on suggestions and critiques from the three validators before being pilot- examined pupils who had previously learned the physics concepts/material tested in the research instrument. After revision, the 24 test items were pilot-tested on students in

Class XII 3 at SMAN 08 to obtain empirical test data, which were examined using Excel and SPSS version 26 to ascertain the test's validity, reliability, discriminative power, and item difficulty levels. Discriminant analysis was conducted to determine The exam items' capacity to differentiate between individuals with high and low ability, while difficulty level analysis was used to determine the difficulty category of each test item.

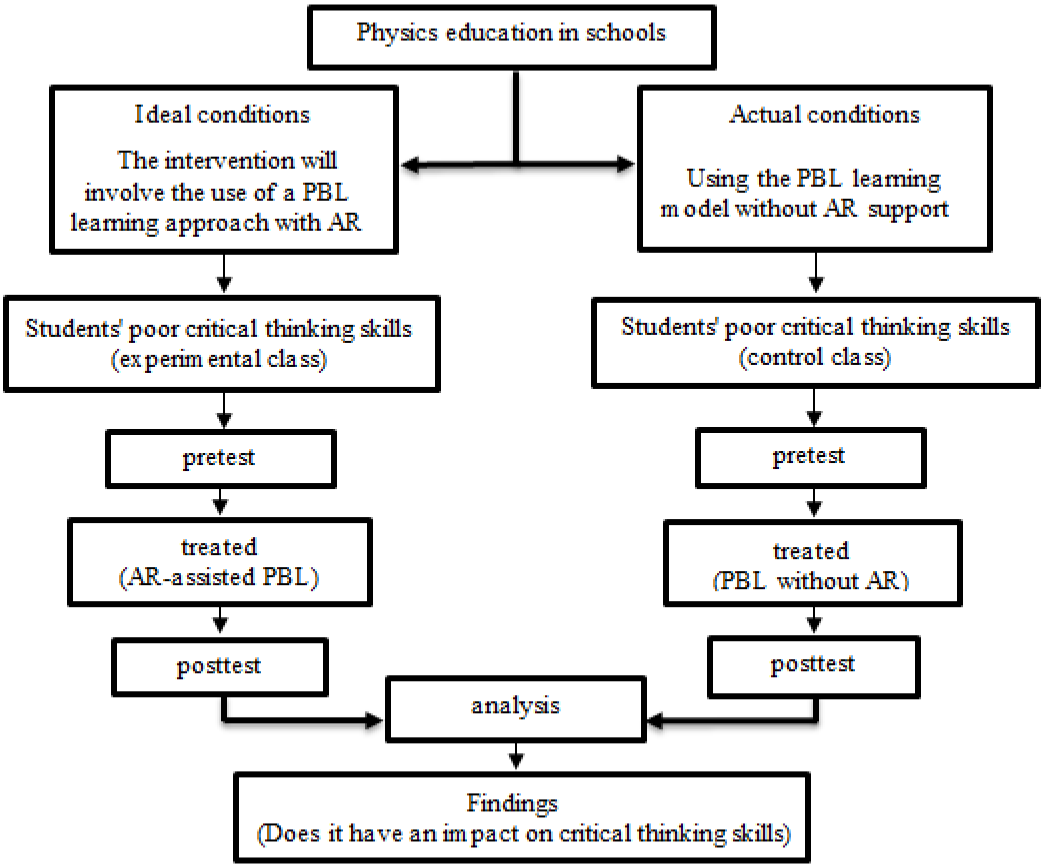


**Figure 1.** Research Procedure Flowchart

Research data analysis techniques consist of both inferential and descriptive analysis. The experimental and control groups' pretest and posttest data were described using descriptive analysis, which employed the mean and standard deviation. In the meanwhile, the study hypothesis is tested by inferential analysis, starting with a homogeneity test using Levene's test and a normality test using the Shapiro-Wilk test with the aid of SPSS version 26. If the Sig. value is greater than 0.05, the data are regarded as homogenous and regularly distributed. If the data satisfied the requirements of normality and homogeneity, an independent samples t-test was used for hypothesis testing; if not, the Mann–Whitney U test was used (Rahmadani & Bina, 2021; Usmandi, 2020; Mashuri, 2022). Additionally, the magnitude of the treatment effect was analyzed using an effect size (ES), the calculation of which was adjusted according to the type of statistical test used; for nonparametric data, it was calculated using Cohen's r formula.

