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The Effect of Scaffolded Project Based Learning on Students' Critical Thinking Skills to Support SDG 4

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ABSTRACT

Objective: *To examine the effect of scaffolded Project-Based Learning on junior high school students' critical thinking skills in science learning on the topic of food additives.* ***Method:*** *Employing a quantitative approach using a quasi-experimental pretest-posttest design involving three intact junior high school classes (Classes 8E, 8F, and 8H). Students participated in scaffolded Project-Based Learning activities on the topic of food additives.* ***Results:*** *The findings revealed that scaffolded Project-Based Learning effectively improved students' critical thinking skills across the three participating classes. The mean N-Gain scores reached 0.70 in Class 8E, 0.94 in Class 8F, and 0.91 in Class 8H, all of which were categorized as high. The greatest improvements were consistently observed in the interpretation, inference, and self-regulation indicators, while the explanation and evaluation indicators demonstrated comparatively lower gains in some classes. These findings indicate that integrating structured scaffolding into Project-Based Learning effectively promotes higher-order thinking by supporting students in interpreting information, analyzing contextual problems, drawing evidence-based conclusions, and regulating their own learning processes.* ***Novelty:*** *Extends previous research by integrating structured scaffolding into Project-Based Learning to strengthen junior high school students' critical thinking skills in science learning on the topic of food additives. Furthermore, the study contributes to the implementation of Sustainable Development Goal (SDG) 4 by providing empirical evidence that scaffolded Project-Based Learning promotes meaningful, student-centered, and competency-based science education that develops essential twenty-first-century skills.*

INTRODUCTION

The preliminary study of this research was based on the occurrence of several cases among junior high school students related to the food and beverages they consume. These cases show that students are frequently exposed to food and beverage products without fully understanding their safety, ingredients, and potential effects on health. In daily life, students often consume packaged snacks, instant drinks, and processed foods that may contain preservatives, colorants, sweeteners, and flavor enhancers. This condition indicates the need for science learning that encourages students to think critically about the products they consume. Therefore, the topic of food additives is highly relevant because it is closely related to students' daily experiences and provides opportunities for them to analyze real-life problems, evaluate information, and make rational decisions.

In the 21st century, education is expected not only to transfer knowledge but also to develop higher-order thinking skills, particularly critical thinking. Critical thinking refers to the ability to interpret, analyze, evaluate, infer, explain, and reflect on information rationally in order to solve problems and face real-life challenges (Krajcik & Shin, 2014; Facione, 2015; Belland et al., 2024). These skills are essential for junior high school students because they enable them to examine information, identify problems, evaluate evidence, and make responsible decisions in everyday situations. In the context of food additives, critical thinking helps students question the content of food products, understand the impact of excessive additive consumption, and develop awareness of healthy consumption habits.

However, students' critical thinking skills are often not optimally developed when learning remains teacher-centered. In such learning conditions, students tend to receive information passively, memorize concepts, and follow teacher explanations without being sufficiently involved in questioning, investigating, evaluating, and solving contextual problems. As a result, students may understand scientific concepts theoretically but find it difficult to apply them in real-life situations. Therefore, science learning needs to be designed to provide active, meaningful, and contextual learning experiences through problem-solving activities (Dewey, 1938; OECD, 2023; Hidayati et al., 2024; Kim & Choi, 2024; Zhao et al., 2024; Anazifa & Djukri, 2023).

Project-Based Learning (PjBL) is one learning model that can support the development of students' critical thinking skills. PjBL involves students in completing projects based on real-world problems, allowing them to conduct investigations, collect and analyze information, collaborate with peers, and produce meaningful products. Through this learning process, students are encouraged to identify problems, formulate ideas, test solutions, and communicate their findings. Thus, PjBL provides an authentic learning environment that supports the development of critical thinking, creativity, communication, and collaboration skills (John & Thomas, 2000).

