

*International Journal of Learning, Teaching and Educational Research*  
Vol. 24, No. 8, pp. 1076-1091, August 2025  
<https://doi.org/10.26803/ijlter.24.8.48>  
Received May 23, 2025; Revised Jul 17, 2025; Accepted Aug 12, 2025

## The Influence of Problem-Solving-Based Physics Learning Models on Students' Critical Thinking Ability and Learning Independence on the Achievement of SDG 4

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**Abstract.** Critical thinking and independent learning are two equally important abilities that students need if they are to support the achievement of Sustainable Development Goals (SDGs), especially SDG 4, which relates to improving the quality of education. This study aimed to determine the influence of a problem-solving-based physics learning model on students' critical thinking skills and learning independence. This study used a quasi-experimental method with a nonequivalent control group of 60 physics students who had been recruited by purposive sampling; each group comprised 30 students. Data on students' critical thinking skills were collected through a written test with a multiple-choice format accompanied by reasons for selecting a certain answer, and data on learning independence were collected through questionnaires. Research data were analyzed with descriptive statistical tests and *t*-tests. After the intervention, the results showed that the average critical thinking ability score of the experimental group was 85.30, and that of the control group was 70.50. In addition, the average student learning independence in the experimental group was 4.16, and for the control group, 3.35. The findings of this study indicate that a physics learning model based on problem-solving significantly affected students' critical thinking skills and learning independence, at a significance level of .05. This research makes an important contribution to improving the quality of education, especially by applying the physics learning model, which can enhance students' ability to think critically and learn autonomously, thereby contributing to advancing education quality, and aligning with SDG 4 in the Indonesian context. It is recommended that further research is conducted to apply this model to various academic disciplines, and over a longer time frame.

**Keywords:** physics learning model; problem-solving; critical thinking; independent learning; SDG 4

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## 1. Introduction

Improving the quality of learning remains a central challenge in higher education, because many students still exhibit poor critical thinking skills and low learning independence. This issue is directly related to Sustainable Development Goal (SDG) 4, which is oriented to achieving inclusive, good quality education and equipping learners with essential 21st-century skills for lifelong learning and employability. Critical thinking skills are among the main skills needed in today's era of information and globalization. Thinking critically enables individuals to process information impartially, make sound judgments, and address challenges with effective solutions (Goodsett, 2020; Julmi, 2019; Raj et al., 2022). Improving students' critical thinking skills is one of the important goals that must be achieved in the 21st century to realize the SDGs, especially SDG 4, which relates to the quality of education—in the case of this study, in Indonesia, specifically (Bappenas, 2024).

SDG 4, as a core component of the SDGs globally, highlights the importance of providing equitable access to education, ensuring education is of good quality, and promoting lifelong learning opportunities for all. Specifically, Target 4.4 of SDG 4 focuses on enhancing relevant skills of youths and adults; these skills include high-level cognitive skills such as critical thinking and problem-solving, which are essential for employability and lifelong learning.

However, the reality in the field is that many students find it difficult to think critically, especially when they are faced with problems that require analytical and evaluative thinking. The capacity for critical thinking is not only crucial in academic settings; it also plays a significant role in everyday decision-making and in solving workplace challenges. Critical thinking enables individuals to evaluate various alternatives and make informed decisions based on real and compelling evidence and reasons (Shavelson et al., 2019).

It is important for many facets of life, including career, finances, and personal health. Critical thinking skills assist individuals to identify problems, analyze their causes, and find practical solutions (Kardoyo et al., 2020; Ramdani et al., 2021; Royce et al., 2019). It is a high-level skill that is in high demand in various fields of work, especially those related to technology, science, and management (Braun et al., 2020; Kartikasari et al., 2022; Magarelli, 2024). Critical thinking encourages individuals to consider problems from different perspectives and to find innovative solutions (Škėrienė & Jucevičienė, 2020; Thornhill-Miller et al., 2023). It can enhance students' creativity and ability to innovate, which is particularly important in a constantly changing world in which new challenges arise continuously.

