

# The Effect of a STEAM Approach Assisted by Digital Mind Mapping (DMM) within the Problem Based Learning Model on Improving Students' Critical Thinking Skill in Work and Energy

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**Abstract:** This study examined the effect of a Science, Technology, Engineering, Arts, and Mathematics (STEAM) approach assisted by Digital Mind Mapping (DMM) integrated into the Problem-Based Learning (PBL) model on students' critical thinking skills in the topic of Work and Energy. A quasi-experimental method with a nonequivalent control group design was employed. The sample consisted of 36 students in the experimental class and 31 students in the control class, selected through purposive sampling. The experimental class was taught using the STEAM approach assisted by DMM integrated into the PBL model, while the control class received the PBL model only. Data were collected using a validated critical thinking skills test comprising 10 multiple-choice items with a Cronbach's alpha reliability coefficient of 0.717. Data were analyzed using significance testing, normalized gain (N-gain), and effect size analysis. The findings showed that the experimental class demonstrated significantly greater improvement in critical thinking skills than the control class, with a higher N-gain across most critical thinking indicators. The effect size of 1.100 indicated a very large treatment effect. These findings suggest that integrating a STEAM approach assisted by DMM into the PBL model is effective in improving students' critical thinking skills in Work and Energy.

**Keywords:** Critical thinking skills; Digital mind mapping; Problem-based learning; STEAM

## Introduction

Critical thinking is one of the essential skills required in the 21st century because it plays a crucial role in addressing various challenges (Zukmadini, 2019). This skill contributes to the development of high-quality individuals by enabling them to solve problems, make informed decisions, and develop a deeper understanding of various phenomena (MS et al., 2020). In everyday life, individuals encounter real-world

problems that require critical analysis and effective decision-making (Yunus & Satnawati, 2025).

However, students' critical thinking skills remain suboptimal (Gusmawan et al., 2021). Limited ability to comprehend information (Yuliarti et al., 2023), difficulties in analyzing problems, selecting appropriate formulas, and providing logical justifications are among the factors contributing to students' low critical thinking skills (Suriati et al., 2021). Compared with other science topics, physics is one of the subjects in which students' critical thinking skills are generally categorized as

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moderate to low (Sitompul & Oktavianty, 2024). One of the most relevant physics topics is Work and Energy, as it provides opportunities for students to engage directly in solving problems related to real-life situations (Hamatun, 2025). However, this topic is considered more challenging than many other physics topics. Many students experience misconceptions regarding the concept of work in physics, assuming that applying a force to an object always constitutes work, even when no displacement occurs. In addition, students often encounter difficulties in distinguishing between kinetic and potential energy, applying the law of conservation of energy, and analyzing the mathematical relationships among physical variables (Samsudin et al., 2021; Mufti & Sunarti, 2024). Mastery of these concepts can be reflected in students' critical thinking skills. Therefore, insufficient conceptual understanding of the Work and Energy topic may hinder the development of students' critical thinking skills (Mubaroqah et al., 2022).

Several studies have been conducted to improve students' critical thinking skills, including the implementation of (PjBL-STEM) in renewable energy topics (Anggraini et al., 2025), the use of a guided inquiry model supported by interactive modules on elasticity (Nursabrina et al., 2024), PBL in the topics of work and simple machines (Anamta et al., 2024) STEAM-PBL in fluid dynamics (Rasmi et al., 2025). Although these studies have reported positive findings, several limitations remain. The improvement in students' critical thinking skills was generally classified as moderate and has not yet reached an optimal level (Anamta et al., 2024). In addition, some instructional approaches have not been sufficiently effective in addressing students' misconceptions or inadequate conceptual understanding (Anggraini et al., 2025). Furthermore, opportunities for students to engage in in-depth analysis remain limited, suggesting that they should be provided with greater opportunities to independently construct knowledge and develop their own conclusions throughout the learning process (Mubaroqah et al., 2022). Furthermore, previous studies have rarely focused on the Work and Energy topic as the primary context for investigating critical thinking skills, while the Problem-Based Learning (PBL) model has been more frequently implemented in other physics topics. Considering its emphasis on authentic problem-solving and conceptual understanding, PBL has been recognized as more effective than many other instructional models in promoting conceptual understanding and, consequently, has strong potential to enhance students' critical thinking skills (Mariskhantari et al., 2022).