Nevertheless, the implementation of Project-Based Learning may present challenges for junior high school students. Some students may experience difficulties in understanding project tasks, organizing information, designing investigations, connecting concepts with real-life problems, and drawing evidence-based conclusions. Therefore, temporary assistance in the form of scaffolding is needed to guide students throughout the learning process. Scaffolding helps students understand tasks, manage information, construct arguments, develop project products, and gradually become more independent learners. This support is in line with the Zone of Proximal Development theory, which emphasizes the importance of teacher or peer assistance in helping students achieve learning goals that they may not be able to accomplish independently (Vygotsky, 1978; Wood et al., 1976; Belland et al., 2024; Kim & Lim, 2024). Accordingly, scaffolded Project-Based Learning is considered appropriate for guiding students in solving contextual problems while progressively strengthening their independence and critical thinking skills.

The development of students' critical thinking skills is also closely related to Sustainable Development Goal 4 (SDG 4), which emphasizes inclusive, equitable, and quality education, as well as lifelong learning opportunities for all. Quality education requires learning that enables students to think critically, solve real-life problems, and make informed decisions. In this context, scaffolded Project-Based Learning on the topic of food additives can contribute to SDG 4 by providing meaningful science learning that is relevant to students' daily lives, supports active participation, and strengthens essential 21st-century competencies. By engaging students in investigating food and beverage products, this learning model is expected to help them become more critical, responsible, and aware of health-related issues in their environment.

Although previous studies have shown that Project-Based Learning can improve students' learning outcomes and higher-order thinking skills, studies that specifically examine the effect of scaffolded Project-Based Learning on junior high school students' critical thinking skills in the context of food additives remain limited. In addition, the integration of this learning model with the aims of SDG 4 provides an important perspective for developing quality science education that is contextual, meaningful, and relevant to students' lives. Therefore, this study is important to provide empirical evidence on how scaffolded Project-Based Learning can improve students' critical thinking skills through contextual science learning.

Based on this background, this study aims to analyze the effect of scaffolded Project-Based Learning on junior high school students' critical thinking skills in learning the topic of food additives. Specifically, this study describes the implementation of scaffolded Project-Based Learning, examines the improvement of students' critical thinking skills, and describes students' responses after participating in scaffolded project-based learning. The findings of this study are expected to contribute to the development of science learning practices that support students' critical thinking skills and the achievement of quality education as emphasized in SDG 4.

RESEARCH METHOD

Research design

This study used a quantitative approach with a quasi-experimental pretest-posttest design. The design was chosen to examine the effect of scaffolded Project-Based Learning on junior high school students' critical thinking skills. The use of a pretest-posttest design is supported by Creswell and Creswell (2018), who explain that this design allows researchers to compare participants' abilities before and after a treatment is implemented. In this study, the pretest was used to identify students' initial critical thinking skills, while the posttest was used to determine students' critical thinking skills after participating in scaffolded Project-Based Learning. The difference between the pretest and posttest scores indicated the extent to which the learning treatment contributed to students' skill improvement.

The critical thinking skills measured in this study consisted of six indicators: interpretation, evaluation, analysis, inference, explanation, and self-regulation. The data were analyzed using descriptive quantitative analysis by comparing the average pretest and posttest scores for each critical thinking indicator. In addition, normalized gain (N-Gain) analysis was used to determine the level of improvement in students' critical thinking skills after the implementation of scaffolded Project-Based Learning. The N-Gain scores were then categorized into low, medium, and high improvement levels.

This design was considered appropriate because the study aimed to measure changes in students' critical thinking skills before and after the learning intervention. The use of three classes also provided a broader description of the consistency of students' critical thinking improvement across different learning groups.

Research participants

The participants of this study were junior high school students from three intact classes, namely Class 8E, Class 8F, and Class 8H. These classes were selected as research participants because they were involved in the implementation of scaffolded Project-Based Learning on the topic of food additives. All participants received the same learning treatment and completed both the pretest and posttest to measure their critical thinking skills before and after the learning process.

