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Problem-Based Learning for Enhancing Scientific Literacy and Conceptual Understanding of Food Additives among Junior High School Students

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Abstract

Background: Scientific literacy is a key competency for students in the 21st century. However, Indonesian students continue to demonstrate relatively low levels of scientific literacy, partly due to teacher-centered instruction and limited contextual learning. Problem-Based Learning (PBL) has the potential to enhance students' engagement, critical thinking, and scientific literacy. This study aimed to examine the effect of the PBL model on students' scientific literacy in learning about food additives. **Methods:** This study employed a true experimental design using a pretest–posttest control group approach. The participants were 72 eighth-grade students from SMP Negeri 19 Ambon, divided equally into an experimental group and a control group. The experimental group was taught using the PBL model, while the control group received conventional instruction. Data were collected through validated scientific literacy and conceptual understanding tests and analyzed using N-gain, paired-sample t-tests, and independent-sample t-tests. **Results:** The average scientific literacy score of the experimental group increased from 56.74 to 85.46, while the control group improved from 58.41 to 74.44. The experimental group achieved a higher N-gain score (0.57) than the control group (0.32). Statistical analyses revealed significant differences between the groups, indicating that students taught through PBL demonstrated greater improvement in scientific literacy and conceptual understanding of food additives. **Conclusion:** Problem-Based Learning effectively improved students' scientific literacy and understanding of food additives. The model promoted critical thinking, problem-solving, and the application of scientific concepts in real-life contexts, making it a valuable strategy for science education.

INTRODUCTION

In today's rapidly changing and information-rich society, students are increasingly required to engage with scientific and socio-scientific issues that directly affect their everyday lives, including food safety, public health, environmental sustainability, and technological change. Meaningful participation in these issues requires more than the ability to recall scientific facts; students need to understand scientific concepts, interpret information and evidence, evaluate scientific claims, explain phenomena, and use scientific reasoning to make informed decisions in authentic contexts. These abilities are particularly important because contemporary students encounter a wide range of scientific information through formal education, digital media, and everyday social interactions. Scientific literacy therefore represents a fundamental competency for contemporary science education and for responsible participation in personal, social, and global life (OECD, 2019). In an increasingly digital information environment, this competency is particularly important because learners must also judge the credibility of scientific information, distinguish evidence-based claims from misinformation, and apply scientific knowledge appropriately when responding to real-world issues (Howell & Brossard, 2021; Mellberg et al., 2025). Consequently, science education needs to provide students with meaningful opportunities to develop not only scientific knowledge but also the reasoning, evaluation, and decision-making skills required to apply that knowledge in everyday situations.

Indonesia's science literacy scores have remained relatively low in recent years compared to other countries. According to the OECD's PISA 2022 report, Indonesian students' science literacy scores were around 383 points. It is below the OECD average of approximately 485 points. Furthermore, only about 34% of students reached the minimum proficiency level, which is Level 2 (OECD, 2023). It indicates that the majority of students still struggle to understand and apply scientific concepts in real-life contexts. When viewed over time, Indonesia's science literacy performance has been fluctuating and has not shown significant improvement. Indonesia's PISA scores showed an increase in 2015 but declined again in 2018 and 2022. In fact, in PISA 2018, Indonesia ranked in the bottom group among participating countries, indicating that students' science literacy competencies remain weak. Nevertheless, there was a slight improvement in Indonesia's ranking in the 2022 PISA, indicating a relative improvement in Indonesia's education system (OECD, 2023).

As preliminary evidence for the present study, the national pattern is also reflected in the educational context of Maluku, where students have been reported to experience difficulties in developing higher-order scientific thinking and applying scientific concepts meaningfully (Leasa, Fenanlampir, et al., 2021). These findings indicate that the challenge of scientific literacy is not limited to national assessment results but is also relevant to the regional learning context. In particular, students require learning experiences that provide opportunities to connect scientific knowledge with authentic situations, analyze information, and construct evidence-based explanations. This preliminary evidence therefore provides an empirical basis for investigating a more contextual and student-centered instructional approach to strengthen scientific literacy among junior high school students in Ambon.