Problem-Based Learning (PBL) is centered on contextual problems that encourage students to analyze situations and develop critical reasoning both

individually and collaboratively. This instructional model also strengthens students' conceptual understanding of the Work and Energy topic by enabling them to relate scientific concepts to real-life situations. For example, students may investigate why a cyclist must exert greater effort when riding uphill than on a flat road. Through such contextual problems, students are encouraged to analyze the relationships among force, displacement, work, and energy transformation, allowing them to develop conceptual understanding rather than merely memorizing formulas (Masrinah et al., 2019). Despite these advantages, PBL still has several limitations, including insufficient integration of technology, limited emphasis on quantitative analysis, and inadequate support for metacognitive reflection (Solano et al., 2023). Integrating the STEAM approach into PBL can address these limitations by strengthening students' mathematical reasoning, technical design skills, and creativity (Kefalis et al., 2025). Furthermore, the integration of STEAM and PBL provides structured guidance for questioning, discussion, and critical thinking while promoting students' active engagement in experimentation, problem-solving, and collaborative learning (Khine & Areepattamannil, 2019). In addition, the STEAM approach equips students with competencies needed to compete in a global society, particularly in developing science- and technology-based innovations (IPTEK) (Fallone et al., 2020).

However, the STEAM approach may place excessive emphasis on the final product while providing insufficient support for students' systematic thinking processes (Haetami, 2023). Meanwhile, the Work and Energy topic involves various interconnected physical quantities, including force, displacement, velocity, acceleration, and kinetic energy (Abadiyah, 2026). Therefore, an instructional tool is needed to help students visualize the relationships among these concepts and reflect on their problem-solving processes within STEAM-based learning. Digital Mind Mapping (DMM) can serve this purpose by enabling students to organize and represent their ideas and arguments through visual and textual formats (Yan & Kim, 2023). Mind mapping has been shown to enhance students' understanding of learning materials, facilitate connections among concepts, and improve information retention through the use of colors and branching structures (Hidayati et al., 2023). In addition, DMM can be used as an assessment tool to evaluate students' critical thinking skills (Sukawati & Budiyo, 2022). It also helps students overcome difficulties in comprehending learning materials while providing opportunities to express their understanding and opinions more freely. Through DMM, students' ideas and arguments can be organized in a more structured,

coherent, and visually engaging manner. Accordingly, integrating the STEAM approach with DMM into the PBL model is expected to foster the development of students' critical thinking skills. Therefore, this study aims to investigate the effectiveness of implementing the STEAM approach assisted by Digital Mind Mapping within the PBL model in improving students' critical thinking skills.

## Method

This study employed a quasi-experimental method using a nonequivalent control group design with a quantitative approach (Creswell & Creswell, 2022). As presented in Table 1, the research sample was divided into two groups: an experimental group and a control group.

**Table 1.** Design quasi experiment nonequivalent control group design

| Class        | Pretest | Treatment | Posttest |
|--------------|---------|-----------|----------|
| Experimental | $O_1$   | $X_1$     | $O_2$    |
| Control      | $O_1$   | $X_2$     | $O_2$    |

(Creswell & Creswell, 2022)

Description:

$X_1$  : Problem-Based Learning (PBL) integrated with the STEAM approach assisted by Digital Mind Mapping (DMM).

$X_2$  : Problem-Based Learning (PBL).

$O_1$  : Pre-test administered to the experimental and control groups.

$O_2$  : Post-test administered to the experimental and control groups.

The study population consisted of eleventh-grade students at SMA Negeri 9 Malang. The sample was selected using purposive sampling based on the similarity of students' initial abilities and the existing class assignments at the school. As a result, Class XI C, comprising 36 students, was assigned as the experimental group, while Class XI B, comprising 31 students, served as the control group. The experimental group received instruction through the STEAM approach assisted by Digital Mind Mapping (DMM) integrated into the PBL model ( $X_1$ ), whereas the control group was taught using the PBL model only ( $X_2$ ). The study was conducted over six instructional sessions using a quasi-experimental nonequivalent control group design, which consisted of three stages: preparation, implementation, and data analysis. During the preparation stage, the lesson modules and the critical thinking skills test instruments were developed and validated by experts. In the implementation stage, both groups completed a pre-test ( $O_1$ ) to assess their initial critical thinking skills, followed by the respective

instructional treatments. At the end of the intervention, both groups completed a post-test ( $O_2$ ) to measure changes in their critical thinking skills.