The students' critical thinking skills were measured based on six indicators, namely interpretation, evaluation, analysis, inference, explanation, and self-regulation. The use of three classes allowed the researcher to obtain a broader description of students' critical thinking skill improvement across different classroom groups. Since the study used existing classroom groups, the participants were not randomly assigned, which is consistent with the quasi-experimental pretest-posttest design used in this research.

Research instruments

The research instrument used in this study was a critical thinking skills test administered in the form of pretest and posttest. The pretest was given before the implementation of scaffolded Project-Based Learning, while the posttest was given after the learning treatment. The instrument was designed to measure students' critical thinking skills on the topic of food additives.

The critical thinking skills test was developed based on six indicators: interpretation, evaluation, analysis, inference, explanation, and self-regulation. These indicators were used to assess students' ability to understand information, evaluate evidence, analyze problems, draw conclusions, explain arguments, and reflect on their own thinking process. The scores obtained from the pretest and posttest were then converted into a scale of 0–100. The indicators of the research instrument are presented in the following table:

Table 1. Indicators of the critical thinking skills assessment instrument

No.	Critical Thinking Indicator	Aspect Assessed
1	Interpretation	Students' ability to understand and identify important information related to food additives in food and beverage products.
2	Evaluation	Students' ability to assess the accuracy, safety, and relevance of information related to the use of food additives.
3	Analysis	Students' ability to analyze the relationship between types of food additives, their functions, and their possible effects on health.
4	Inference	Students' ability to draw logical conclusions based on data, facts, or information about food additives.
5	Explanation	Students' ability to explain ideas, reasons, and arguments clearly based on evidence.
6	Self-regulation	Students' ability to reflect on their answers, reconsider information, and evaluate their own thinking process.

The same indicators were used in both the pretest and posttest to ensure that the improvement in students' critical thinking skills could be measured consistently. The results of the test were analyzed by comparing the average pretest and posttest scores for each indicator. Furthermore, the N-Gain score was calculated to determine the the N-Gain score was calculated to determine the level of improvement in students' critical thinking skills after participating in scaffolded Project-Based Learning.

Data analysis techniques

Data were collected using a critical thinking skills test administered in two stages: pretest and posttest. The pretest was conducted before the implementation of scaffolded Project-Based Learning to determine students' initial critical thinking skills, while the posttest was administered after the learning intervention to measure students' critical thinking skills following the learning process. Both tests used the same assessment instrument to ensure consistency in measuring students' improvement.

The implementation of scaffolded Project-Based Learning was carried out in three intact classes (Class 8E, Class 8F, and Class 8H) on the topic of food additives. During the learning process, students completed project-based learning activities with teacher scaffolding designed to guide them in identifying problems, analyzing information, drawing conclusions, and developing project outcomes. After the intervention, the posttest was administered using the same instrument as the pretest.

The collected data consisted of students' pretest and posttest scores on six critical thinking indicators: interpretation, evaluation, analysis, inference, explanation, and self-regulation. The data were analyzed descriptively by calculating the mean pretest score, mean posttest score, score improvement, and the normalized gain (N-Gain) for each critical thinking indicator. To determine the effectiveness of scaffolded Project-Based Learning in improving students' critical thinking skills, the normalized gain (N-Gain) was calculated using the formula proposed by Hake (1998):

$$g = \frac{S_{\text{post}} - S_{\text{pre}}}{S_{\max} - S_{\text{pre}}} \tag{1}$$

Information:

- g= normalized gain (N-Gain)
- S_{post}= posttest score
- S_{pre}= pretest score
- $S_{\max}$= maximum possible score

The N-Gain values were interpreted according to the criteria proposed by Hake (1998), as presented in Table 2.

Table 2. Categories of normalized gain (N-Gain)

N-Gain Score	Category
(g \geq 0.70)	High
(0.30 \leq g < 0.70)	Medium
(g < 0.30)	Low

The N-Gain values for each critical thinking indicator were then categorized as high, medium, or low to describe the level of students' improvement after participating in scaffolded Project-Based Learning. Finally, the results were presented descriptively in tables to explain the effectiveness of scaffolded Project-Based Learning in improving students' critical thinking skills across the three participating classes.

