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# Development and Evaluation of a Multi-Methods Discovery Learning Strategy to Enhance Students' Critical Thinking Skills in Physics

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***Abstract –*** *Critical thinking is one of the essential competencies in physics education because it enables students to analyze phenomena, evaluate evidence, and draw logical conclusions in scientific learning. However, students' critical thinking skills in physics remain relatively low, partly because instructional practices are still often dominated by single-method and teacher-centered approaches. This study aimed to develop and evaluate a multi-methods discovery-learning strategy to enhance senior high school students' critical thinking skills in physics. The study employed a research and development approach using the ASSURE instructional design model, followed by a quasi-experimental posttest-only control group design. The participants were 64 eleventh-grade students in the physics specialization program at a public senior high school in Majene, Indonesia, divided into an experimental group and a control group, with 32 students in each class. The instruments included expert validation sheets, a learning implementation observation sheet, teacher and student response questionnaires, and a critical thinking skills test. Data were analyzed using descriptive analysis, Aiken's V, and an independent samples t-test with the assistance of SPSS version 26. The results showed that the developed strategy met the criteria of validity, practicality, and effectiveness. Expert judgment indicated that the learning materials and instruments were valid, while teacher and student responses confirmed the strategy's practicality. Furthermore, the t-test results revealed a statistically significant difference in critical thinking scores between the experimental and control groups. The novelty of this study lies in the systematic integration of expository, practicum, trial, and simple research methods within a structured discovery learning framework. In conclusion, the multi-methods discovery learning strategy is effective in improving students' critical thinking skills. It makes a meaningful contribution to physics education by providing an integrative, student-centered instructional approach.*

**Keywords:** *critical thinking; discovery learning; physics education; learning strategy; high school*

## I. INTRODUCTION

Physics is a branch of natural science that examines matter, energy, and their interactions in space and time through objective, quantitative methods. It investigates natural phenomena across microscopic and macroscopic scales through observation, measurement, modeling of relationships among variables, and the formulation of scientific laws and principles. As a fundamental science, physics also underpins the development of other scientific disciplines and modern technological advancement. Therefore, physics learning should not merely emphasize conceptual mastery but also foster students' ability to interpret natural phenomena and apply scientific knowledge in real-world contexts. One important component of physics learning is the ability to use measuring instruments accurately and effectively, such as vernier calipers, micrometer screw gauges, stopwatches, and multimeters. Mastery of these tools not only facilitates conceptual understanding but also promotes scientific attitudes, precision, and students' critical thinking through direct measurement activities in inquiry-oriented learning (Sakliressy et al., 2021). Practical activities involving observation, measurement, and data analysis have likewise been shown to improve scientific skills, including observation, data interpretation, and appropriate decision-making (Suryadi et al., 2021).

Several studies indicate that the ability to use measuring instruments in physics learning is closely associated with improvements in students' scientific literacy. Participation in experimental activities can strengthen students' observational skills, data analysis, and scientific reasoning, enabling them to connect theoretical concepts with authentic phenomena (Husna et al., 2022). In addition, developing appropriate instructional strategies is necessary to cultivate critical thinking skills relevant to the demands of twenty-first-century learning (Erdogan, 2019). Critical thinking is one of the major goals of science education. At the senior high school level, physics learning is expected not only to provide conceptual understanding but also to train students to think analytically, logically, and systematically in solving scientific problems (Kassiavera et al., 2024; Neswary et al., 2023). In the context of the national curriculum, physics learning is also intended to engage students in simple scientific investigations through activities such as formulating problems, developing hypotheses, designing experiments, collecting and analyzing data, and drawing scientific conclusions (BSKAP, 2022).

Accordingly, critical thinking constitutes an essential competency that should be systematically developed in physics learning (Denny et al., 2020). However, previous studies have shown that students' critical thinking skills in physics remain relatively low. Research findings indicate that students' motivation to learn, responsibility, discipline, and critical thinking skills in physics remain in the moderate range, although these variables are positively related to one another (Dewanthikumala et al., 2021). International evidence also suggests that Indonesian students' critical thinking and scientific literacy require substantial improvement. According to the 2022 report by the Organization for Economic Co-operation and Development's Program for International Student Assessment (PISA), Indonesian students' performance in reading, mathematics, and science remains below the OECD average. This condition implies that students' scientific reasoning and critical thinking skills have not yet developed to an optimal level. One factor contributing to this issue is the continued dominance of teacher-centered instruction. Learning that relies mainly on lectures, question-and-answer sessions, and assignments tends to limit students' active engagement in analytical and problem-solving processes, thereby constraining the development of critical thinking skills (Dina et al., 2024; Uminingsih & Lestari, 2019).

This problem is also reflected in the local context of physics learning in West Sulawesi. Based on data collected by the researcher in 2024 from several senior high school physics teachers, students' critical thinking scores in physics over the previous two years ranged only from 60 to 70 (Marisda et al., 2024; Yulvinamaesari et al., 2026; Zaidah et al., 2018). Findings from unstructured interviews further revealed that efforts to foster students' critical thinking had generally been limited to using learning media such as video presentations, problem-solving exercises, and group discussions, as well as implementing the Problem-Based Instruction model. These findings suggest that physics teachers in West Sulawesi have not yet optimized the structured use of instructional methods, including expository teaching, laboratory practicum, experiments, and hands-on activities, to achieve the goals of physics learning, particularly to enhance students' critical thinking. Furthermore, a preliminary study conducted by the researcher, involving 711 senior high school students across the province, showed an average critical-thinking score of 18.61 out of 40, confirming that students' critical-thinking skills remain low.