In today's era with its abundance of information, the ability to assess the credibility and relevance of information is essential. Critical thinking enables individuals to filter out inaccurate or biased information and use valid data for decision-making (Ceschi et al., 2019; Dror, 2020). Critical thinking skills are the foundation for many academic activities, such as research, scientific writing, and academic discussion (Liu & Pásztor, 2022; Mahanal et al., 2019). Students with

good critical thinking skills are more successful in their studies and understand complex concepts better. In the context of physics subjects, the ability to think critically is essential because physics is a science that studies natural phenomena and the basic principles that govern the universe (Coccia, 2020; Galili, 2019). Physics often requires students to understand abstract concepts, analyze data, and apply scientific principles to solve puzzles.

The physics students of today face a variety of challenges that affect their critical thinking skills. A curriculum centered on rote memorization and the unidirectional transmission of knowledge, from lecturers to students, without engaging students in complex problem-solving tasks, may impede the cultivation of critical thinking abilities (Sasson et al., 2022; Shanta & Wells, 2022). Conventional learning that tends to be passive is also less effective at honing critical thinking skills (Chusni et al., 2021; Roberts, 2017). The availability of diverse learning resources and advanced education technology can facilitate the development of critical thinking skills (Faridi et al., 2021; Jia & Tu, 2024; Silber-Varod et al., 2019).

However, not all educational institutions can access these resources and technologies adequately. A conducive learning environment that includes support from lecturers and peers can help students develop critical thinking skills (Lorencová et al., 2019; Rusticus et al., 2023). Intensive academic discussions and collaboration on scientific projects can provide experiences that enrich critical thinking skills (Langeveldt et al., 2023; Machado & Carvalho, 2020; Ruiz-Rojas et al., 2024). Participation in scientific research enables physics students to hone their critical thinking skills (Faridi et al., 2021). Through research, students learn to formulate hypotheses, collect and analyze data, and draw conclusions based on existing evidence. Critical thinking skills are also influenced by students' mental readiness and motivation (Berestova et al., 2022; Padilla et al., 2020; Pu et al., 2019). Learners who demonstrate strong motivation and a willingness to consider diverse viewpoints are generally more capable of enhancing their critical thinking abilities.

In addition to critical thinking skills, learning independence is an important aspect that needs to be developed in higher education. Learning independence reflects the capacity of students to manage their learning processes independently, from planning and implementation to learning evaluation (Hill et al., 2020; Zheng et al., 2020). Several empirical studies and theoretical frameworks identify multiple factors that influence students' learning independence. These include internal motivation, self-efficacy, metacognitive awareness, and prior academic experience (Berestova et al., 2022; Hill et al., 2020; Padilla et al., 2020).

External factors, such as the availability of learning resources, teaching strategies that encourage active participation, and support from lecturers and peers, also play significant roles (Lorencová et al., 2019; Rusticus et al., 2023). These factors shape students' ability to plan, monitor, and evaluate their learning process, which is essential for developing independent learning habits. In the context of 21st-century learning, which emphasizes lifelong learning skills, independent

learning is a key skill that enables students to continue learning and adapting amid rapid changes in science and technology (González-Pérez & Ramírez-Montoya, 2022; González-Salamanca et al., 2020; Moore, 2020). Students who have high learning independence tend to be more active in exploring learning resources, are more able to solve problems independently, and exhibit intrinsic motivation to understand complex concepts. Learning independence is also a prerequisite for developing optimal critical thinking skills because independent students are more prepared and open to high-level thinking activities, such as analysis, evaluation, and information synthesis.

In turn, some students are highly dependent on lecturers and are not used to taking the initiative in the learning process, especially at the beginning of lectures. This dependency can impede the development of critical thinking competencies and undermine the effectiveness of active learning methodologies, particularly problem-solving, which inherently require a high degree of learner autonomy and active engagement. Therefore, strengthening learning independence is integral to improving the quality of higher education and is in line with the goals of continuing education as stated in SDG 4.

From the findings of initial observations and empirical data gathered by the researcher as a lecturer in the Department of Physics of a university, early-level physics students tend to struggle to understand the concept of critical thinking. They find it difficult to apply the knowledge and concepts of physics to analyze problems (Riantoni et al., 2017). Lack of practice in solving scientific problems, limited learning resources, biased perceptions, and too little learning time contribute to students' poor critical thinking skills (Franklin et al., 2022). In high school, students were accustomed to memorizing, had poor mastery of concepts, and were poorly trained in critical thinking. A lack of basic knowledge causes difficulties when they are required to solve problems and find alternative solutions.