RESULTS AND DISCUSSION

Results

Improvement of students' critical thinking skills in class 8E

Table 3. pretest, posttest, and N-Gain scores of critical thinking skills in class 8E

No.	Critical Thinking Indicator	Pretest	Posttest	N-Gain	Category
1	Interpretation	48.3	95.8	0.92	High
2	Evaluation	78.8	95.0	0.76	High
3	Analysis	83.8	92.9	0.56	Medium
4	Inference	45.8	97.9	0.96	High

No.	Critical Thinking Indicator	Pretest	Posttest	N-Gain	Category
5	Explanation	79.2	85.0	0.28	Low
6	Self-regulation	80.0	94.2	0.71	High

Table 3 presents the pretest, posttest, and N-Gain scores of students' critical thinking skills in Class 8E after the implementation of scaffolded Project-Based Learning. Overall, the posttest scores were higher than the pretest scores for all six critical thinking indicators. Among the six indicators, inference obtained the highest N-Gain score (0.96), followed by interpretation (0.92), evaluation (0.76), and self-regulation (0.71), all of which were categorized as high. The analysis indicator obtained an N-Gain score of 0.56 and was categorized as medium, while explanation showed the lowest N-Gain score (0.28), which was categorized as low. These results indicate differences in the level of improvement across the six critical thinking indicators in Class 8E. Detailed comparisons of the pretest, posttest, and N-Gain scores for each indicator are presented in Table 3.

Improvement of students' critical thinking skills in class 8F

Table 4. Pretest, posttest, and N-Gain scores of critical thinking skills in class 8F

No.	Critical Thinking Indicator	Pretest	Posttest	N-Gain	Category
1	Interpretation	56.3	100.0	1.00	High
2	Evaluation	94.6	99.2	0.85	High
3	Analysis	92.5	99.2	0.89	High
4	Inference	54.2	94.6	0.88	High
5	Explanation	92.0	100.0	1.00	High
6	Self-regulation	87.5	100.0	1.00	High

Table 4 presents the pretest, posttest, and N-Gain scores of students' critical thinking skills in Class 8F after the implementation of scaffolded Project-Based Learning. The posttest scores were higher than the pretest scores across all six critical thinking indicators. All six indicators achieved the high category based on the N-Gain analysis. The interpretation, explanation, and self-regulation indicators obtained the highest N-Gain score (1.00). The analysis indicator achieved an N-Gain score of 0.89, followed by inference (0.88) and evaluation (0.85). The results show that all critical thinking indicators in Class 8F were classified in the high improvement category. Detailed data on the pretest scores, posttest scores, N-Gain values, and improvement categories for each critical thinking indicator are presented in Table 4.

Improvement of students' critical thinking skills in class 8H

Table 5. Pretest, posttest, and N-Gain scores of critical thinking skills in class 8H

No.	Critical Thinking Indicator	Pretest	Posttest	N-Gain	Category
1	Interpretation	51.0	99.0	0.98	High
2	Evaluation	88.2	94.4	0.53	Medium
3	Analysis	91.3	100.0	1.00	High
4	Inference	50.7	97.9	0.96	High
5	Explanation	78.0	100.0	1.00	High
6	Self-regulation	91.7	100.0	1.00	High

Table 5 presents the pretest, posttest, and N-Gain scores of students' critical thinking skills in Class 8H after the implementation of scaffolded Project-Based Learning. The posttest scores exceeded the pretest scores for all six critical thinking indicators. Based on the N-Gain analysis, five indicators were categorized as high, namely interpretation (0.98), analysis (1.00), inference (0.96), explanation (1.00), and self-regulation (1.00). The evaluation indicator obtained an N-Gain score of 0.53, which was categorized as medium. Overall, the results indicate that most critical thinking indicators in Class 8H achieved a high level of improvement following the learning intervention.