This situation is closely linked to teaching practices that remain dominated by teacher-centered approaches, in which students often act as passive recipients of

information and focus primarily on memorizing facts rather than developing conceptual understanding and problem-solving abilities (Garrett, 2008; Treve, 2024). Such instructional practices provide limited opportunities for students to engage in scientific inquiry, critical thinking, and evidence-based reasoning. Furthermore, the lack of contextual learning experiences makes it difficult for students to connect scientific concepts with real-life situations, reducing the relevance and meaningfulness of science learning. As a result, students tend to demonstrate low levels of scientific literacy and scientific process skills (Dadiara et al., 2026; Hemtasin et al., 2026). Scientific literacy requires not only the acquisition of scientific knowledge but also the ability to interpret data, evaluate information critically, and make decisions based on scientific evidence (Wang et al., 2019). Therefore, there is a growing need to shift from traditional teacher-centered instruction toward more student-centered learning approaches that actively engage students in constructing knowledge and solving authentic problems (Garrett, 2008; Goodwin, 2024).

One promising approach to addressing this challenge is the Problem-Based Learning (PBL) model. PBL emphasizes learning through the investigation and resolution of real-world problems, encouraging students to take an active role in the learning process (Baran & Sozbilir, 2018; Batlolona & Diantoro, 2023). Through collaborative inquiry, discussion, and reflection, students develop higher-order thinking skills, including analysis, evaluation, and problem-solving. Unlike conventional instruction, PBL places students at the center of learning and requires them to seek, evaluate, and apply scientific information to solve contextual problems (Valdez & Bungihan, 2019). Previous studies have demonstrated that PBL can significantly improve students' scientific literacy by engaging them directly in scientific inquiry and evidence-based decision-making processes (Almulla, 2020). In addition, PBL has been shown to foster students' motivation, self-regulated learning, and critical thinking skills, all of which are essential components of scientific literacy in contemporary science education (Dolmans et al., 2016; Muhali & Asy, 2026).

Previous studies have provided evidence that PBL can strengthen scientific literacy, critical thinking, problem-solving, motivation, and self-regulated learning by engaging students in inquiry and authentic problem solving (Dolmans et al., 2016; Almulla, 2020; Muhali & Asy, 2026). However, the existing evidence remains uneven in relation to the topic and setting examined in the present study. First, relatively limited research has examined PBL specifically for learning food additives at the junior high school level, despite the topic's direct relevance to food safety, health, consumer awareness, and students' everyday decision-making. Second, research conducted in Maluku has addressed contextual learning, local resources, STEM, and higher-order thinking, but empirical evidence on PBL for developing scientific literacy through everyday food-related problems remains limited (Hudha et al., 2019; Aksan, 2023). Third, previous studies have often examined scientific literacy or conceptual learning as separate outcomes, leaving insufficient evidence on whether PBL can improve scientific literacy while simultaneously strengthening students' conceptual understanding of food additives. This gap is theoretically important because scientific literacy involves the application of scientific knowledge to authentic problems, while it is practically important because food-additive decisions require students to interpret labels, evaluate information, and judge potential benefits and risks. The present study therefore addresses this gap by empirically comparing PBL-based and conventional instruction among eighth-grade students in

Ambon, using food additives as an authentic learning context and examining both scientific literacy and conceptual understanding as learning outcomes.

Despite these encouraging findings, several research gaps remain. First, previous studies have established the potential of PBL to improve scientific literacy and higher-order thinking skills, but evidence concerning its application to the specific topic of food additives at the junior high school level remains limited. Second, studies conducted in Maluku have emphasized contextual learning, local wisdom, STEM learning, and students' higher-order thinking (Aksan, 2023; Jamaludin et al., 2025), but limited empirical attention has been given to the implementation of PBL specifically for developing scientific literacy through everyday food-related problems. Third, previous research has often focused on scientific literacy or other learning outcomes separately, leaving limited evidence regarding whether PBL can simultaneously strengthen students' scientific literacy and their conceptual understanding of food additives. These gaps indicate the need for a controlled empirical study comparing PBL and conventional instruction within the specific educational context of junior high school students in Ambon.