Therefore, the learning process should require essential critical thinking skills, so that students learn to interpret, analyze, evaluate, integrate, explain, and organize themselves to find alternative solutions and make decisions. Learning experiences that involve activities that stimulate critical thinking skills can significantly affect the development of those abilities. These observations are reasonable because Nua and Haris (2023) and Purwanto and Winarti (2016) found that students had poor critical thinking skills for solving high school physics problems. Sari et al. (2021) report similar findings, namely that the ability of students of several Makassar City high schools to solve high-level thinking problems was at a medium level.

Based on the challenges and realities of the critical thinking ability and learning independence of physics students, the problem-solving approach of the physics learning model could be an alternative way to make a significant contribution. The problem-solving-based physics learning model is useful for developing students' critical thinking skills and independent learning (Birgili, 2015). In the education literature, problem-solving-based learning is one of the most-talked-about models (Eyisi, 2016; Häkkinen et al., 2017). It focuses on a structured

approach to resolving issues, starting from recognizing the problem, then analyzing relevant data, formulating solutions, and assessing outcomes (Kılıç, 2017; Wüstenberg et al., 2014). By applying this learning model, students are expected to hone their critical thinking skills through hands-on experience of solving a variety of problems.

While numerous studies have explored the role of problem-solving-based learning in enhancing academic performance, investigations specifically addressing the impact of problem-solving-oriented physics instruction on the critical thinking and independent learning of physics students remain scarce, particularly in the Indonesian higher education context. There has been no research that has specifically evaluated the relationship between critical thinking skills and learning independence in an instructional framework. In response to this gap, the present study posed the following research question: Can a problem-solving-centered physics learning model significantly enhance students' critical thinking and self-directed learning capacities?

This research was designed to assess the combined influence of such a model on both competencies. Its novelty lies in the way it integrated two essential 21st-century skills—critical thinking and autonomous learning, one comprehensive evaluation structure, while contextualizing this approach in university-level physics education. These findings are expected to provide theoretical references and practical implications for more effective and contextually relevant learning designs to improve the quality of higher education in Indonesia.

## 2. Methods

This research used a quasi-experimental method (Reichardt, 2019; Rogers & Révész, 2019) with a nonequivalent control group design (Adam et al., 2025; Liline et al., 2024), in which the two groups each received a different treatment. The experimental group were subjected to a problem-based learning physics learning model, while the control group received traditional instruction, such as lectures and discussions. The subjects of this research were 2024 students who were members of the introductory physics Class II at the State University of Makassar. Sample selection was done using a purposive sampling technique to select classes with characteristics relevant to the research objectives.

The number of research subjects was 60, and the experimental and control groups had 30 students each. The sample size of 60 students (30 in each group) was determined according to previous similar quasi-experimental studies in physics education that successfully detected significant effects with comparable sample sizes (Riantoni et al., 2017; Nua & Haris, 2023). In addition, given that the expected effect size is moderate to large and the significance level is less than .05, the sample size of this study is considered adequate at baseline to detect significant differences between groups.

The critical thinking ability test comprises multiple-choice questions accompanied by reasons for selecting a certain answer; the questions were designed to measure students' critical thinking abilities (Thornhill-Miller et al., 2023). Student learning

independence was measured using a questionnaire (Alevizou et al., 2024; Lämsä et al., 2023). Examples of items from the critical thinking skills test include Explain why the answer to this physics problem is correct or incorrect and identify alternative explanations for a given phenomenon. Examples from the learning independence questionnaire include statements such as I can plan my study schedule effectively, and I keep learning even when I encounter difficulties, with responses rated on a Likert scale. Both variables were measured before and after treatment to determine how ability changed.