The detailed results of the pretest scores, posttest scores, N-Gain values, and improvement categories for each critical thinking indicator are presented in Table 5.

Comparison of students' critical thinking skills improvement across the three classes

To provide an overall comparison of the implementation of scaffolded Project-Based Learning, the N-Gain scores of the six critical thinking indicators in Classes 8E, 8F, and 8H were compared. The comparison is presented in Table 6 and Figure 1.

Table 6. Comparison of N-Gain scores of critical thinking skills across classes

Critical Thinking Indicator	Class 8E	Category	Class 8F	Category	Class 8H	Category
Interpretation	0.92	High	1.00	High	0.98	High
Evaluation	0.76	High	0.85	High	0.53	Medium
Analysis	0.56	Medium	0.89	High	1.00	High
Inference	0.96	High	0.88	High	0.96	High
Explanation	0.28	Low	1.00	High	1.00	High
Mean N-Gain	**0.70**	**High**	**0.94**	**High**	**0.91**	**High**

Table 6 shows the N-Gain scores of the six critical thinking indicators in the three participating classes. Class 8F obtained the highest mean N-Gain score (0.94), followed by Class 8H (0.91) and Class 8E (0.70). The complete comparison of the N-Gain scores is illustrated in Figure 1.

Figure 1. Comparison of N-Gain scores of critical thinking skills across classes

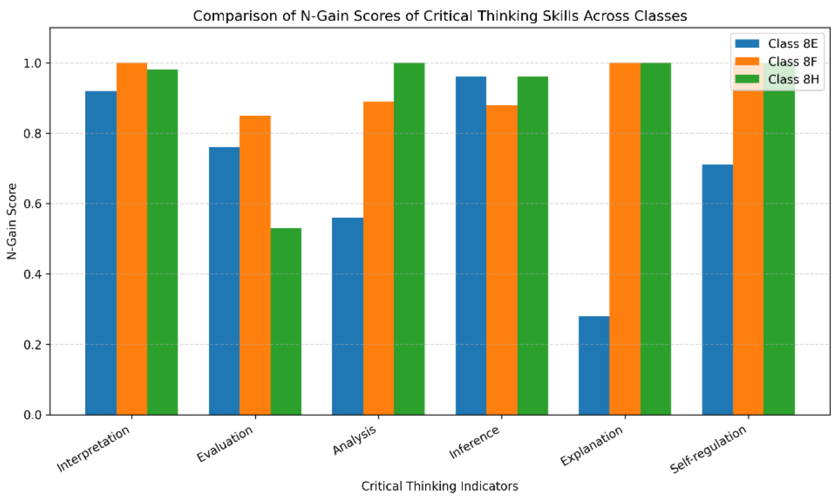

Figure 1 presents the distribution of N-Gain scores across the six critical thinking indicators for the three classes. The figure visually summarizes the differences in students' improvement following the implementation of scaffolded Project-Based Learning, corresponding to the data presented in Table 6.

Discussion

Scaffolded project-based learning improved students' critical thinking skills

The findings of this study indicate that the implementation of scaffolded Project-Based Learning effectively enhanced students' critical thinking skills across the three participating classes. Overall, all classes achieved high levels of improvement, although the magnitude of improvement differed across the six critical thinking indicators. These findings suggest that integrating project-based learning with structured scaffolding creates a learning environment that actively engages students in constructing knowledge through authentic problem-solving rather than passively receiving information. In this study, students investigated real-life issues related to food additives, identified problems, analyzed scientific information, discussed alternative solutions, and presented project outcomes. Such learning experiences required students to actively interpret information, evaluate evidence, analyze relationships among concepts, formulate conclusions, and communicate scientific reasoning, which are fundamental components of critical thinking (Facione, 2015).