$$r = \frac{Z}{\sqrt{N}} \quad (1)$$

Description:
$r$ = ES coefficient
Z = the p-value of the Mann–Whitney U test
N = sample size

## RESULT AND DISCUSSION

The A critical thinking skills exam with 12 open-ended questions that were created using Ennis's critical thinking indicators served as the study's instrument. Every item relates to a different aspect of critical thinking abilities (giving a brief explanation, developing fundamental skills, coming to conclusions, offering more explanations, and developing strategies and tactics) and contextualized within the topics of gravitational force, friction, centripetal force, Newton's laws, and Kepler's laws (see Table 2).

The instrument's empirical validity was assessed using item-total correlations. The analysis showed that all 12 items met the validity criteria at the 5% significance level, with p-values < .05 for each item. The range of the item correlation coefficients (r) was 0.455 to 0.769 and were classified as moderate to very high. These correlation values indicate that each item has an adequate relationship with the total score and can represent the construct of the critical thinking skills being measured. Item analysis also showed that discrimination power (DP) ranged from 0.372 to 0.740, falling within the adequate-to-very good range. In contrast, the difficulty level (DL) ranged from 0.418 to 0.718, indicating a moderate-to-easy level of difficulty. Thus, the selected items are deemed capable of distinguishing students with high and low critical thinking abilities and have an appropriate level of difficulty for use with 11th-grade students.

The instrument's Cronbach's alpha was used to examine reliability and evaluate the internal consistency of the items (Ghozali, 2021). The instrument was considered reliable if its α value was above 0.70, indicating adequate internal consistency. The instrument has a Cronbach's α reliability coefficient of 0.894, which is in the extremely high range, according to the analysis results. This number shows that the test items have a high degree of internal consistency and may accurately assess students' critical thinking abilities, consistent manner across the pretest and posttest contexts for use with 11th-grade students.

**Table 2.** Findings from the Critical Thinking Skills Instrument's Empirical Validity Test

| Dimensions of Critical Thinking | Indicator | Concept | Question Number | Item Validation | | | |
|---|---|---|---|---|---|---|---|
| | | | | Koef r (criteria) | P-Value (criteria) | DP (criteria) | TK (criteria) |
| Elementary Clarification | Focusing the question<br>Analyzing the question<br>Asking and answering questions | Weight, friction, centripetal force, and gravitational force | 1 A | 0.573** (Height) | 0.001 (Valid) | 0.520 (Good) | 0.718 (Easy) |
| | | | 1 B | 0.455** (Fair) | 0.009 (Valid) | 0.372 (Fair) | 0.638 (Moderate) |
| | | | 1 C | 0.529** (Height) | 0.002 (Valid) | 0.453 (Good) | 0.644 (Moderate) |
| Basic Support | Determining whether a source is | Newton's Laws I, II, III | 2 A | 0.532** (Height) | 0.002 (Valid) | 0.489 (Good) | 0.712 (Easy) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | reliable or not Observin, reviewing observation reports | | 2 B | 0.769** (Very High) | <0.001 (Valid) | 0.740 (Very Good) | 0.600 (Moderate) |
| Inference | Performing and considering the results of the deduction | The concept of friction | 3 A | 0.688** (Height) | <0.001 (Valid) | 0.648 (Good) | 0.594 (Moderate) |
| | Performing and evaluating the results of induction | | 3 B | 0.598** (Height) | <0.001 (Valid) | 0.541 (Good) | 0.600 (Moderate) |
| | Creating and determining weighting values | | 3 C | 0.686** (Height) | <0.001 (Valid) | 0.641 (Good) | 0.618 (Moderate) |
| Advanced Clarification | Defining, considering a definition | The Relationship Between Weight, Centripetal Force, and Gravity in Newton's Laws | 4 A | 0.652** (Height) | <0.001 (Valid) | 0.606 (Good) | 0.518 (Moderate) |
| | Identifying assumptions | | 4 B | 0.688** (Height) | <0.001 (Valid) | 0.646 (Good) | 0.418 (Moderate) |
| Techniques and Approaches | Choosing a course of action | Kepler's III Law and its connection to Newton's Laws | 5 A | 0.664** (Height) | <0.001 (Valid) | 0.614 (Good) | 0.582 (Moderate) |
| | Engaging with other people | | 5 B | 0.646** (Height) | <0.001 (Valid) | 0.585 (Good) | 0.676 (Moderate) |