In addition, approximately 82% of students obtained scores below the conversion benchmark of 75.00. These findings indicate that most students still experience difficulties in analyzing, evaluating, and drawing conclusions from information critically in physics learning. Document analysis of teaching modules used by teachers also revealed that several important stages of discovery-based learning had not been implemented optimally, particularly data collection through experimentation, analysis of experimental results, and formulation of conclusions based on empirical findings. This suggests that discovery learning strategies in physics classrooms have not yet been implemented comprehensively. Previous studies have shown that discovery learning can improve students' critical thinking skills by encouraging them to construct concepts independently through exploration and scientific investigation (Ridwan, 2021; Ramadhani & Ratnawulan, 2022). Experimental activities in physics learning have also been reported to strengthen critical thinking by promoting analytical reasoning, logical thinking, and problem-solving abilities (Delisa & Akhdinirwanto, 2022; Nugroho & Waslam, 2020). Similarly, laboratory activities that emphasize experimental skills positively affect students' development of critical thinking (Walsh et al., 2022; Rini & Aldila, 2023).

Despite these findings, most previous studies have focused on implementing a single instructional model or method in isolation. Studies that explicitly employ a multi-methods, discovery-based strategy in physics learning remain limited. Nevertheless, several prior works are conceptually relevant to this approach. One study compared several instructional methods, including multiple intelligences, problem-based learning, peer instruction, and a combination of methods, and found that the combined-method group showed greater improvements in student engagement and science process skills than groups exposed to a single method. These findings indicate that the simultaneous use of multiple instructional methods can improve the quality of learning. Another study by Sahara et al. (2020) reported that discovery learning supported by multiple representations was more effective in improving students' conceptual understanding. Together, these studies provide a theoretical basis for the argument that integrating several instructional methods within a systematic strategy may improve both the learning process and students' critical thinking skills.

In this study, the term multi-methods discovery learning strategy refers to a discovery-oriented instructional approach that integrates several teaching methods within a coherent learning framework. Grounded in discovery learning and constructivist principles, this strategy promotes students' active engagement through exploration, experimentation, demonstration, and scientific discussion, strengthening conceptual understanding and critical thinking skills. This study, therefore, contributes to the physics education literature by proposing and validating an integrative learning strategy supported by appropriate instructional materials and assessment instruments.

The development of learning media, instructional modules, and critical-thinking assessment instruments can help teachers identify and systematically foster students' critical-thinking skills (Hanicza et al., 2021; Barus et al., 2020; Abdulah & Wangid, 2021). Various learning models, such as Problem-Based Learning, inquiry learning, project-based learning, and discovery learning, have also been shown to improve critical thinking by encouraging students' active involvement in the learning process (Dewi et al., 2023). Discovery learning has been reported to significantly improve students' critical thinking skills compared with conventional instructional approaches (Nursakinah & Suyanta, 2023; Septiany et al., 2024).

However, most previous studies still emphasize the use of a single instructional method. There is, therefore, a clear need to develop a more integrative instructional strategy that combines several relevant teaching methods within a systematic learning framework. In response to this gap, the present study aims to develop a multi-methods, discovery-based physics learning strategy to improve senior high school students' critical thinking skills. The development process employs the ASSURE model, which consists of Analyze Learners, State Objectives, Select Methods, Media and Materials, Utilize Media and Materials, Require Learner Participation, and Evaluate and Revise. The ASSURE model was selected because it provides a systematic and student-centered framework for designing effective instruction (Lubis & Maulida, 2024). In addition, this model has been shown to support the development of students' critical and creative thinking skills in science learning (Batır & Sadi, 2021; Roviati & Widodo, 2019).

Although numerous studies have investigated discovery learning in physics education, most have employed only a single instructional method, which may limit the breadth of pedagogical support available to learners. Learning is complex, multidimensional, and contextual, involving diverse cognitive activities among students that require support from a range of instructional methods. Therefore, this study develops a multi-methods discovery-based physics learning strategy through the ASSURE model to systematically integrate expository instruction, practicum, trial activities, and experiments within a structured discovery learning framework. The novelty of this study lies in the systematic integration and pedagogical sequencing of these methods at each stage of discovery learning, allowing each method to play a complementary role in facilitating concept exploration, empirical data collection and analysis, and concept verification and generalization. Through this approach, the developed strategy is expected to provide a more comprehensive and meaningful learning experience in enhancing senior high school students' critical thinking skills. Therefore, this study aims to develop and examine the validity, practicality, and effectiveness of a multi-methods discovery-based physics learning strategy to improve senior high school students' critical thinking skills.

## II. METHODS

This study employed a research and development approach to design and evaluate a multi-methods discovery learning strategy in physics intended to enhance senior high school students' critical thinking skills. The development process was guided by the ASSURE instructional design model, selected for its systematic, learner-centered framework for integrating instructional methods, media, materials, and assessment into classroom practice (Lubis & Maulida, 2024). In addition, the ASSURE model has been reported to support the development of higher-order thinking, including critical and creative thinking, in science learning contexts (Batır & Sadi, 2021; Roviati & Widodo, 2019). In the present study, the model was operationalized through the following stages: analyzing learners; stating objectives; selecting methods, media, and materials; utilizing media and materials; requiring learner participation; and evaluating and revising the developed strategy. The overall development framework is presented in Figure 1.