The Problem-Based Learning (PBL) model is particularly effective for improving students' scientific literacy in the context of food additives because the topic is closely related to students' daily lives. Through PBL, students are encouraged to investigate authentic issues concerning the use of additives in food products, their functions, benefits, and potential health risks. Rather than merely memorizing definitions and classifications, students learn to analyze food labels, evaluate scientific information, and make informed decisions regarding food consumption. This contextualized learning process allows students to construct scientific understanding in meaningful ways and enhances their ability to transfer knowledge to real-life situations. According to context-based science education research, learning experiences that are connected to students' everyday lives significantly improve conceptual understanding and the functional application of scientific knowledge (Suryawati & Osman, 2018; Podschuweit & Bernholt, 2018).

This learning process contributes substantially to the development of scientific literacy, particularly in students' ability to understand, interpret, and utilize scientific information. Through engagement with authentic problems, students learn how scientific concepts can be applied to explain phenomena, evaluate claims, and support evidence-based decision-making. Nainggolan et al. (2021) argues that PBL promotes scientific literacy by encouraging students to explore contextual problems, formulate explanations, and justify conclusions using scientific evidence. Similarly, Dogan (2017) emphasize that context-based approaches enhance the relevance of science education by helping students recognize the connections between classroom learning and everyday experiences. Consequently, students develop a deeper understanding of scientific concepts while simultaneously strengthening their critical thinking and reasoning skills.

In Maluku, the persistently low levels of scientific literacy among students are often associated with instructional practices that have not yet fully emphasized scientific literacy development. Many students still experience difficulties in understanding scientific concepts and applying them to real-life contexts, suggesting that science instruction remains largely focused on theoretical content rather than contextual application (Leasa, Batlolona, et al., 2021). Moreover, the limited integration of local contexts into science instruction reduces students' opportunities to connect scientific concepts with their daily experiences and surrounding environment. In the context of Maluku, local resources, maritime culture, coastal ecosystems, and community traditions provide rich learning

opportunities that can make science education more meaningful and relevant. Previous studies have shown that context-based STEM learning utilizing local environmental and cultural resources can enhance student engagement, improve conceptual understanding, and promote more active and meaningful learning experiences (Harianto et al., 2026). When science learning is linked to students' real-life contexts, learners are better able to understand scientific concepts and apply them to authentic situations, thereby supporting the development of scientific literacy and higher-order thinking skills (Palinussa et al., 2025; Jamaludin et al., 2026). These findings suggest that the underutilization of contextual, innovative, and student-centered learning approaches is one of the major factors contributing to low levels of scientific literacy among students in the region.

Therefore, implementing scientific literacy-oriented instructional models such as Problem-Based Learning represents a promising strategy for improving students' scientific literacy. PBL facilitates meaningful learning by linking scientific concepts to authentic problems that students encounter in their daily lives. Furthermore, integrating local wisdom and environmental phenomena from Maluku into science learning can enhance the relevance and authenticity of educational experiences. Research has consistently demonstrated that culturally responsive and context-based learning environments promote deeper conceptual understanding, higher engagement, and improved scientific literacy outcomes (Limba et al., 2024; Martha et al., 2026). Consequently, combining PBL with local contextual resources may provide an effective framework for strengthening students' scientific literacy and fostering lifelong learning skills.

Building on these research gaps, the novelty of the present study lies in applying PBL as a scientific-literacy-oriented instructional approach using food additives as an authentic everyday-life context for eighth-grade students in Ambon. Unlike previous studies that have primarily examined PBL in relation to general learning outcomes, critical thinking, or scientific literacy in other science topics, this study simultaneously evaluates students' scientific literacy and conceptual understanding of food additives through a comparison between PBL-based and conventional instruction. Furthermore, food additives are not treated merely as curricular content but as authentic problems through which students analyze food products and labels, evaluate the functions and potential effects of additives, interpret scientific information, and make evidence-based decisions related to everyday food consumption. Thus, this study provides contextual empirical evidence regarding the effectiveness of PBL for developing scientific literacy and conceptual understanding among junior high school students in Ambon, Maluku. The topic of food additives is highly suitable for implementation through the PBL model because it offers numerous opportunities for students to investigate real-world issues related to food safety, health, and consumer awareness. Through problem-based activities, students can examine the use of additives in commercially available foods, evaluate potential risks and benefits, and develop evidence-based recommendations for consumers. Such learning experiences encourage students to connect scientific concepts with everyday decision-making processes, thereby strengthening both conceptual understanding and scientific literacy. This research aims to improve students' scientific literacy through the application of the PBL model in science learning at the junior high school level.