To characterize the features of students' critical thinking skill scores, descriptive analysis was performed on pretest and posttest data from the experimental and control groups. The lowest and maximum values, mean, standard deviation (SD), skewness, and kurtosis values are among the descriptive statistics displayed to evaluate the distribution's form (see Table 5). Pretest results in the experimental class varied from 6.67 to 45.00, with a mean (M) of 18.49 and a standard deviation (SD) of 9.69, while posttest scores ranged from 18.33 to 85.00 has a 53.39 mean (M) and a 16.87 standard deviation (SD). Pretest scores in the control group varied from 0.00 to 64.00, with a mean (M) of 24.95 and a standard deviation (SD) of 20.27; posttest scores varied from 10.00 to 70.50, with a mean (M) of 43.42 and a standard deviation (SD) of 16.49. The skewness and kurtosis values for both groups remained within acceptable ranges for further analysis, thus satisfying the assumption of a distribution approximating normality.

Descriptively, the mean posttest scores increased in all groups, although the experimental class's rise (M = 53.39; SD = 16.87) was higher than the control class's (M = 43.42; SD = 16.49). This trend suggests that using the AR-assisted PBL learning paradigm may be more successful than PBL without AR in enhancing students' critical thinking abilities; inferential analysis in the section that follows supports this assertion. Table 3 provides a detailed display of the descriptive analysis results.

**Table 3.** Results of the Descriptive Analysis

| Class | Test | Minimum Value | Value Maximum | Mean | Standard Deviation | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| Experiment | Pretest | 6.67 | 45.00 | 18.48 | 9.69 | 0.928 | 0.572 |
| | Posttest | 18.33 | 85.00 | 53.38 | 16.87 | -0.217 | -0.461 |
| Control | Pretest | 0.00 | 64.00 | 24.95 | 20.27 | 0.360 | -1.306 |
| | Posttest | 10.00 | 70.50 | 43.42 | 16.49 | 0.087 | -0.667 |

A normality test was performed to see if the distribution of critical thinking skill scores met the assumption of normality, which is a basis for selecting subsequent statistical tests. Normality was Shapiro-Wilk testing is advised for small to medium sample sizes. The information are considered not to deviate significantly from normality if the significance value (Sig.) is larger than 0.05; on the other hand, if Sig. is less than 0.05, they are regarded as deviating from normalcy. Table 4 displays the findings of the normalcy test for the pretest and posttest scores in both groups.

**Table 4.** Results of the Normality Test

| Class | Test | Statistics | Sig. |
|---|---|---|---|
| Experiment | Pretest | 0.165 | 0.014 |
| | Posttest | 0.084 | 0.862 |
| Control | Pretest | 0.173 | 0.005 |
| | Posttest | 0.147 | 0.189 |

Table 4 shows the significant values for the experimental class's pretest results (0.014) and the control class (0.005) were both less than 0.05. Indicates that the distribution of pretest scores in both classes deviated significantly from normality (Sig. < 0.05). Meanwhile, the significance values of the posttest scores both the control class and the experimental class (0.862) (0.189) are both greater than 0.05; thus, there is insufficient evidence to indicate a deviation from normality in the posttest data (Sig. > 0.05).