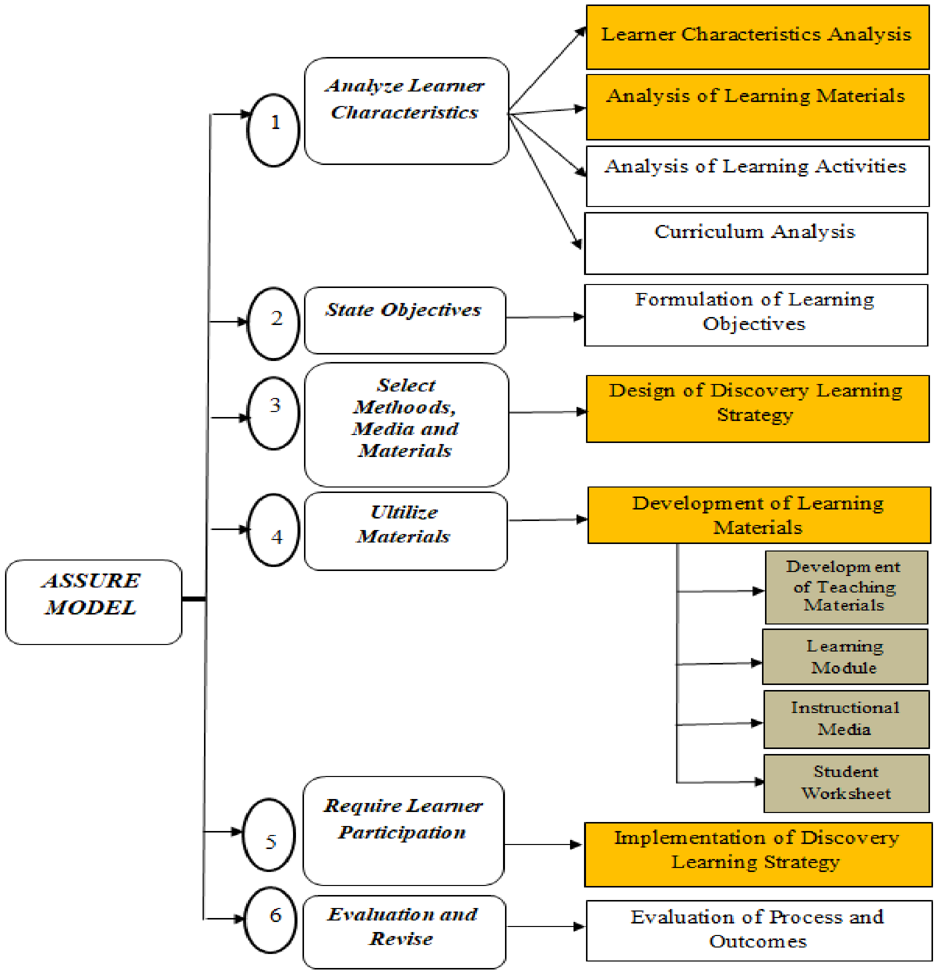


**Figure 1.** Development framework of multi-methodss discovery-based physics learning materials based on the ASSURE instructional design model

The study was conducted at a public senior high school in Majene, Indonesia, during the 2025/2026 academic year. The participants were eleventh-grade students enrolled in the physics specialization program. The population consisted of three classes, from which two classes were selected through simple random sampling. Each selected class consisted of 32 students. Because the intervention was implemented at the classroom level, the two classes were randomly assigned to the experimental and control groups to reduce potential treatment bias. The experimental group received instruction using the developed multi-methods discovery learning strategy, whereas the control group was taught using the teacher's conventional discovery learning strategy. Information obtained from the classroom teacher, along with students' prior academic records, indicated that the two groups had comparable academic ability before the intervention.

Nevertheless, because the sample was drawn from a single school and a specific academic track, the findings should be interpreted in the context of students with relatively homogeneous cognitive characteristics in physics.

Following the development phase, the strategy's effectiveness was examined using a quasi-experimental posttest-only control group design, adapted from Sugiyono (2019). This design was chosen to compare students' critical thinking skills following the implementation of the developed strategy, without altering the main structure of classroom instruction. In this design, the experimental group received the developed multi-methods, discovery-based instruction, whereas the control group received the teacher's conventional discovery-learning strategy. At the end of the intervention, both groups completed a posttest designed to measure critical thinking skills. The design of the experiment is illustrated in Figure 2.

| | | |
|---|---|---|
| R | X | O1 |
| R | - | O2 |

(1)

(Sugiyono, 2019)

**Figure 2.** Posttest-only control group design

The study employed five main instruments, namely an expert validation sheet, a student response questionnaire, a teacher response questionnaire, a learning implementation observation sheet, and a critical thinking skills test. These instruments were used to evaluate the validity, practicality, and effectiveness of the developed learning strategy. The expert validation sheet was administered to assess the appropriateness of the developed learning materials and research instruments in terms of content, language, and instructional relevance. The student and teacher response questionnaires were used to assess the strategy's practicality and acceptability during classroom implementation. In contrast, the observation sheet was used to assess the extent to which the learning procedures were implemented as intended. The critical thinking skills test served as the primary outcome measure to assess the effect of the developed strategy on students' critical-thinking performance.