METHODS

This study was conducted to investigate the effectiveness of PBL in enhancing students' scientific literacy on the topic of food additives. The study population consisted of 142 eighth-grade students enrolled at SMP Negeri 19 Ambon. Because the students were organized into intact classes, sample selection was conducted at the class level rather than by selecting individual students. Purposive sampling was employed to select two classes with comparable academic characteristics, particularly based on their previous science learning achievement and the recommendation of the science teacher. From the available eighth-grade classes, two classes that met these criteria were selected for participation in the study. After the classes had been selected, one class was designated as the experimental group and the other as the control group. Each selected class consisted of 36 students; therefore, the final sample comprised 72 students, with 36 students in the experimental group and 36 students in the control group. The experimental group received instruction using the PBL model integrated with scientific literacy activities, whereas the control group received conventional instruction. A true experimental method employing a pretest–posttest control group design was adopted to evaluate the impact of the intervention, as presented in Table 1.

Table 1. Pretest-posttest control group design

Group	Pretest	Treatment	Posttest
Experiment	O_1	X (PBL Model)	O_2
Control	O_1	C (Conventional)	O_2

Notes:

O1 : Pretest
X : Treatment using the Problem-Based Learning (PBL) model
C : Conventional learning
O2 : Posttest (final test)

The sampling technique used was purposive sampling (Campbell et al., 2020), assuming that the students' abilities were homogeneous. The instruments used were a science literacy test and a test of students' conceptual understanding of food additives, both developed by the author. For the science literacy skills, an instrument developed based on the *Programme for International Student Assessment* (PISA) science literacy framework was used. It covers four aspects: knowledge, competence, context, and attitudes toward science (OECD, 2019), using a Likert scale.

Table 2. Weighted likert scale values

Criteria	Score
Very Good	4
Good	3
Good Enough	2
Not Good Enough	1

The four components above use an assessment rubric for the following aspects: knowledge (explaining scientific concepts and facts), competencies (explaining scientific phenomena, designing investigations, and interpreting scientific data and evidence),

context (connecting scientific concepts to real-life problems), and attitude (students' interest in and engagement with science learning). Assessment of the instrument is conducted using a 1–4 scale rubric, with score categories of 4 (excellent), 3 (good), 2 (adequate), and 1 (poor) that are adjusted according to the accuracy of answers, analytical ability, completeness of explanations, and students' attitudes during the learning process.

As for the food additives material, some indicators have been developed. The topics include: the definition of food additives; types of food additives (artificial and natural); effects of using food additives; hazardous food additives; food labeling; and connections to science literacy. The questions developed have undergone construct validation by two expert lecturers qualified in their respective fields of science, as well as instrument feasibility testing by two science teachers. The instrument validation process also included a small-scale pilot test of the questions, which were analyzed to determine their validity, reliability, discriminant power, and difficulty level. To determine the effect of implementing PBL on the improvement of science literacy skills, the calculation of the normalized average gain score (N-gain) developed by Hake (1998). The obtained average n-gain scores were then interpreted. Subsequently, the N-gain scores were classified according to the criteria presented in Table 3.

Table 3. Interpretation of average n-gain scores

Score	Criteria
$\langle g \rangle \geq 0.7$	High
$0.3 \leq \langle g \rangle < 0.7$	Medium
$\langle g \rangle < 0.3$	Low

Sources: (Hake, 1998)

The collected data were analyzed using descriptive and inferential statistical techniques. Pretest, posttest, and normalized gain (N-gain) scores from both the experimental and control groups were examined to evaluate the extent of improvement in students' scientific literacy. To identify differences in learning outcomes between the two groups, an independent-samples t-test was performed. In addition, paired-samples t-tests were employed to compare students' performance before and after the intervention within each group and to determine the significance of the observed improvements in scientific literacy.