This difference in results indicates that after the treatment, the distribution of posttest scores became closer to normal, particularly in the experimental class. However, since the pretest data for both groups did not meet the assumption of normality, the hypothesis testing continued to use nonparametric tests. The choice of nonparametric tests was intended to ensure that the analysis procedure was appropriate to the data characteristics, thereby maintaining valid and scientifically sound test results.

One of the parametric test assumptions was not satisfied, according to the findings of the normality test, which showed that the data were not regularly distributed. Thus, posttest results on critical thinking abilities were compared between the experimental and control groups using a nonparametric Mann-Whitney U test. The hypothesis being examined is that students who learned physics using the AR-assisted PBL model and those who learned physics using the PBL model had significantly different critical thinking abilities without AR.

Test decisions were based on the significance value (Asymp. Sig.) compared to the significance level $\alpha = 0.05$. Data were considered not substantially different if

Sig. > 0.05, and significantly different if Sig. < 0.05 (Selpia et al., 2024). Table 5 displays the Mann-Whitney test findings for the posttest data.

**Table 5.** Results of the Mann–Whitney Test on Posttest Data

| Class | Mean | Significant |
|---|---|---|
| Experiment | 53.38 | 0.025 |
| Control | 43.42 | |

According to Table 5, there is a statistically significant difference between the critical thinking skills posttest scores of students in the experimental class and the control class, with a significance value (Asymp. Sig.) of 0.025 (< 0.05). Students who engaged in AR-assisted PBL had superior critical thinking abilities, as evidenced by the experimental class's mean posttest score (M = 53.38) being higher than the control class's (M = 43.42). As a result, the research hypothesis is accepted, and it can be said that using the AR-assisted PBL learning approach improves students' critical thinking abilities.

To quantify the extent of the treatment's impact on students' critical thinking abilities, an effect size analysis was carried out. Cohen's r coefficient was used in this study to determine the effect size based on the Mann-Whitney test statistic (Z) and the sample size (N), using (Formula 1). This approach provides additional information regarding the strength of the effect, so that the results do not rely solely on statistical significance.

According to the studies' findings, a Z-value of 2.245 and a sample size of N = 65 were obtained, resulting in an effect size of r = 0.278. This value indicates that the AR-assisted PBL treatment improved critical thinking abilities of the pupils after the lesson. Cohen's standards classify a r value of around 0.10 as a modest influence, 0.30 as a moderate effect, and 0.50 as a large effect as a large effect. Thus, the r value of 0.278 falls within the small-to-moderate range, indicating a quite significant impact on learning. Although classified as a small effect, this effect size still holds important practical significance in educational research influenced by numerous factors. This value shows that using the AR-assisted PBL paradigm regularly improves students' critical thinking abilities. These results imply that the AR-assisted PBL model has the potential to be improved and refined in physics education and is deserving of attention as a novel approach to improve learning quality.

The study's findings show that using an AR-assisted PBL learning paradigm has an impact on students' critical thinking abilities, as seen by the experimental class's higher average score on the posttest compared to the control group. This distinction not only shows that critical thinking abilities have improved, but it also implies that the implemented learning process fosters a more systematic, focused, and analysis-based approach to problem-solving among students. This finding aligns with recent research indicating that the integration of AR into PBL can strengthen students' critical thinking skills by encouraging active participation in authentic problem-solving activities and facilitating a deeper understanding of concepts (Indra et al., 2025). In other words, integrating PBL and AR have an impact on students' performance as well as cognitive processes, enabling deeper understanding, analysis, and assessment of data.

According to Ennis (2011), critical thinking abilities are the ability to reason logically and thoughtfully while deciding what to believe or do. According to the study's findings, critical thinking abilities were observed in both the experimental and control classes; however, a greater improvement occurred in the class that implemented AR-assisted PBL. Indicates that the treatment administered had a bigger influence on the growth of critical thinking abilities than learning without AR. Estimurti and Pantiwati (2026) also reported that the use of AR within a PBL approach contributed to the improvement of students' critical thinking skills by supporting structured inquiry and collaborative problem-solving during instruction. To obtain a more detailed picture of the aspects of critical thinking abilities that developed during learning, an analysis was conducted on each indicator of critical thinking skills.