The validity of the learning materials and instruments was established through expert judgment using Aiken's V coefficient, following Aiken's (1985) procedure. This coefficient was used to estimate the degree of agreement among validators regarding the relevance of each item to the intended construct. In this study, the developed materials and instruments were considered valid when the resulting coefficient met the researchers' criterion for acceptability. Before being administered in the main study, the critical thinking test was also empirically validated to assess item appropriateness. Item validity was analyzed using the Pearson product-moment correlation, and only valid items were retained for the main implementation. The reliability of the final test was then examined using the Kuder–Richardson 20 formula to ensure internal consistency.

Data collection was carried out during the implementation of the developed learning strategy in classroom settings. One physics teacher served as the model teacher, while two other physics teachers acted as observers to strengthen the credibility of the implementation process. During the field trial, data were gathered from classroom observations, expert validation results, teacher and student questionnaire responses, and students' posttest scores. The implementation phase was intended not only to test the instructional feasibility of the strategy but also to examine whether the learning materials were sufficiently clear, readable, and appropriate for use in actual classrooms.

The data were analyzed using both qualitative and quantitative procedures. Qualitative analysis was applied to the expert validation results to describe the feasibility of the developed materials and instruments based on the validators' judgments. Quantitative analysis was used to interpret teacher and student responses using a four-point Likert scale, with score interpretation criteria adapted from Sugiyono (2019) and presented in Table 1.

**Table 1**. Interpretation criteria of Likert scale scores

| No | Score interval | Interpretation |
|---|---|---|
| 1 | 3.26 – 4.00 | Very relevant |
| 2 | 2.51 – 3.25 | Relevant |
| 3 | 1.76 – 2.50 | Less relevant |
| 4 | 1.00 – 1.75 | Not relevant |

To test the effectiveness of the developed strategy, students' posttest scores from the experimental and control groups were compared using an independent-samples t-test in IBM SPSS Statistics. This analysis was conducted to determine whether the multi-methods discovery-based learning strategy produced a statistically significant difference in students' critical thinking skills compared with the conventional instructional approach.

## III. RESULTS

Interviews with three physics teachers teaching tenth-grade classes across three public senior high schools in Tebo Regency revealed that classroom instruction remained dominated by conventional, teacher-centered practices. The teachers primarily relied on textbooks, PowerPoint slides, and static videos, with limited implementation of experimental or inquiry-based activities. These practices restricted students' opportunities to explore and generate creative ideas. Although teachers acknowledged the practicality of these methods, they admitted that such approaches failed to stimulate students' curiosity and imagination. Teachers also highlighted that renewable energy topics were among the most difficult to teach due to their abstract nature and lack of direct visualization. One teacher noted that students only see solar cells in pictures; they never explore how sunlight is converted into electricity. Teachers further observed that their students often demonstrated algorithmic rather than divergent problem-solving tendencies, as students tended to wait for sample problems and rarely attempted alternative approaches.

This section presents the study's findings on the design, validity, and effectiveness of the developed multi-methods discovery learning strategy in physics. The results are organized into three main parts: the design of the developed strategy, the content validity of the learning devices and research instruments, and the strategy's effect on students' critical thinking skills. Overall, the findings indicate that the developed strategy meets validity criteria and supports the improvement of students' critical thinking skills in physics learning.

### 3.1 Design of the multi-methods discovery learning strategy in physics

The results of the document analysis showed that the conventional discovery-based physics learning strategies implemented by teachers primarily emphasized the application of concepts, formulas, and process skills. However, this emphasis had not yet effectively facilitated the development of students' critical thinking skills, particularly in interpretation, analysis, evaluation, and inference. Based on these findings, this study designed a multi-methods discovery learning strategy to optimize the development of students' critical thinking skills in physics.

The developed strategy integrates several instructional methods into a structured discovery learning framework. Each method was assigned a specific pedagogical function to support the gradual development of critical thinking skills. As presented in Table 2.

**Table 2.** Stages of developing a multi-methods discovery learning strategy

| Stage | Method | Objective | Procedure | Developed indicator(s) |
|---|---|---|---|---|
| 1 | Expository | Enhancing students' conceptual understanding of physics | 1. The teacher presents a physics phenomenon<br>2. Explains basic concepts<br>3. Formulates triggering questions/ guiding questions | Understanding initial concepts to train the interpretation indicator |
| 2 | Practicum | Developing students' process skills | 1. Students follow the practicum procedure<br>2. Conduct the practicum in groups<br>3. Compare the results with the theoretical predictions | The ability to assess data and concepts to train the evaluation indicator |

| | | | | |
|---|---|---|---|---|
| 3 | Trial | Training students to discover concepts, principles, and laws | 1. Students conduct a simple experiment<br>2. Collect observational data and engage in discussion<br>3. Record the relationships between variables and the observed phenomena | Connecting concepts with empirical facts to train the analysis indicator |
| 4 | Experiment (simple research) | Developing students' critical thinking skills | 1. Students design an experiment<br>2. Collect and analyze data<br>3. Present the experimental results and engage in discussion | High-level critical thinking skills to train the inference indicator |
| 5 | Evaluation/ reflection | Measuring students' critical thinking skills | Preparing a non-numerical (contextual) competency-based assessment instrument. | Assessing critical thinking skills using Facione's four indicators |