The research instruments consisted of instructional instruments and assessment instruments. The instructional instruments included lesson modules, student worksheets, teaching materials, learning media, and laboratory activity materials developed based on the syntax of the STEAM-assisted Digital Mind Mapping (DMM) integrated into the PBL model. The assessment instruments consisted of a classroom observation sheet to evaluate the implementation of the learning process and a 10-item multiple-choice test designed to assess students' critical thinking skills based on Ennis's (1985) critical thinking indicators (Astutik et al., 2020). All instruments were validated by experts and met the required validity and feasibility criteria for use in the study.

Research data were collected through the administration of pre-tests and post-tests to both groups. Data analysis began with the Shapiro-Wilk normality test. Since the data were not normally distributed, differences in students' critical thinking skills between the experimental and control groups were analyzed using the Mann-Whitney U test. Improvements in students' critical thinking skills were measured using the normalized gain (N-gain), while the magnitude of the treatment effect was determined by calculating Cohen's effect size (d).

## Result and Discussion

Students' critical thinking skills were measured using a 10-item multiple-choice test. The assessment was conducted in two stages: a pre-test administered before the instructional intervention and a post-test administered after the completion of the learning process. The descriptive statistical results for both groups are presented in Table 2.

**Table 2.** Descriptive statistics

| Class        | N  | Pretest |       | Posttest |       |
|--------------|----|---------|-------|----------|-------|
|              |    | M       | SD    | M        | SD    |
| Experimental | 36 | 42.22   | 15.14 | 83.61    | 10.18 |
| Control      | 31 | 37.10   | 12.16 | 71.94    | 11.08 |

As shown in Table 2, the mean pre-test scores of the experimental and control groups were relatively similar, indicating no substantial difference in students' initial critical thinking skills. However, the experimental group achieved a higher mean post-test score than the control group. These findings suggest that implementing the STEAM approach assisted by Digital Mind Mapping (DMM) within the PBL model was more effective in

improving students' critical thinking skills than the PBL model alone.

Subsequently, the normality of the data was examined using the Shapiro-Wilk test. The significance values for the pre-test and post-test scores are presented in Table 3.

**Table 3.** Result of the Shapiro-Wilk normality test

|          |              | Shapiro Wilk |    |       |
|----------|--------------|--------------|----|-------|
| Class    |              | Statistic    | df | sig   |
| Pretest  | Experimental | 0.89         | 36 | 0.002 |
|          | control      | 0.86         | 31 | 0,001 |
| Posttest | Experimental | 0.90         | 36 | 0,004 |
|          | control      | 0.85         | 31 | 0,001 |

As presented in Table 3, the significance (*p*) values for both the pre-test and post-test in the experimental and control classes were all below 0.05. These results indicate that the data were not normally distributed. Since the assumption of normality was not satisfied, a non-parametric statistical analysis was performed using the Mann-Whitney U test to examine differences between the two groups.

The results of the non-parametric Mann-Whitney U test are presented in Table 4.

**Table 4.** Mann-Whitney U test result

|                       | Pretest All | Posttest All |
|-----------------------|-------------|--------------|
| Mann-whitney u        | 523.00      | 256.50       |
| Wilcoxon w            | 1051.00     | 752.50       |
| Z                     | -.06        | -3.92        |
| Asymp. Sig. 2-tailed) | .94         | .00          |

As shown in Table 4, the post-test results of the experimental and control groups yielded a significance value of 0.000 ( $p \leq 0.05$ ), indicating a statistically significant difference between the two groups. Therefore, it can be concluded that the critical thinking skills of students in the experimental group differed significantly from those of the control group. These findings indicate that the implementation of the (STEAM) approach assisted by Digital Mind Mapping (DMM) within the PBL model had a significantly greater effect on students' critical thinking skills than the PBL model alone.