Analysis of improvements in the experimental class showed that all critical-thinking skill indicators improved after the implementation of AR-assisted PBL. These improvements occurred across all indicators, with relatively varying percentages. The largest improvement occurred in the indicator of building basic skills at 46.49%, followed by drawing conclusions at 44.39%, formulating strategies and tactics at 42.70%, providing simple explanations at 42.33%, and providing further explanations at 37.55%. These findings indicate that implementing AR-assisted PBL not only supports a specific indicator It also makes it easier for all critical thinking skill markers to grow. Combination of AR and PBL can strengthen different dimensions of critical thinking, as students engage in interactive learning activities situated in meaningful contexts (Arumawati et al., 2025).

Improvements in the indicator for building basic skills indicate that students can gather, identify, and use relevant information in problem-solving, including distinguishing between important and unimportant information. In the indicator for drawing conclusions and formulating strategies and tactics, students can connect observational results to physics concepts, draw logical conclusions, and design solution steps based on analysis, thereby demonstrating the ability to integrate concepts in problem-solving. Meanwhile, regarding indicators of providing simple and advanced explanations, students are active in discussions and presentations by expressing opinions, providing logical reasons, and defending arguments with evidence, including the ability to clarify their thoughts when receiving feedback, thereby reinforcing their understanding through reflection. The integration of interactive digital technology into PBL creates opportunities for students to examine information critically, formulate explanations based on evidence, and further develop their critical thinking skills in physics (Rosyida & Kurnia, 2025; Marsila et al., 2026).

This improvement can be explained through the stages of the PBL model utilized during the educational process. Students are given contextual issues pertaining to motion dynamics in daily life throughout the problem-orientation stage. This stage encourages students to identify problems, ask questions, and analyze the initial information available before determining a solution. Through these activities, students not only receive information directly but are guided to begin building an initial understanding of the problems they face. This process contributes to their ability to provide simple explanations because students are trained to understand situations more closely and to identify relevant information as a basis for problem-solving. Arici and Yilmaz (2023) state that this stage plays a role in fostering students' curiosity and initial analytical skills. This study further revealed that presenting students with contextual physics problems at the start of the learning process enabled them to recognize relevant information, develop an initial understanding of the problem, and determine appropriate solution strategies.

During the stage of organizing students for learning, students are divided into groups and guided to plan problem-solving strategies, identify necessary information, assign tasks, and select relevant learning resources. At this stage, students begin to actively engage in the learning planning process, so that they do not merely act as recipients of information but also as key agents in its collection and processing. This activity trains students to develop foundational skills through independent or collaborative searching, selecting, and evaluating information within a group. These findings are consistent with Andriyatno et al. (2023); Hidayah and Nuraini (2025), who state that PBL encourages students to actively seek, select, and process information independently to solve problems.

The role of AR becomes particularly evident during the inquiry phase of the PBL model, where students use AR media to observe physical phenomena visually and interactively. AR helps visualize abstract concepts—such as force, mass, acceleration, and the motion of objects—in a more concrete way. Three-dimensional visual representations allow students to understand phenomena from various perspectives, thereby helping them interpret the relationships between physical concepts more deeply. Additionally, the interactive nature of AR encourages students to actively explore and observe changes in physical phenomena, providing an inquiry-based learning experience that supports analysis, evaluation, and the drawing of logical conclusions. These activities contribute to the development of the skill of concluding, an indicator of critical thinking. Hasan et al. (2025) state that AR makes abstract ideas easier to comprehend by helping us picture them through interactive learning experiences. Marsila et al. (2026) also found that the integration of AR in physics learning enabled students to transform abstract concepts into more meaningful visual representations. This approach enhanced conceptual understanding and supported the development of analytical thinking during classroom activities.

During the stage of developing and presenting their work, Students share with the class the outcomes of their group talks and receive feedback from other groups in the form of questions, counterarguments, or suggestions. This process creates an evaluative environment that encourages students not only to provide answers but also to defend their reasoning openly. Additionally, students are required to revise or strengthen their arguments based on the feedback they receive, thereby fostering a deeper reflective process. Syamsidah and Suryani (2018) state that interactions during group discussions can enhance students' capacity for critical thought through idea sharing.