The strategy begins with the expository method to strengthen students' initial conceptual understanding through the presentation of physics phenomena, the explanation of fundamental concepts, and the use of guiding questions. This stage is intended to support the interpretation aspect of critical thinking. The second stage employs practicum activities to develop students' process skills through group-based practical work and comparison between empirical results and theoretical predictions, thereby supporting the evaluation aspect. The third stage involves trial activities in which students conduct simple experiments, collect observational data, and discuss the relationships between variables and observed phenomena. This stage is designed to strengthen the analysis aspect of critical thinking. The fourth stage focuses on experiment or simple research activities, in which students design experiments, collect and analyze data, and present the results of their investigation. This stage is intended to foster inference skills. The final stage consists of evaluation and reflection through a contextual competency-based assessment aligned with Facione's four indicators of critical thinking. These findings indicate that the developed strategy was systematically structured to align instructional methods with the targeted dimensions of students' critical thinking skills.

### 3.2 Content validity of the developed learning devices

The findings from the expert validation process indicate that all developed learning devices met the required content validity criteria. The assessed components included teaching materials, lesson plans, student worksheets, and learning media. Across these components, Aiken's V values exceeded the minimum validity threshold, indicating that the developed learning devices were considered valid in terms of content, presentation, language, and instructional coherence. These findings suggest that integrating the multi-methods strategy into the developed learning devices was pedagogically appropriate and theoretically acceptable for classroom implementation. The content validity results for the teaching materials are presented in Table 3.

**Table 3.** Content validity results of teaching materials

| No | Aspect | Aiken's V | Category |
|---|---|---|---|
| 1 | Module cover layout and typography | 0.93 | Valid |
| 2 | Module content design | 0.82 | Valid |
| 3 | Content accuracy and relevance | 0.96 | Valid |
| 4 | Material organization | 0.89 | Valid |
| 5 | Module completeness | 0.87 | Valid |
| 6 | Integration of a multi-methods strategy | 0.94 | Valid |
| 7 | Language clarity | 0.89 | Valid |
| 8 | Dialogic and interactive features | 0.89 | Valid |

All assessed aspects obtained Aiken's V values above 0.80, indicating that the teaching materials met the content validity criteria. The highest score was for content accuracy and relevance (0.96), while the lowest was for module content design (0.82). Based on expert feedback, revisions were made by adding user instructions, material summaries, and a glossary of key terms, and by improving the clarity of several visual elements. These results indicate that the teaching materials were considered sufficiently valid to support the implementation of the developed learning strategy. The expert evaluation results for the lesson plans are shown in Table 4.

**Table 4.** Content validity results of the lesson plans

| No | Aspect | Aiken's V | Category |
|---|---|---|---|
| 1 | Format | 0.89 | Valid |
| 2 | Language | 0.78 | Valid |
| 3 | Content | 0.81 | Valid |
| 4 | Assessment | 0.85 | Valid |

All assessed aspects were categorized as valid. The format aspect received the highest score (0.89), while the language aspect received the lowest (0.78). Revisions based on validators' suggestions included adding performance observation instruments, incorporating essay questions on higher-order thinking skills, and integrating deep learning concepts into the assessment instruments. These results indicate that the lesson plans were deemed valid and appropriate to support the classroom implementation of the developed strategy. The validity results for the student worksheets are presented in Table 5.

**Table 5.** Content validity results of the student worksheets

| No | Aspect | Aiken's V | Category |
|---|---|---|---|
| 1 | Content | 0.91 | Valid |
| 2 | Language | 0.91 | Valid |

Both assessed aspects, namely content and language, obtained Aiken's V values of 0.91, indicating that the worksheets met the required validity criteria. Based on expert suggestions, minor revisions were made to improve the clarity of task instructions and the presentation of worksheet activities. This finding indicates that the student worksheets were considered valid and suitable for use in the learning process. The validation results for the learning media are presented in Table 6.

**Table 6.** Content validity results of learning media

| No | Aspect | Aiken's V | Category |
|---|---|---|---|
| 1 | Format and components | 0.85 | Valid |
| 2 | Content | 0.82 | Valid |
| 3 | Language | 0.78 | Valid |

All aspects were categorized as valid, with the highest score found in format and components (0.85), followed by content (0.82), and language (0.78). Based on validators' feedback, revisions were made by adding brainstorming slides, learning objective slides, case examples, student activity slides, and conclusion slides to support instructional implementation. These results indicate that the learning media were considered valid and capable of supporting the multi-methods discovery-learning process.

### 3.3 Validity of the research instruments

The results of the validation process also indicate that all research instruments met acceptable validity criteria. These instruments included the critical thinking skills test, the learning implementation observation sheet, the teacher response questionnaire, and the student response questionnaire. The validity findings support the use of these instruments in evaluating the quality and effectiveness of the developed strategy.