The effectiveness of scaffolded Project-Based Learning can be explained through constructivist learning theory, which emphasizes that knowledge is actively constructed through meaningful experiences and social interaction. According to Vygotsky (1978), students achieve higher cognitive performance when they receive appropriate instructional support within their Zone of Proximal Development (ZPD). In this study, scaffolding was provided through teacher guidance, questioning strategies, collaborative discussions, and structured project activities that gradually transferred learning responsibility from the teacher to students. This temporary support enabled students to complete cognitive tasks that would have been difficult to accomplish independently while progressively developing greater learning autonomy. Consequently, students were not only able to understand scientific concepts related to food additives but also apply these concepts to analyze authentic problems encountered in their daily lives.

Another important factor contributing to the improvement in students' critical thinking skills is the nature of Project-Based Learning itself. Unlike conventional teacher centered instruction, Project-Based Learning positions students as active investigators who continuously collect information, evaluate evidence, and revise their understanding throughout the learning process. Thomas (2000) argues that Project-Based Learning encourages meaningful learning because students solve authentic problems through sustained inquiry and collaborative investigation. Similarly, Krajcik and Shin (2014) emphasize that project-based science learning provides opportunities for students to develop higher-order thinking by integrating scientific knowledge with real-world contexts. The findings of the present study support these perspectives, indicating that students demonstrated substantial improvements after participating in project activities supported by systematic scaffolding.

The results are also consistent with recent studies reporting the effectiveness of scaffolded Project Based Learning in promoting critical thinking. Belland et al. (2024) reported that instructional scaffolding significantly enhances students' higher-order thinking by providing cognitive support during complex learning tasks while gradually fostering independent problem-solving abilities. Likewise, Kim and Lim (2024) found that scaffolding within project-based environments improves students' reasoning processes by helping learners organize information, evaluate evidence, and formulate scientific explanations more effectively. These findings suggest that the combination of authentic projects and structured instructional support provides more effective learning experiences than implementing Project-Based Learning without sufficient guidance.

From the perspective of Sustainable Development Goal 4 (SDG 4), the findings demonstrate that scaffolded Project-Based Learning contributes to the development of quality education by promoting competencies required for the twenty-first century. SDG 4 emphasizes not only access to education but also the provision of meaningful learning experiences that develop critical thinking, problem-solving, collaboration, and lifelong learning skills. Through contextual investigations of food additives, students connected classroom knowledge with everyday issues affecting their health and daily decision-making. Therefore, the learning approach implemented in this study not only improved students' critical thinking skills but also supported the broader objective of preparing learners to become scientifically literate, reflective, and responsible citizens capable of addressing real world challenges.

Differences in the improvement of critical thinking indicators

Although scaffolded Project-Based Learning improved students' critical thinking skills across the three classes, the level of improvement varied among the six critical thinking indicators. This variation indicates that each dimension of critical thinking requires different cognitive processes and develops at different rates depending on the nature of the learning activities. According to Facione (2015), critical thinking is a multidimensional construct consisting of interpretation, analysis, evaluation, inference, explanation, and self-regulation. Each component represents a distinct cognitive process, and therefore instructional interventions may influence each indicator differently.

The interpretation and inference indicators consistently demonstrated high improvement across the three classes. These findings suggest that scaffolded Project-Based Learning effectively supported students in identifying relevant information, recognizing scientific concepts, and drawing logical conclusions from the evidence collected during project activities. Throughout the learning process, students were required to investigate food additive products, identify different types of additives, compare information from multiple sources, and determine whether the additives met food safety standards. Such activities encouraged students to interpret scientific information before making evidence-based conclusions. This finding supports Krajcik and Shin (2014), who argue that inquiry-oriented project learning strengthens students' ability to construct meaning from authentic scientific experiences.

Similarly, the analysis indicator showed considerable improvement, particularly in Classes 8F and 8H. Analysis requires students to examine relationships among concepts, identify patterns, distinguish relevant from irrelevant information, and connect scientific evidence with problem situations (Facione, 2015). During project implementation, students analyzed the functions, benefits, and potential health effects of various food additives before proposing solutions or presenting project findings. The structured scaffolding provided by teachers enabled students to organize information systematically, making analytical reasoning more accessible. These findings are consistent with Belland et al. (2024), who reported that scaffolding enhances analytical thinking by reducing unnecessary cognitive load during complex learning tasks.