The study was implemented across five instructional meetings. The first meeting was devoted to administering the pretest, followed by three learning sessions in which the instructional treatments were applied. The final meeting involved the administration of a posttest to measure changes in students' scientific literacy and to compare the outcomes of the experimental and control groups. During the intervention, the experimental group was taught using the Problem-Based Learning (PBL) framework proposed by Arends. This framework encompasses five sequential phases: introducing students to a problem situation, organizing students for learning activities, facilitating investigation, guiding the development and presentation of solutions, and evaluating both the problem-solving process and its outcomes. Previous studies have consistently reported that these PBL stages contribute to the enhancement of critical thinking, problem-solving abilities, and scientific literacy among students (Karan & Brown, 2022; Yu & Zin, 2023; Sholahuddin et al., 2020). In addition, to assess students' level of understanding of the concept of food

additives, the Learning Objective Achievement Criteria (LOAC) were used, with the following scale:

Table 4. Learning objective achievement criteria

Score range	Criteria
86 – 100	Excellent
66–85	Good
41–65	Fair
0–40	Need Guidance

RESULT AND DISCUSSION

The research data consist of students' science literacy scores and their conceptual understanding of food additives, obtained from test scores in the experimental and control classes, which have been validated and are reliable. A summary of the descriptive results of the science literacy ability of eighth-grade students at Public Junior High School 19 Ambon is presented in Table 5.

Table 5. Summary of average science literacy scores

	Pretest		*Posttest*	
Statistics	**Experimental**	**Control**	**Experiment**	**Control**
Average	56.74	58.41	85.46	74.44
Highest Value	70.00	70.00	94.00	77.00
Lowest Value	30.00	25.00	50.00	47.00
(%) Completion Rate	5.5%	90.3%	83%	50%

Table 5 indicates that the mean pretest scores for scientific literacy in the experimental and control groups were 56.74 and 58.41, respectively. The relatively small difference between these scores suggests that both groups had comparable initial levels of scientific literacy before the treatment was administered. The highest pretest score obtained in both groups was 70.00. At this stage, students were generally able to identify scientific concepts and facts, describe scientific phenomena, and recognize scientific information. However, many students still encountered difficulties in providing scientific explanations, linking scientific concepts to everyday situations, and demonstrating awareness of environmental issues and science learning. The lowest score recorded in the experimental group was 30.00, while the control group obtained a minimum score of 25.00. These low scores reflected students' limited ability, as they were only able to explain basic concepts and relate them to daily experiences.

Following the implementation of the learning activities, the posttest results revealed an improvement in scientific literacy skills in both groups. Nevertheless, the increase was more substantial in the experimental group than in the control group. The average posttest score of the experimental group rose to 85.46, whereas the control group achieved an average score of 74.44. The highest score obtained in the experimental group was 94.00. This result indicates that students were able to complete almost all literacy components successfully, although some difficulties remained in interpreting graphical data, which occasionally affected the accuracy of their conclusions. In comparison, the highest score achieved by the control group was 77.00. Students in this

group were generally able to explain scientific concepts and facts, describe scientific phenomena, and read data, but many still struggled to interpret data accurately. They were also capable of relating scientific concepts to real-life contexts and showing positive attitudes toward environmental issues and science learning.

In terms of the lowest scores, the experimental group improved from 30.00 to 50.00, while the control group increased from 25.00 to 47.00. Students who obtained these scores were generally able to explain scientific concepts and phenomena, connect scientific knowledge to everyday situations, and demonstrate concern for science and environmental issues; however, their literacy competencies remained limited compared to higher-achieving students. Therefore, despite the overall improvement shown in the posttest results, several students in both groups still achieved relatively low scores. Differences in learning achievement were also evident from the percentage of students who met the established learning criteria. In the experimental group, the proportion of students achieving mastery increased markedly from 5.5% in the pretest to 83% in the posttest. Meanwhile, in the control group, the percentage increased from 9.03% to only 50%. The considerably higher level of achievement in the experimental group suggests that the majority of students were able to attain the expected learning outcomes after participating in instruction based on the Problem-Based Learning model.

The greater improvement in scientific literacy observed in the experimental group can be attributed to the characteristics of the PBL approach, which actively involves students in solving contextual problems encountered in everyday life. In learning about food additives, students were not only introduced to theoretical concepts but were also encouraged to analyze the use of additives in food products, examine food labels, evaluate potential health impacts, and relate scientific knowledge to real-world situations. Through these learning experiences, students became more engaged in constructing knowledge, developing critical thinking skills, and making decisions based on scientific evidence. As a result, their scientific literacy improved more substantially than that of students who participated in conventional instruction. To determine the magnitude of students' improvement, learning gains were analyzed using the normalized N-gain formula. This analysis was conducted to measure the extent to which students' scientific literacy skills improved before and after the instructional intervention. The results of the N-gain analysis for both the experimental and control groups are presented in Table 6.