The observed difference in critical thinking skills between the experimental and control groups can be attributed to the implementation of the STEAM-assisted DMM approach within the PBL model. This instructional approach not only emphasizes conceptual understanding but also encourages students to actively construct knowledge through problem-solving in accordance with constructivist learning theory. The PBL model enables students to identify problems, analyze relevant information, and independently formulate

conclusions, thereby promoting the development of critical thinking skills (Aisy et al., 2024). Furthermore, the integration of STEAM actively engages students in analyzing problems and designing appropriate solutions, which further supports the development of critical thinking skills (Darmawati & Mustadi, 2023; Pangaribuan et al., 2026). In addition, the STEAM approach strengthens the learning process through a multidisciplinary perspective that promotes creativity, collaboration, and contextual problem-solving (Ilma et al., 2023; Ichsan et al., 2024; Putri et al., 2023).

The use of Digital Mind Mapping (DMM) also contributed to the improvement of students' critical thinking skills by helping them visualize relationships among concepts and organize information systematically, thereby facilitating the construction of logical arguments and the formulation of conclusions (Winata & Rahmat, 2022). In addition to increasing students' engagement in the learning process, DMM supports reflection and reinforces knowledge structures, making abstract concepts easier to understand (Ahmed et al., 2022; Hidayati et al., 2020).

In contrast, students in the control group, who were taught using the PBL model alone, did not benefit from the support of a multidisciplinary approach or visual learning media. As a result, the organization of concepts and the connection between learning materials and real-world contexts were less effective. These findings indicate that integrating the Science, Technology, Engineering, Arts, and Mathematics (STEAM) approach and Digital Mind Mapping (DMM) into the Problem-Based Learning (PBL) model is more effective in enhancing students' critical thinking skills than implementing the PBL model alone.

The improvement in students' critical thinking skills was further evaluated using the normalized gain (N-gain). The N-gain results are presented in Table 5.

**Table 5.** N-gain analysis result

| Class        | N-gain | Category |
|--------------|--------|----------|
| Experimental | 0.726  | High     |
| Control      | 0.565  | Moderate |

As presented in Table 5, the experimental group achieved an N-gain score of 0.726, which falls into the high category, whereas the control group obtained an N-gain score of 0.565, which is classified as moderate. These results indicate that the improvement in students' critical thinking skills was greater in the experimental group than in the control group.

The greater improvement can be attributed to the characteristics of the Problem-Based Learning (PBL) model, which provides students with opportunities to identify problems, analyze information, and independently construct solutions through student-

centered learning. These findings are consistent with those reported by Wijnia (2025) who concluded that PBL is effective in promoting higher-order critical thinking skills through problem analysis and problem-solving processes. Furthermore, integrating the STEAM approach strengthened this effect by connecting physics concepts to real-world contexts through active, collaborative, and multidisciplinary learning, thereby enhancing students' abilities in analysis, evaluation, and decision-making (Lestari, 2021; Naura et al., 2022). These findings are further supported by previous studies reporting that STEAM-integrated learning improved students' critical thinking skills, with N-gain scores of 0.76 and 0.71, respectively (Adhelacahya, 2023; Wicaksana, 2025).

The use of Digital Mind Mapping (DMM) during the learning process also contributed to strengthening students' conceptual understanding, particularly in the Work and Energy topic, which involves abstract concepts. DMM enabled students to visualize relationships among concepts in a systematic manner, making the processes of analysis and conclusion drawing more structured and meaningful. Although the mind maps produced by students still required improvement in terms of conceptual accuracy and visual organization, DMM effectively facilitated reflection and knowledge organization throughout the learning process. This finding is supported by Hazaymeh & Alomery (2022) who reported that DMM is highly effective in enhancing students' critical thinking skills in educational settings.

In contrast, the control group achieved an N-gain score of 0.565, which falls into the moderate category. This finding indicates that implementing the Problem-Based Learning (PBL) model without the integration of the STEAM approach and visual learning media such as Digital Mind Mapping (DMM) was not sufficient to maximize the development of students' critical thinking skills. Compared with previous studies, the findings reported by Hartati et al. (2023) and Saputra (2022) also demonstrated that STEAM-based PBL can improve students' critical thinking skills, although the observed improvements remained within the moderate category (Wildani & Budiyo, 2022).