In contrast, the evaluation indicator showed relatively lower improvement in Class 8H than in the other classes. Evaluation involves judging the credibility, accuracy, and relevance of evidence before making decisions, which requires sophisticated reasoning skills and the ability to compare multiple perspectives (Facione, 2015). Although students participated in project investigations, evaluating the quality of scientific information may have remained challenging because it requires experience in assessing the reliability of evidence rather than simply identifying correct information. Similar findings have been reported by Kim and Lim (2024), who found that students generally require repeated opportunities to evaluate evidence critically before this ability develops consistently.

The explanation indicator also showed notable variation, with Class 8E demonstrating lower improvement than the other two classes. Explanation is one of the most complex components of critical thinking because students must not only understand scientific concepts but also communicate logical arguments supported by valid evidence (Facione, 2015). In project-based learning, students are expected to justify conclusions, defend their opinions, and explain project outcomes systematically. However, junior high school students often experience difficulties in organizing scientific arguments coherently, particularly when they are unfamiliar with evidence-based reasoning. Consequently, explanation skills may develop more gradually than interpretation or inference. This finding aligns with previous research indicating that scientific argumentation requires continuous practice through structured questioning, peer discussion, and teacher feedback (Belland et al., 2024).

Overall, the variation among the six critical thinking indicators demonstrates that scaffolded Project-Based Learning does not influence every cognitive skill to the same extent. Skills closely associated with understanding information and drawing conclusions tended to improve more rapidly, whereas skills involving scientific evaluation and evidence-based explanation required more extensive cognitive processing and sustained instructional support. These findings highlight the importance of designing scaffolding strategies that are specifically aligned with different dimensions of critical thinking so that each cognitive skill can be developed more effectively throughout project-based science learning.

Comparison of critical thinking skill improvement across the three classes

The comparison of N-Gain scores among the three participating classes revealed differences in the magnitude of students' critical thinking improvement following the implementation of scaffolded Project-Based Learning. Although all classes achieved a high overall improvement, Class 8F obtained the highest mean N-Gain score (0.94), followed by Class 8H (0.91) and Class 8E (0.70). These findings indicate that scaffolded Project-Based Learning consistently improved students' critical thinking skills across different classroom settings while producing different levels of learning gains.

The consistently higher mean N-Gain scores in Classes 8F and 8H were also reflected in the performance of individual critical thinking indicators. In Class 8F, all six indicators were categorized as high, with interpretation, explanation, and self-regulation achieving the maximum N-Gain score of 1.00, while analysis (0.89), inference (0.88), and evaluation (0.85) also demonstrated substantial improvement. Similarly, Class 8H showed high improvement in five indicators, including analysis (1.00), explanation (1.00), self-regulation (1.00), interpretation (0.98), and inference (0.96), whereas only the evaluation indicator remained in the medium category (0.53). These findings suggest that most dimensions of critical thinking responded positively to the implementation of scaffolded Project-Based Learning.

In contrast, although Class 8E also achieved an overall high mean N-Gain (0.70), the improvement was more varied across the six indicators. Four indicators reached the high category, namely inference (0.96), interpretation (0.92), evaluation (0.76), and self-regulation (0.71). However, analysis showed only moderate improvement (0.56), while explanation obtained the lowest N-Gain score (0.28) and remained in the low category. This variation indicates that different dimensions of critical thinking developed at different rates, even when students experienced the same learning intervention.

The differences in learning gains among the three classes may be associated with variations in students' initial readiness, classroom learning dynamics, and the way students responded to scaffolded project activities. Although all classes received the same instructional treatment, students entered the learning process with different levels of prior knowledge and learning experiences, which may have influenced how effectively they utilized the scaffolding provided during project completion. According to Vygotsky (1978), instructional support is most effective when it is aligned with learners' Zone of Proximal Development, enabling students to progressively perform tasks that would otherwise be difficult to accomplish independently.