The results of the reliability tests of the instruments for critical thinking skills and student independence were obtained; Cronbach's Alpha values of .90 and .84, respectively, were measured and the tests were declared reliable (Vázquez-Parra et al., 2024). Both instruments were validated through an expert review involving physics education specialists and assessment experts, to ensure content validity. In addition, before the main study, trials were undertaken with a group of students who were not in the sample to refine items for clarity and relevance. According to the instrument grid of critical thinking skills and learning independence after the trial, all aspects or indicators were declared theoretically and empirically feasible. This shows that all instruments are valid.

The research commenced with a preparatory phase that involved developing problem-solving-based and conventional physics learning models. This stage also included the construction of instruments to assess critical thinking skills and learning independence, followed by validation and reliability testing of these tools. Then, the experimental group received instructions using the problem-solving model, while the control group underwent conventional teaching over four weeks. Post tests were then administered to both groups to measure changes in the two variables.

In the data analysis phase, posttest results were subjected to descriptive and inferential statistical procedures. Descriptive statistics were used first to assess students' critical thinking and independent learning levels after the intervention. Next, the Kolmogorov-Smirnov test was used to assess the data distribution, after which Levene's test was applied to check the equivalence of variance between groups. Once the data were declared regular and homogeneous, an independent *t*-test was performed to determine the observed significance between the experimental and control groups, using a significance threshold of .05.

To assess the practical impact of the intervention, Cohen's *d* was calculated to measure the effect size; values above 0.8 are considered significant and above 1.2 very large. The independent *t*-test thus evaluated whether the instructional model had a statistically significant effect on both competencies. A *p*-value under .05 indicated that the improvements in critical thinking and learning independence were unlikely to be the result of random variation, thereby confirming the effectiveness of the problem-solving-based learning approach. This analytical strategy reinforces the credibility of the study's findings through empirical validation.

### 3. Results and Discussions

Descriptive statistics provide a preliminary picture of the average and distribution of data for each variable studied. The results of the descriptive analysis are presented in Table 1.

**Table 1: Descriptive statistical analysis results**

Variable	Group	N	Mean	SD
Critical thinking skills	Experiment	30	85.30	5.25
	Control	30	70.50	6.10
Learning independence	Experiment	30	4.16	0.40
	Control	30	3.35	0.45

Table 1 shows that the average critical thinking ability of the experimental group was higher ( $M = 85.30$ ;  $SD = 5.25$ ) than that of the control group ( $M = 70.50$ ;  $SD = 6.10$ ). A similar finding emerged for the learning independence variable, for which the experimental group had a higher average value ( $M = 4.16$ ;  $SD = 0.40$ ) than the control group ( $M = 3.35$ ;  $SD = 0.45$ ). This difference indicates the potential influence of the treatment given to the experimental group. Furthermore, the analysis of the normality and homogeneity of the data group met the assumptions of normal and homogeneous distribution, which is a prerequisite in parametric tests such as the  $t$ -test, as presented in Tables 2 and 3.

**Table 2: Normality test results (Kolmogorov-Smirnov)**

Variable	Group	Value Sig. ( $p$ )	Distribution
Critical thinking skills	Experiment	.102	Normal
	Control	.085	Normal
Learning independence	Experiment	.122	Normal
	Control	.097	Normal

**Table 3: Results of the variance homogeneity test (Levene's test)**

Variable	F	Sig. ( $p$ )	Information
Critical thinking skills	1.204	.276	Homogeneous
Learning independence	0.985	.327	Homogeneous

Independent  $t$ -tests were conducted for both variables to assess whether there were notable differences between the experimental and control groups. As outlined in Table 4, the results revealed statistically significant disparities in students' critical thinking skills and independent learning;  $p$ -values are less than .05. These findings suggest that the instructional intervention exerted a meaningful impact on both measured outcomes.

**Table 4: Independent t-test results**

Variable	<i>t</i>	df	Sig. (2-tailed)	Information
Critical thinking skills	9.627	58	0.000	Significant: There is a significant difference
Learning independence	7.849	58	0.000	Significant: There is a significant difference

A measure of Cohen's effect, *d*, was used to measure the magnitude of the effect of treatment on outcomes. Effect measures provide information about how big a difference is in a practical sense, not just statistically. Table 5 shows that the effect size for both variables was very large (Cohen's  $d > 0.80$ ), which indicates that the differences between the experimental and control groups were statistically significant as well as practically significant.