Overall, the N-gain results in this study confirm that integrating STEAM, Digital Mind Mapping (DMM), and the PBL model in the experimental group produced greater improvements than implementing the PBL model alone in the control group. The integration of these three components not only encouraged students to construct concepts independently but also helped them organize and reflect on their understanding in a more structured manner. Consequently, students' critical thinking skills developed more effectively.

To further examine students' improvement in critical thinking skills, N-gain scores were analyzed for each critical thinking indicator. The results are presented in Table 6.

**Table 6.** N-gain scores for each critical thinking indicator

| Indicator              | Experimental Group | Control Group   |
|------------------------|--------------------|-----------------|
|                        | N-gain             | N-gain          |
| Basic Clarification    | 0.78 (high)        | 0.71 (high)     |
| Bases for Decision     | 0.79 (high)        | 0.71 (high)     |
| Inference              | 0.49 (moderate)    | 0.20 (low)      |
| Advanced Clarification | 0.71 (high)        | 0.48 (moderate) |
| Strategies and Tactics | 0.96 (high)        | 0.90 (high)     |

As presented in Table 6, all critical thinking indicators in the experimental group achieved higher N-gain scores than those in the control group. Among the five critical thinking indicators, Basic Clarification, Bases for Decision, Advanced Clarification, and Strategies and Tactics in the experimental group were classified in the high category, whereas Inference was classified in the moderate category. In contrast, the control group achieved high categories for Basic Clarification, Bases for Decision, and Strategies and Tactics, while Advanced Clarification was categorized as moderate and Inference as low.

The improvement in students' critical thinking skills can be further examined through the N-gain score of each indicator. For the Basic Clarification indicator, the experimental group obtained an N-gain score of 0.789 (high), whereas the control group achieved 0.717 (high), although this value was lower than that of the experimental group. These findings indicate that implementing the STEAM approach assisted by DMM within the PBL model was more effective in training students to identify problems, formulate questions, and provide fundamental explanations through contextual problem-solving. The implementation of STEAM has been shown to be more effective in supporting the improvement of students' critical thinking skills. This finding is further supported by previous research showing that the STEM-integrated Project-Based Learning (PjBL) model resulted in an N-gain score of 0.76 (Sukarso & Syuzita, 2023). While the implementation of STEAM-integrated Problem-Based Learning (PBL) achieved an N-gain score of 0.71 (Kohohon et al., 2023). The integration of STEAM encourages students to construct knowledge independently through contextual learning (Wilson et al., 2021). While DMM helps students organize concepts visually, thereby enhancing their critical thinking skills (Trisnawati & Wahyuni, 2022).

For the Bases for Decision indicator, the experimental group obtained an N-gain score of 0.790 (high), which was higher than that of the control group (0.714, high). This result suggests that investigation, data

analysis, and discussion activities implemented through the STEAM-DMM-PBL approach enabled students to make evidence-based decisions more logically (Gürler & Kaplan, 2023). Individuals with strong critical thinking skills are able to analyze information effectively, thereby increasing their ability to make appropriate decisions and draw valid conclusions (Daryanes et al., 2023).

The Inference indicator showed the lowest improvement, with an N-gain score of 0.491 (moderate) in the experimental group and 0.207 (low) in the control group. Nevertheless, students in the experimental group demonstrated a greater ability to formulate conclusions based on analytical evidence because they were accustomed to organizing concepts through DMM and engaging in problem-based discussions. This finding is consistent with the study by Limbong et al. (2023), which reported that active participation in problem-solving activities enhances students' ability to draw valid conclusions.

For the Advanced Clarification indicator, the experimental group achieved an N-gain score of 0.717 (high), whereas the control group obtained 0.487 (moderate). The use of DMM enabled students to connect concepts, equations, and assumptions more systematically, allowing them to provide more comprehensive explanations (Lestari & Muhajir, 2021). Furthermore, the integration of STEAM facilitated students' understanding of how physics concepts are applied in real-life situations. In contrast, students in the control group generally failed to provide well-supported assumptions and tended to base their responses on approximate answers to the given problems, resulting in less in-depth explanations.