Overall, the comparison across the three classes demonstrates that scaffolded Project-Based Learning consistently promoted students' critical thinking skills. Despite the differences in the magnitude of improvement, all three classes achieved high overall N-Gain categories, providing empirical evidence that integrating authentic project activities with systematic scaffolding can effectively foster critical thinking in junior high school science learning. These findings are consistent with Thomas (2000), who argued that Project-Based Learning promotes meaningful learning through authentic inquiry, and Belland et al. (2024), who emphasized that scaffolding enhances students' higher-order thinking by providing structured cognitive support during complex learning tasks.

CONCLUSION

Fundamental Finding: This study demonstrates that the implementation of scaffolded Project-Based Learning effectively improved junior high school students' critical thinking skills in science learning on the topic of food additives. The findings showed that all three participating classes achieved overall high levels of improvement, with mean N-Gain scores of 0.70 in Class 8E, 0.94 in Class 8F, and 0.91 in Class 8H. The greatest improvements were consistently observed in the interpretation, inference, and self-regulation indicators, whereas the explanation and evaluation indicators demonstrated comparatively lower improvement in some classes. These findings indicate that integrating structured scaffolding into Project-Based Learning effectively supports students in interpreting scientific information, analyzing contextual problems, drawing logical conclusions, and regulating their own learning processes. However, more cognitively demanding skills, such as scientific evaluation and evidence-based explanation, require sustained instructional support and repeated opportunities for scientific argumentation. **Implication:** The findings provide empirical evidence that scaffolded Project-Based Learning is an effective instructional approach for promoting critical thinking in junior high school science education. By engaging students in authentic investigations related to food additives while providing systematic instructional guidance, this learning approach creates meaningful learning experiences that encourage inquiry, collaboration, problem-solving, and reflective thinking. The results suggest that science teachers should integrate structured scaffolding throughout project activities, particularly during evidence evaluation, scientific explanation, and argument construction, to maximize students' higher-order thinking development. Furthermore, these findings contribute to the achievement of Sustainable Development Goal (SDG) 4 by supporting quality, inclusive, and student-centered education that develops essential twenty-first-century competencies required for lifelong learning and responsible citizenship. **Limitation:**

This study was conducted in only three junior high school classes within a single educational context, which may limit the generalizability of the findings to broader educational settings. In addition, the effectiveness of scaffolded Project-Based Learning was evaluated primarily through pretest-posttest measurements of students' critical thinking skills without examining long-term retention or the sustainability of learning outcomes. The study also focused exclusively on the topic of food additives; therefore, the findings may differ when applied to other science topics or educational contexts. **Future Research:** Future studies are recommended to involve larger and more diverse samples from different schools, regions, and educational levels to strengthen the generalizability of the findings. Experimental studies comparing scaffolded Project-Based Learning with other student-centered instructional models would provide stronger evidence regarding its relative effectiveness. In addition, future research should investigate the long-term impact of scaffolded Project-Based Learning on students' critical thinking, scientific argumentation, problem-solving, creativity, and self-regulated learning. Further exploration of digital scaffolding, artificial intelligence-supported learning environments, and interdisciplinary STEM project-based learning is also recommended to examine how innovative instructional approaches can further contribute to the achievement of Sustainable Development Goal (SDG) 4 through high-quality science education.

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AUTHOR CONTRIBUTIONS

Martini: Conceptualization, methodology, investigation, data curation, formal analysis, writing original draft, and visualization. **Erman:** Supervision, validation, writing review and editing, and project administration. **I Gusti Made Sanjaya:** Conceptualization, methodology, supervision, validation, writing review and editing, and resources. All authors have read, reviewed, and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

AI tools were used only for language editing, grammar improvement, and discussion support. The authors take full responsibility for all aspects of the research and the final content of the manuscript.

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