**Table 5: Effect size analysis results (Cohen's *d*)**

Variable	Cohen's <i>d</i>	Interpretation
Critical thinking skills	2.64	Very large
Learning independence	1.95	Very large

This difference shows that the problem-solving-based physics learning model can significantly improve students' critical thinking skills and learning independence. These findings are consistent with prior studies (Birgili, 2015; Liu & Pásztor, 2022; Mahanal et al., 2019), which emphasizes that structured problem-solving strategies enable learners to practice high-level cognitive skills. The substantial improvement in critical thinking ability ( $M = 85.30$  in experimental vs.  $M = 70.50$  in control groups) can be interpreted as evidence that actively engaging students in identifying, analyzing, and evaluating problems cultivates deeper reasoning skills (Xu et al., 2023). Similarly, the increase in learning independence ( $M = 4.16$  vs.  $M = 3.35$ ) aligns with research that suggests that problem-solving models foster self-directed learning and metacognitive regulation (Almulla & Al-Rahmi, 2023; Hill et al., 2020; Maksum et al., 2021). This suggests that students' autonomy and motivation improve when they are responsible for planning and evaluating their learning strategies.

The large effect sizes (Cohen's  $d = 2.64$  for critical thinking and  $1.95$  for learning independence) highlight statistical significance and practical significance, thereby suggesting that the intervention had a meaningful impact on students' cognitive and self-regulatory skills. These outcomes support the theoretical framework of problem-based learning and prepare students for the complex problem-solving and decision-making required in the 21st century (González-Pérez & Ramírez-Montoya, 2022; Xu et al., 2023).

Furthermore, this study contributes to the discourse on SDG 4 by demonstrating that contextual, student-centered learning approaches can enhance critical thinking and independent learning, which is critical for lifelong learning and quality education. SDG 4, which was proposed by the United Nations, targets

explicitly inclusive and good-quality education that equips learners with the skills they need in the 21st century. Target 4.4 emphasizes the development of relevant skills such as critical thinking and problem-solving, thereby aligning directly with the outcomes of this study, which found significant improvement in these competencies through problem-solving-based learning.

Today's 21st-century education requires students to master factual, conceptual, and critical thinking skills, problem-solving processes, and independent learning. Integrating problem-solving indicators in the learning process is a key strategy for developing critical thinking competencies and learning independence (Almulla & Al-Rahmi, 2023; Maksum et al., 2021; Xu et al., 2023). This study shows that problem-solving indicators, such as understanding problems, planning, implementing, and evaluating solutions, significantly strengthen both competencies. This aligns with the SDG 4 global agenda, which targets quality and inclusive education that promotes lifelong learning opportunities for all (Adipat & Chotikapanich, 2022; Elfert, 2019). The first indicator in problem-solving, "understanding the problem," requires that students conduct an in-depth analysis of the situation (Aminah et al., 2023; Sangsawang, 2020).

This process involves identifying important facts, variables that play a role, and the relationship between elements of the problem. This activity is closely related to the ability to think critically, especially to clarify and interpret information. Strong critical thinking skills help students evaluate the information obtained, avoid cognitive bias, and establish logical initial steps. The second indicator, "planning the solution," requires students to develop logical, effective, and efficient strategies. This includes identifying alternative solutions and evaluating their benefits and risks (Mahanal et al., 2022). At this stage, critical thinking skills play a role in analyzing the logical implications of the various strategies available. The ability to assess, compare, and choose the best solution is integral to critical thinking competence.

Furthermore, the indicator of "implementing a strategy" tests the ability of students to execute the plan that they designed (Burhaein et al., 2021; Stebner et al., 2022). This requires precision, precision thinking, and self-monitoring skills. This stage is not only a technical implementation but also involves decision-making when obstacles arise. Students learn adaptive thinking, evaluate their actions continuously, and consider modifying strategies, if necessary. Finally, the "evaluating the solution" indicator involves a reflective moment during which learners analyze the effectiveness of the solution they implemented, identify the weaknesses of the strategy, and reflect on their thought process (Hong & Choi, 2019; Lee et al., 2024; Supena et al., 2021).