Next, while the problem-solving method is being analyzed and evaluated, students reflect on the solutions they have arrived at by comparing various alternative answers derived from group discussions and analyses. Through this process, students must not only embrace a single solution but also to consider the strengths and weaknesses of each alternative based on the data and physics concepts they have learned. Students then formulate problem-solving strategies and tactics and make rational, justifiable decisions by integrating the results of analysis, logical reasoning, and evaluation of evidence before determining the most appropriate solution. Aligns with Ennis (2011) who identifies rational decision-making as a crucial component of critical thinking abilities. Reflective evaluation also helps students recognize limitations in their reasoning and improve the strategies they use to solve similar problems in future learning situations.

The usage of AR as a learning tool supports the development of critical thinking abilities in addition to being impacted by the PBL stages. AR benefits pupils visualize the dynamics of motion more concretely, thereby facilitating analysis and problem-solving. Students become more active in discussing, exchanging ideas, and evaluating arguments logically. These conditions foster collaborative, student-centered learning, thereby encouraging the growth of critical thinking abilities. Aligns with Suharti et al. (2024) who state that collaborative learning can enhance student participation and the caliber of their reasoning processes.

The application of AR in this research focuses on visualizing dynamic motion phenomena as a basis for analysis. Through these visualizations, students can more easily understand cause-and-effect relationships, draw conclusions, and determine solutions to the problems presented. In this study, AR served not only as a visualization tool but also as a means of supporting the reasoning process in PBL backed by Utami et al. (2025), who claim that AR creates contextual and interactive learning experiences, and by Sri and Guspatni (2023), who emphasize its role in strengthening students' thinking processes. Therefore, the use of AR serves as an effective supporting factor in helping students understand concepts while developing Critical thinking abilities.

The observation's findings demonstrate that pupils were actively engaged in every stage of AR-assisted PBL. Students discussed, exchanged ideas, and responded to arguments logically. This environment fostered collaborative learning that supported critical thinking skills. In addition, students systematically integrated the concepts of force, motion, and the laws of physics into their problem-solving. Documentation of the educational activities is shown in Figure 2.


**Figure 2.** (a) Experimental Class Using an AR-Assisted PBL Learning Model, (b) The Group is Presenting the Results of Their Discussion

Overall, the research findings indicate that improvements in critical thinking skills result from the synergy between the PBL stages and AR support. PBL provides structure to the problem-solving process, while AR reinforces conceptual understanding through concrete visualizations. When the two are combined, learning becomes relevant, engaging, and active, which improves students' critical thinking abilities. These results are consistent with those of Dilviana et al. (2025), who claim that AR-assisted PBL successfully enhances critical thinking abilities by combining problem-solving and visualization help. Therefore, the integration of AR into the PBL model can create a learning environment that effectively supports the development of students' critical thinking skills.

## CONCLUSION

According to the study's findings, 11th-grade students' critical thinking abilities are significantly impacted by the use of the AR-assisted PBL learning approach. the subject of dynamics, with the magnitude of the effect falling into the small-to-moderate category (r = 0.278). This is demonstrated by the Mann-Whitney U test findings, which showed that the study hypothesis was accepted with a significance value of 0.025 < 0.05. The experimental class's mean posttest score (53.38) was also higher than the control group's (43.42), suggesting that using the AR-assisted PBL paradigm is more successful than learning without AR support. Students' capacity to give straightforward explanations, develop core skills, draw conclusions, provide further explanations, and come up with plans and approaches for addressing problems all shown improvements in critical thinking abilities in accordance with Ennis's indicators. Through problem-based learning, students are encouraged to actively discuss, ask questions, and solve problems based on the concepts they have learned. AR media helps visualize abstract concepts more concretely and enhances students' conceptual understanding, particularly regarding the dynamics of motion. Thus, the implementation Utilizing the AR-assisted PBL paradigm is seen to be successful in enhancing students' capacity for critical thought.

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