The critical thinking skills test instrument was developed based on Facione's indicators of critical thinking, namely interpretation, analysis, evaluation, and inference. The content validity analysis using Aiken's V showed that all items obtained a validity coefficient of 0.83, indicating that the instrument met the validity criteria based on expert judgment. Following the content validation stage, the instrument, which originally consisted of 48 multiple-choice items, was piloted with Grade XII students. The empirical validation results showed that 32 items were valid, while 16 items were invalid and excluded from further use. Reliability analysis using the Kuder–Richardson 20 formula yielded a coefficient of 0.87, indicating very high reliability. Therefore, the 32 valid items were retained as the final instrument for measuring students' critical thinking skills following the strategy's implementation. The validity results of the learning implementation observation sheet are presented in Table 7.

**Table 7.** Content validity results of the learning implementation observation sheet

| No | Aspect | Aiken's V | Category |
|---|---|---|---|
| 1 | Instructions | 1.00 | Valid |
| 2 | Language | 1.00 | Valid |
| 3 | Content | 0.83 | Valid |
| 4 | Layout | 0.83 | Valid |

The Aiken's V values ranged from 0.83 to 1.00, indicating that all assessed aspects were valid. The instruction and language aspects obtained the highest scores (1.00), while the content and layout aspects each obtained 0.83. Minor revisions were made to improve the clarity of several assessment indicators. Overall, the observation sheet was considered valid and suitable for monitoring the implementation of the learning process. The validity results of the teacher response questionnaire are presented in Table 8.

**Table 8.** Content validity results of the teacher response questionnaire

| No | Aspect | Aiken's V | Category |
|---|---|---|---|
| 1 | Instructions | 0.94 | Valid |
| 2 | Response aspects | 0.96 | Valid |
| 3 | Language | 1.00 | Valid |

The Aiken's V values ranged from 0.94 to 1.00, indicating that all aspects met the validity criteria. The language aspect obtained the highest score (1.00), followed by the response aspect (0.96) and the instruction aspect (0.94). Based on validators' input, minor revisions were made to improve the wording of several items. These findings indicate that the instrument was valid and appropriate for data collection. The student response questionnaire also demonstrated satisfactory validity, as shown in Table 9.

**Table 9.** Content validity results of the student response questionnaire

| No | Aspect | Aiken's V | Category |
|---|---|---|---|
| 1 | Objectives | 1.00 | Valid |
| 2 | Content | 1.00 | Valid |
| 3 | Language | 0.83 | Valid |

All aspects obtained Aiken's V values above 0.80. The objectives and content aspects each obtained 1.00, while the language aspect obtained 0.83. Minor revisions were made to improve the clarity of several statements. Overall, the student response questionnaire was categorized as valid and feasible for use in this study.

### 3.4 Results of students' critical thinking skills test

The posttest results indicate a clear difference in students' critical thinking skills between the experimental and control groups. Students who were taught using the developed multi-methods discovery-based learning strategy demonstrated higher critical-thinking performance compared to those who received conventional discovery-based instruction. This finding suggests that the integration of multiple instructional methods within a structured discovery learning framework contributes positively to students' higher-order thinking development.

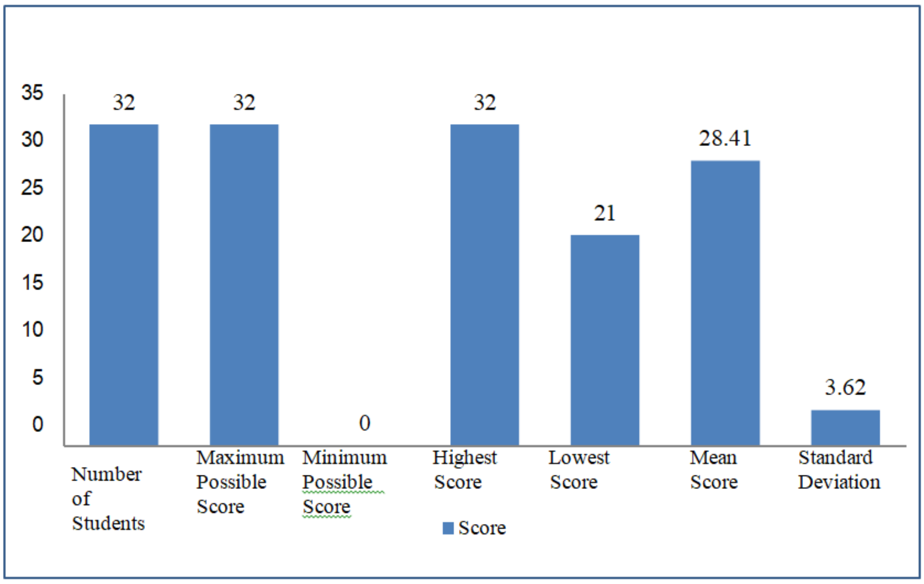


**Figure 3.** Bar chart of students' critical thinking scores in the experimental group

Figure 3 presents the distribution of students' critical thinking scores in the experimental group. The data show that all 32 students participated in the assessment, with a maximum possible score of 32 and a minimum possible score of 0. The highest score achieved by students in this group was 32, while the lowest score was 21. The mean score was 28.41, indicating a high level of critical-thinking performance among students exposed to the multi-methods strategy. In addition, the standard deviation of 3.62 suggests that the variation in students' scores was relatively low, meaning that most students performed consistently well. Overall, the distribution reflects that the majority of students in the experimental group achieved scores close to the maximum, highlighting the effectiveness of the implemented learning strategy.