This step represents the culmination of critical thinking activities, when students evaluate the results and the mental processes they used to arrive at their results. Thus, all problem-solving indicators systematically strengthen the dimensions of critical thinking, including clarification, inference, interpretation, analysis, and evaluation. This is consistent with the indicators of SDG 4, notably Target 4.4, which seeks to significantly expand the proportion of young people and adults

who are equipped with technical and vocational competencies, including advanced cognitive abilities such as critical thinking and problem-solving.

In addition to critical thinking, problem-solving indicators are fundamental for encouraging learning independence. Learning independence refers to the ability of learners to organize, monitor, and evaluate their learning process. These skills include internal motivation, time management, metacognitive strategies, and the ability to cope with learning challenges independently. In the indicator of “understanding the problem,” students are encouraged to actively seek information, ask questions, and explore the context of the problem (Gebremeskel et al., 2025; Saleh et al., 2022). Doing so fosters curiosity and responsibility towards the learning process. This activity demands individual initiative in understanding information, which is the cornerstone of independent learning. The “plan for completion” indicator involves students deciding on strategies, managing their work time, and choosing relevant learning resources. This self-regulated learning process strengthens students’ active role in determining the direction of their learning.

These capabilities are critical for supporting lifelong learning, one of the key pillars of SDG 4. In the “implement strategy” indicator, students face a real situation that requires them to independently assess the success of their steps (de Almeida et al., 2019). They must find alternative solutions and adapt to existing conditions when they encounter obstacles. This strengthens confidence and reflective skills that are at the core of independent learning. The last indicator, “evaluating solutions,” provides space to reflect on achievements and processes undertaken. Reflection is key to self-paced learning because it enables learners to identify their strengths and weaknesses and plan for future improvement. These capabilities are critical for developing lifelong learners, in line with Target 4.7 of SDG 4, which emphasizes the importance of knowledge and skills for supporting sustainable development.

#### **4. Conclusion**

Implementing a learning model that is rooted in problem-solving strategies has proven beneficial for boosting students’ analytical thinking and autonomous learning habits. Each stage of problem-solving (understanding the problem, planning solutions, implementing, and systematically evaluating results) is essential for fostering high-level thinking and self-study habits. Integrating these two competencies is essential for preparing adaptive, innovative graduates who can navigate complex global challenges. The principal contribution of this research lies in empirically mapping the relationship between problem-solving indicators and two pivotal 21st-century skills: critical thinking and independent learning.

By combining these perspectives, this study extends the theoretical framework for problem-solving models in higher education and demonstrates their practical benefits in authentic classroom contexts. Moreover, this research provides quantitative and qualitative evidence that supports the application of problem-solving strategies to develop student competencies that are aligned with lifelong

learning principles. This alignment is instrumental for advancing Indonesia's national education goals and strengthening SDG 4 targets, especially promoting inclusive, equitable, high-quality education and providing lifelong learning opportunities for all. Overall, the findings emphasize that problem-solving-based learning improves students' analytical abilities and nurtures their autonomy and resilience, thereby equipping them with essential skills for continuous growth and employability in an ever-evolving global landscape.

## 5. Implications

These findings have important implications for learning practices at college level. Lecturers must design learning that emphasizes mastery of content and provides space for students to engage in contextual and relevant problem-solving. Using a problem-solving approach can be an effective strategy for building an active, collaborative, and holistic learning environment that is oriented toward developing student competencies. In addition, the curriculum and assessments need to be adjusted to support this problem-based learning process. Assessment measures the outcome and the students' thinking, collaboration, and reflection process while solving problems. This approach also aligns with outcome-based education principles and graduate learning outcomes, which focus on developing higher-level thinking skills.

## 6. Recommendations

Although the study results promote the application of the problem-solving model, several limitations must be noted. First, this research was conducted in the context of a physics course with a limited number of students. Therefore, care must be taken when generalizing results to other contexts. Second, the duration of the intervention may have been too short to observe changes in learning behavior overall. Further research is recommended to apply this model in various disciplines and with a longer time frame. In addition, developing a more comprehensive instrument to measure the dimensions of critical thinking and learning independence in depth is necessary. The qualitative approach can also be used to explore students' perceptions and experiences related to problem-solving-based learning in more depth.

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