Table 6. Results of the *n-gain* test on the improvement in literacy skills

Class	*Pretest*	*Posttest*	N-*Gain*	Category
Control	58.41	74.44	0.32	Moderate
Experimental	56.74	85.46	0.57	Moderate

The N-gain analysis revealed that the experimental group obtained an average score of 0.57, which was classified as moderate. Similarly, the control group achieved an average N-gain of 0.32, also falling within the moderate category. Among the 72 participants, 28 students were categorized as having moderate improvement, while 44 students were classified in the low category, and no students reached the high category. Although both groups were classified within the same N-gain level, the experimental group demonstrated a considerably higher gain score than the control group. This finding indicates that students who participated in the PBL-based instruction experienced greater improvement in scientific literacy, as reflected by the larger increase between their pretest

and posttest scores. To further examine the effectiveness of the intervention, statistical analyses were conducted using t-tests. In addition to calculating the N-gain values, an independent-samples t-test was performed to investigate differences in the average scientific literacy scores between the experimental and control groups. After establishing differences in the mean scores of the two groups, a paired-samples t-test was employed to determine whether significant improvements occurred within each group from pretest to posttest. This analysis was based on students' scores before and after the learning intervention, and the results are presented in Table 7.

Table 7. Comparison of pretest and posttest data

Class	*Pretest*	*Posttest*	N - Gain	Category	T-calculated	T-table
Control	58.41	74.44	0.32	Moderate	12.40	1.98
Experimental	56.74	85.46	0.57	Moderate	19.23	1.98

The paired-samples t-test results revealed that students in the experimental group achieved a t-value of 19.23 at the 0.05 significance level. Given that the critical t-value for df = 71 was 1.98, the obtained t-value was substantially higher than the threshold value. This outcome indicates a statistically significant increase in scientific literacy scores from pretest to posttest, suggesting that the Problem-Based Learning (PBL) intervention effectively enhanced students' scientific literacy. For the control group, the analysis generated a t-value of 12.40, which also exceeded the critical value of 1.98 at the same significance level and degree of freedom. This finding confirms that students' scientific literacy improved following conventional instruction. Nevertheless, the extent of improvement observed in the control group was less pronounced than that recorded in the experimental group. To examine differences between the two instructional approaches, an independent-samples t-test was subsequently performed. The analysis produced a t-value of 8.23, which was considerably greater than the critical value of 1.98. As a result, the null hypothesis was rejected and the alternative hypothesis was accepted, indicating a significant difference in scientific literacy achievement between the two groups. These results provide evidence that students who participated in PBL-based learning demonstrated superior scientific literacy outcomes compared with those who experienced traditional classroom instruction. The graph below shows the level of students' understanding of the concept of additives, divided into the experimental group and the control group as follows:

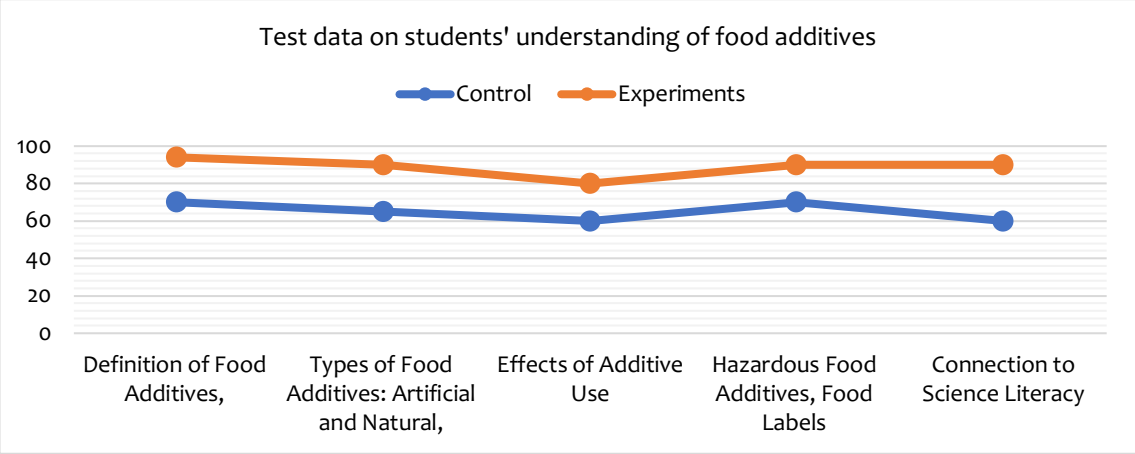


Figure 1. Test data on students' understanding of the concept of food additives

Figure 1 shows that students' understanding of the concept of food additives varies across indicators, with the experimental class consistently scoring higher than the control class. For the indicator of understanding food additives, the experimental class scored 94, far above the control class, which scored 70, indicating a better grasp of the basic concepts. For the indicator on types of food additives (artificial and natural), the experimental class also outperformed the control class, scoring 90 compared to 65. The low scores were attributed to limited classification skills; students tended to memorize rather than truly understand the differences between natural and artificial food additives, and to a lack of relevant, concrete examples in the learning process. Furthermore, regarding the indicator of additive impact, both classes showed a decline compared to other indicators. However, the experimental class's score remained higher (80) than the control class's (60). It indicates that students still have a sufficient understanding of the impact of additive use. Meanwhile, regarding indicators for hazardous food additives and food labels, the experimental class also scored higher (90) than the control class (70), reflecting the students' ability to identify hazardous substances and understand food label information. The most notable difference was observed in the science literacy indicator, where the experimental class scored 90. In contrast, the control class scored only 60 on the impact of additive use and its connection to science literacy (60). The low score indicates that students are not yet able to analyze and relate concepts to real-life situations. It may be due to a learning process that does not sufficiently emphasize high-order thinking activities, such as analysis, evaluation, and problem-solving, which cause students to struggle with understanding the long-term effects of food additives and the importance of making decisions based on scientific information (e.g., reading food labels). Additionally, a lack of active student engagement and a scarcity of contextual approaches also contribute to the limited level of understanding.

The present study revealed that students who learned through the PBL model demonstrated significantly higher scientific literacy achievement than those who received conventional instruction. The experimental group achieved a greater increase in scientific literacy scores and a higher N-gain value than the control group, indicating that PBL provides a more effective learning environment for fostering scientific literacy competencies. These findings reinforce the growing body of evidence suggesting that student-centered pedagogies are more effective than traditional teacher-centered approaches in promoting deeper scientific understanding and transferable skills required in the twenty-first century. One possible explanation for this improvement is that PBL engages students in authentic learning experiences that require active knowledge construction. According to Savery (2006), PBL encourages learners to investigate real-world problems, identify relevant information, and develop evidence-based solutions through collaborative inquiry. Such learning experiences mirror the practices of scientists and support the development of scientific reasoning. In the present study, students were challenged to analyze issues related to food additives that are closely connected to their daily lives. This contextualization likely enhanced students' motivation and enabled them to recognize the relevance of scientific knowledge in solving practical problems.

The substantial increase in scientific literacy scores also suggests that PBL successfully promoted higher-order cognitive processes. Scientific literacy is no longer viewed solely as the acquisition of scientific facts but as the ability to apply scientific knowledge, evaluate evidence, and make informed decisions in complex situations. Holbrook & Rannikmae (2009) argue that scientifically literate individuals must be capable

of critically evaluating scientific information and applying it in personal and societal contexts. Through problem analysis, information gathering, group discussions, and solution development, students in the experimental group were repeatedly exposed to activities requiring critical thinking, argumentation, and evidence-based reasoning. Consequently, they developed a deeper understanding of scientific concepts and their applications. Another important finding concerns students' conceptual understanding of food additives. The experimental group consistently outperformed the control group across all conceptual indicators, suggesting that PBL facilitates meaningful conceptual learning. This finding supports the cognitive engagement theory proposed by Chi et al. (2014), which emphasizes that learning outcomes improve when students actively generate explanations, evaluate information, and interact with learning materials rather than passively receiving information. During the PBL process, students actively examined food labels, discussed potential health effects, and evaluated the safety of food products. Such activities likely strengthened conceptual connections and reduced rote memorization, leading to better learning outcomes.