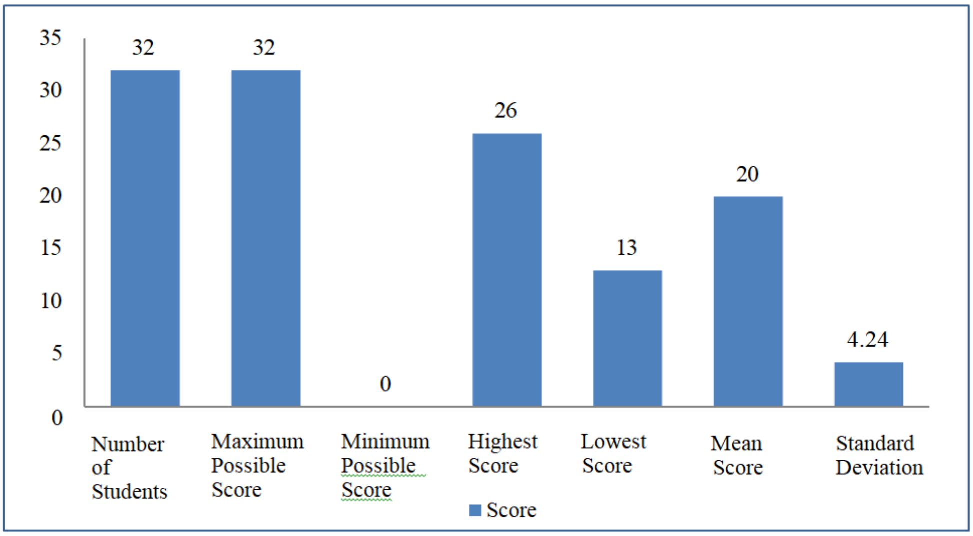


**Figure 4.** Bar chart of students' critical thinking scores in the control group

Figure 4 shows the distribution of students' critical thinking scores in the control group. Similar to the experimental group, all 32 students completed the test, with the same maximum and minimum possible scores. However, the highest score obtained in this group was only 26, and the lowest score was 13, indicating a wider gap in student performance. The mean score of 20.00 is considerably lower than the experimental group's, suggesting that students in the control group demonstrated weaker critical thinking skills. Furthermore, the standard deviation of 4.24 indicates greater variability in student performance, meaning that students' abilities were more unevenly distributed. This distribution implies that conventional discovery-based instruction was less effective at promoting consistent critical-thinking outcomes. The descriptive statistics of students' critical thinking scores in both groups are summarized in Table 10.

**Table 10.** Independent-samples statistics for critical thinking scores

| No | Group | N | Mean | Std. deviation | Std. error mean |
|---|---|---|---|---|---|
| 1 | Experimental group | 32 | 28.41 | 3.618 | 0.640 |
| 2 | Control group | 32 | 20.00 | 4.235 | 0.749 |

Table 10 presents the independent-samples statistics for both groups. The experimental group, consisting of 32 students, achieved a mean score of 28.41, with a standard deviation of

3.618 and a standard error of the mean of 0.640. In contrast, the control group, which also consisted of 32 students, obtained a mean score of 20.00, with a standard deviation of 4.235 and a standard error of the mean of 0.749. These results clearly demonstrate that students in the experimental group outperformed those in the control group in terms of critical thinking skills. The higher mean score, combined with lower variability, indicates not only better overall performance but also more consistent achievement among students exposed to the multi-methods discovery-based learning strategy

These findings indicate that the experimental group outperformed the control group in terms of critical thinking achievement. The higher mean score of the experimental group suggests that the developed multi-methods discovery learning strategy was more effective at facilitating students' critical thinking skills than the conventional discovery learning strategy implemented in the control group. This difference was further supported by the independent samples t-test, which showed a statistically significant difference between the two groups ($p < 0.05$). Therefore, the results provide empirical evidence that the developed strategy contributed positively to students' critical thinking skills in physics learning.

## IV. DISCUSSION

The findings of this study indicate that the developed multi-methods discovery learning strategy contributed positively to the improvement of students' critical thinking skills in physics. Students in the experimental group achieved higher critical-thinking scores than those in the control group, suggesting that the developed strategy created a more effective instructional environment for promoting higher-order thinking. This result is consistent with the general view that instructional approaches emphasizing active learning, investigation, and concept construction are more likely to foster critical thinking than teacher-centered approaches. In the present study, the integration of several instructional methods within a discovery learning framework appears to have enabled students to engage more intensively in processes of interpreting information, analyzing relationships among variables, evaluating evidence, and drawing conclusions from empirical findings. These processes are central to critical thinking and directly correspond to the indicators adopted in this study.

One important explanation for these findings can be derived from discovery learning theory. Discovery learning emphasizes students' active involvement in constructing knowledge through exploration, questioning, experimentation, and independent meaning-making. In physics learning, such an approach is particularly relevant because understanding physical concepts often requires students to connect abstract ideas with observable phenomena. When students are encouraged to discover principles through structured learning experiences rather than merely receiving explanations, they are more likely to develop analytical and reflective ways of thinking. In this study, the developed strategy extended the conventional discovery learning model by embedding multiple instructional methods into a coherent pedagogical sequence. As a result, students not only encountered concepts abstractly but also interacted with them through observation, practicum, trial activities, and simple research. This broader instructional structure may explain why students in the experimental group demonstrated stronger critical thinking performance.