The Strategies and Tactics indicator exhibited the greatest improvement, with an N-gain score of 0.965 (high) in the experimental group and 0.909 (high) in the control group. These findings indicate that integrating STEAM, DMM, and the PBL model effectively developed students' ability to determine appropriate problem-solving strategies through collaborative, investigative, and context-based learning activities (Rizki & Marlina, 2024).

Overall, the N-gain analysis for each critical thinking indicator demonstrated that the experimental group achieved greater improvements than the control group. These findings confirm that integrating the (STEAM) approach assisted by Digital Mind Mapping (DMM) into the Problem-Based Learning (PBL) model creates a more active, contextual, and well-structured learning environment, thereby enhancing the development of students' critical thinking skills in the Work and Energy topic.

To determine the magnitude of the effect of implementing the STEAM-assisted DMM approach within the PBL model on students' critical thinking

skills, Cohen's effect size (d) was calculated. The results of the effect size analysis are presented in Table 7.

**Table 7.** Cohen's d effect size result

| Effect size (d) | Category |
|-----------------|----------|
| 1.10            | High     |

As presented in Table 7, the calculated Cohen's effect size (d) was 1.10, which is classified as a large effect. This result indicates a substantial difference in students' critical thinking skills between the experimental group, which was taught using the Science, Technology, Engineering, Arts, and Mathematics (STEAM) approach assisted by Digital Mind Mapping (DMM) within the Problem-Based Learning (PBL) model, and the control group, which received instruction using the PBL model alone. Students' critical thinking skills tend to improve more significantly when the STEAM approach is implemented, as it produces a larger effect size. This finding is supported by previous research through the implementation of a Hybrid-Based Learning model integrated with STEAM, which reported an effect size (ES) of 1.052 (Utomo et al., 2023). The large effect size further demonstrates that integrating STEAM and DMM into the PBL model had a strong positive impact on improving students' critical thinking skills.

The findings of this study provide evidence that implementing the STEAM-assisted DMM approach within the PBL model effectively enhances students' critical thinking skills. Nevertheless, several limitations should be acknowledged. The instructional intervention was conducted within a limited timeframe, and the use of DMM had not yet been fully optimized during the learning process. Therefore, future research is recommended to investigate the implementation of the STEAM-assisted DMM approach within the PBL model in other physics topics as well as in the development of other cognitive skills. Future studies should also ensure adequate instructional time to maximize the effectiveness of the learning process under appropriate teacher or researcher guidance, thereby creating a more structured and systematic learning environment. In addition, teachers are encouraged to provide more comprehensive training in the use of DMM so that students can organize concepts and information more effectively throughout the learning process.

## Conclusion

The findings of this study demonstrate that implementing the STEAM approach assisted by Digital Mind Mapping (DMM) within the PBL model has a significant positive effect on students' critical thinking skills in the topic of Work and Energy. The results of the Mann-Whitney U test revealed that students in the

experimental group achieved significantly greater improvements in critical thinking skills than those in the control group. These findings were further supported by a large effect size (Cohen's  $d = 1.10$ ), indicating a very strong treatment effect, and a higher normalized gain ( $N$ -gain) score in the experimental group (0.726, high category) compared with the control group (0.565, moderate category). Improvement in the experimental group was observed across nearly all critical thinking indicators, with four indicators reaching the high category and one remaining in the moderate category. These results suggest that integrating STEAM and DMM into the PBL model creates a more meaningful learning experience through contextual problem-solving, project-based activities, and concept visualization, thereby fostering the development of students' critical thinking skills. Future studies are recommended to investigate the implementation of this instructional approach in other physics topics and to examine its effects on students' cognitive achievement and other 21st-century skills.

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#### Author Contributions

Conceptualization, methodology, software, formal analysis, investigation, resources, data curation, writing—original draft preparation, R.N.D.O.; validation, writing—review and editing, visualization, supervision, project administration, P., R.K., and M.A. All authors have read and agreed to the published version of the manuscript.

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#### Conflicts of Interest

The authors declare no conflict of interest.

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