Despite these positive results, the N-gain value remained within the moderate category. This finding indicates that although PBL contributed significantly to scientific literacy development, the intervention may not have been sufficiently long to produce maximum gains. Scientific literacy is a complex construct involving knowledge, competencies, attitudes, and decision-making abilities that require continuous development over time. Research by Rudolph (2024) suggests that meaningful growth in scientific literacy often requires sustained exposure to inquiry-based and context-oriented learning experiences across multiple instructional units. Therefore, the relatively short duration of the intervention may have limited the extent to which students could internalize scientific inquiry processes and transfer them to new contexts. The lower performance observed on indicators related to analyzing the effects of food additives suggests that students still encountered difficulties when dealing with tasks requiring advanced analytical reasoning. This finding may indicate that students are more accustomed to recalling information than evaluating evidence and drawing conclusions. Osborne (2014) emphasizes that scientific literacy development requires opportunities for students to engage in scientific argumentation, where they must justify claims using evidence and critically assess competing explanations. Therefore, future implementations of PBL should incorporate more structured argumentation activities, data interpretation exercises, and socio-scientific issue discussions to strengthen students' evaluative and reasoning skills.

From an educational perspective, the findings highlight the importance of transforming science classrooms into environments that promote inquiry, collaboration, and contextual problem solving. The improvement achieved through PBL demonstrates that scientific literacy can be enhanced when students are provided with opportunities to engage actively in authentic scientific practices. Particularly in the Indonesian context, where scientific literacy achievement remains a major educational challenge, the adoption of PBL may serve as an effective strategy for bridging the gap between theoretical knowledge and practical application. By positioning students as active participants in knowledge construction, PBL supports the development of scientifically literate citizens capable of addressing contemporary societal challenges. Overall, the findings suggest that PBL is not only effective in improving students' conceptual understanding but also contributes substantially to the development of scientific literacy competencies. However,

achieving higher levels of scientific literacy may require longer implementation periods, repeated exposure to inquiry-based learning experiences, and the integration of socio-scientific issues that encourage deeper critical reflection and evidence-based decision-making.

CONCLUSION

The implementation of the PBL model has been shown to improve students' science literacy at a moderate level, with the most significant improvement observed in scientific competence or process. These findings indicate that problem-based learning is effective in developing investigative skills, critical thinking, and a positive attitude toward science through students' active engagement in solving contextual problems. Although the improvement in the application of science continues to improve, this study's results reinforce that PBL is a relevant strategy for supporting the development of multidimensional science literacy. The implementation of the PBL model has been shown to improve students' science literacy to a moderate degree, with the most significant improvement observed in scientific competence or process. These findings indicate that problem-based learning is effective in developing investigative skills, critical thinking, and a positive attitude toward science through students' active engagement in solving contextual problems. Although the improvement in the application of science continues to improve, the results of this study reinforce that PBL is a relevant strategy for supporting the development of multidimensional science literacy. Further research is recommended to implement interventions over a longer period and with a larger sample to obtain a more comprehensive picture of effectiveness. This improvement is evident in students' ability to explain scientific phenomena, interpret data, and relate scientific concepts to everyday life contexts. However, this study has several limitations. First, the study was conducted at a single school with a small sample size, so the generalizability of the findings remains limited. Second, the study period was relatively short, so it was not yet able to illustrate the long-term impact of implementing *the Problem-Based Learning* model. Third, the instruments used were limited to measuring aspects of science literacy, so they did not comprehensively cover all dimensions. Given these limitations, it is recommended that future researchers conduct studies with a broader scope, involving more schools, and employing stronger research designs such as experiments or longitudinal studies. Additionally, more comprehensive science literacy instruments need to be developed, and local contexts should be integrated more deeply into the learning process. Theoretically, this study contributes to research on the effectiveness of the PBL model in enhancing science literacy, particularly in the context of education in Indonesia. This study also reinforces the relationship between problem-based learning and the development of higher-order thinking skills in science literacy. From both a scientific and a practical perspective, the results of this study can serve as a reference for teachers and education practitioners in designing more contextually relevant and science-literate science learning. Furthermore, this study can serve as a foundation for developing learning policies that improve the quality of science education at the junior high school level.

DECLARATION OF GENERATIVE AI

During the preparation of this work, the author used ChatGPT to assist with paraphrasing sentences, grammar checking, and improving the clarity of the manuscript. The author also used Grammarly to assist with grammar and language editing. After using thesetools, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

CONFLICTING INTEREST STATEMENT

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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