From a constructivist perspective, the effectiveness of the developed strategy can also be understood because of meaningful cognitive engagement. Constructivist learning theory posits that learners actively construct knowledge through interaction with experiences, prior understanding, and social contexts. The multi-methods discovery learning strategy developed in this study provided students with opportunities to actively process information through a range of learning activities, including guided exploration, discussion, practical work, and experimentation. Such activities likely facilitated deeper conceptual processing because students were required not only to receive information, but also to test ideas, interpret evidence, and negotiate meaning collaboratively. In this sense, the strategy functioned not merely as a sequence of classroom activities but as an environment that supported the active construction of knowledge and the refinement of reasoning processes.

The improvement in students' critical thinking skills may also be associated with the complementary roles of the instructional methods integrated into the strategy. The expository component helped students build initial conceptual understanding and establish a foundation for subsequent inquiry. The practicum component provided opportunities to examine data against theoretical expectations, thereby promoting evaluative thinking. The trial activities encouraged students to observe patterns and relationships, which are closely related to analytical thinking. Furthermore, the experiment or simple research stage required students to formulate procedures, analyze results, and communicate findings, thereby supporting inference and evidence-based reasoning. The effectiveness of the strategy, therefore, does not appear to stem from the use of discovery learning alone, but from the systematic combination and sequencing of multiple methods that addressed different dimensions of critical thinking within a unified instructional framework.

The present findings are consistent with previous studies showing that discovery-oriented and inquiry-based learning can improve students' critical thinking skills and conceptual understanding in science education. Prior research has shown that learning environments emphasizing active participation, exploration, and investigation tend to facilitate deeper learning and stronger higher-order cognitive performance (Ridwan, 2021; Ramadhani & Ratnawulan, 2022). Similarly, studies on experimental and laboratory activities in physics have demonstrated their positive contributions to students' development of analytical reasoning and critical thinking (Delisa & Akhdinirwanto, 2022; Nugroho & Waslam, 2020; Walsh et al., 2022; Rini & Aldila, 2023). The results of the present study reinforce these findings by showing that integrating multiple instructional methods within a discovery-based framework can further strengthen the learning process. In this regard, the study extends existing literature not by rejecting earlier findings, but by offering a more integrative instructional formulation that combines several relevant methods within a systematically designed strategy.

Another important finding of this study concerns the practicality and feasibility of the developed strategy. Positive responses from teachers and students indicate that the strategy was not only pedagogically meaningful, but also implementable in actual classroom settings. This is a significant point because the success of an instructional innovation depends not only on its theoretical soundness but also on its usability in real educational practice. The structured stages of the strategy, the alignment between activities and critical thinking indicators, and the support provided through learning materials and assessment instruments appear to have helped teachers implement the learning process more effectively. At the same time, students were positioned as active participants who observed, discussed, tested, and reflected on physics concepts. These conditions likely contributed to the positive classroom atmosphere observed during implementation and to the stronger learning outcomes achieved by the experimental group.

Despite these promising findings, the interpretation of the results should be considered within the scope of the study design. The participants were drawn from a single school and one academic specialization, which may limit the generalizability of the results to broader educational contexts. In addition, the effectiveness of the strategy was examined within a specific physics topic and over a particular implementation period. Therefore, although the findings provide evidence that the multi-methods discovery learning strategy can enhance students' critical thinking skills, further studies are needed to examine its application across different physics topics, school settings, and student characteristics. Broader implementation would be valuable for assessing the strategy's consistency and transferability.

Overall, the findings suggest that the developed multi-methods discovery-learning strategy makes a meaningful contribution to physics learning by creating a more engaging, inquiry-oriented, and cognitively demanding classroom environment. Through the systematic integration of expository instruction, practicum, trial activities, and simple research within a discovery learning framework, the strategy supports students in interpreting information, analyzing evidence, evaluating results, and drawing logical conclusions. These outcomes indicate that the strategy has strong potential as an effective instructional approach for improving students' critical thinking skills in physics education.

## V. CONCLUSION AND SUGGESTION

This study developed and evaluated a multi-methods discovery-based physics learning strategy to enhance senior high school students' critical thinking skills. The findings show that the developed strategy met the criteria of validity, practicality, and effectiveness. Expert validation confirmed the validity of the learning materials and research instruments, and the implementation results demonstrated the strategy's practicality, as evidenced by positive responses from both teachers and students. In addition, the effectiveness test revealed a statistically significant difference in critical thinking skills between the experimental and control groups, indicating that the multi-methods discovery learning strategy contributed to improving students' critical thinking skills in physics learning.

Despite these promising findings, this study has several limitations. The participants were drawn from a single school and a specific academic track, which may limit the generalizability of the findings to other educational contexts. In addition, the implementation was conducted within a specific physics topic and over a limited period. Therefore, future research is recommended to examine the application of this strategy across different physics topics, school contexts, grade levels, and broader samples to confirm its broader effectiveness and adaptability. This study contributes to the field of physics education by offering an integrative instructional strategy that systematically combines multiple teaching methods within a discovery-learning framework to support the development of students' critical-thinking skills. Practically, the study also provides teachers with a structured instructional alternative and supporting learning materials that may facilitate more active, meaningful, and student-centered physics learning.

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