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Effectiveness of STEM Project Using *Caesalpinia sappan L.* Natural Dye to Enhance High School Students' Chemical Literacy and Food Safety Awareness

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Abstract
This study examined changes following STEM-integrated Project-Based Learning (STEM-PjBL) using natural dye extracted from secang wood (*Caesalpinia sappan* L.) to examine chemical literacy and describe post-intervention food safety awareness in acid–base learning. A pre-experimental one-group pretest–posttest design was employed with 35 eleventh-grade students selected through purposive sampling. Data were collected using a validated chemical literacy test and a food safety awareness questionnaire. Validation scores ranged from 93% to 100%, and chemical literacy test reliability was acceptable (Cronbach's alpha = 0.80). The Shapiro–Wilk test indicated that posttest scores were not normally distributed ($p = .001$); therefore, the Wilcoxon signed-rank test was used to examine differences between pretest and posttest scores. The results showed a significant increase in chemical literacy, with the mean score increasing from 46.88 to 88.29. The Wilcoxon test indicated a statistically significant difference ($Z = -5.193$, $p < .001$), with a large effect size ($r = 0.88$). The N-gain was 0.78, indicating a high level of improvement. The post-intervention food safety awareness questionnaire score was 85.29%; no baseline awareness score was available. These findings indicate an improvement in chemical literacy scores following STEM-PjBL, while food safety awareness was described only after the intervention.

Keywords: Acid–base; Chemical literacy; Food safety awareness; Secang wood natural dye; STEM-PjBL.

INTRODUCTION

Chemistry learning requires students to understand chemical concepts and relate them to observable phenomena in everyday life. However, chemistry is often perceived as a highly theoretical subject because many chemical concepts involve submicroscopic phenomena that cannot be directly observed. This difficulty is particularly evident in topics such as acid–base chemistry, which requires students to understand abstract concepts and connect them with observable phenomena, including changes in indicator color (Assi & Cohen, 2024; Wiyarsi et al., 2021). Limited laboratory facilities and opportunities for practical activities may further restrict students' experiences in connecting theoretical knowledge with direct experimentation (Im et al., 2023; Jegstad, 2024). Consequently, chemistry learning needs to provide contextual and practical learning experiences that enable students to investigate chemical phenomena, interpret experimental evidence, and relate chemical concepts to real-life applications. Project-based activities that can be conducted using simple and accessible materials may provide an alternative approach for connecting chemical theory with practice and supporting students' conceptual understanding and engagement (Cao et al., 2025; Minata et al., 2022). Contextual chemistry instruction is also reviewed by Demelash et al. (2023) and Assi and Cohen (2024).

These learning challenges are closely related to the development of chemical literacy. Chemical literacy refers not only to the acquisition of chemical facts but also to students' ability

to understand chemical concepts, interpret chemical information, explain phenomena using chemical knowledge, and apply that knowledge in relevant contexts. Recent research describes chemical literacy as involving conceptual knowledge, interpretation of evidence, and informed decisions in socially relevant contexts (Sjöström & Yavuzkaya, 2024; Wiyarsi et al., 2021). In the present study, chemical literacy is operationalized through students' ability to apply acid–base concepts, interpret pH and indicator evidence, explain observed chemical phenomena, and relate chemical concepts to a real-life food context. These competencies are particularly relevant to acid–base learning because students are required to move beyond memorizing definitions toward interpreting experimental observations and explaining them using appropriate chemical concepts. Therefore, learning activities that provide opportunities to investigate, interpret, and apply chemical knowledge are needed to support the development of students' chemical literacy. Comparable emphasis on evidence and application appears in Febriningtyas and Dwiningsih (2024), Alwathoni et al. (2024), and Ruslan and Agus (2024).

The application of chemical knowledge in food-related contexts is also important because food safety remains a relevant public-health concern. The inappropriate use of synthetic food dyes may expose consumers to substances that are not permitted for food use and may pose health risks (Limon, 2022; Sameshima & Akamatsu, 2023). Food-safety education can help students evaluate food-colorant information and distinguish permitted food additives from substances not intended for consumption (Limon, 2022; Sameshima & Akamatsu, 2023). Such conditions indicate the importance of helping students recognize the relationship between chemical substances, their properties, and the safety of their use in food. Chemistry education can therefore provide a meaningful context for developing students' understanding and concern regarding food safety, particularly by introducing safer alternatives and encouraging students to critically consider the materials used in food products. In this study, food safety awareness is examined separately from chemical literacy through a questionnaire administered after the learning intervention; it is not treated as the direct measure of the effectiveness of the learning intervention. Educational evidence also distinguishes food-safety knowledge from subsequent behavior (Limon, 2022). Natural origin alone does not establish food-use safety; suitability depends on the material, preparation, intended use, and applicable safety standards (Limon, 2022; Septiyani et al., 2025).

One potential contextual material for connecting acid–base chemistry with food safety is secang wood (*Caesalpinia sappan* L.), a locally available natural dye source that has long been used in Indonesia. Secang wood contains brazilin as a major coloring compound, which can be oxidized to brazilein and produces characteristic color changes under different conditions (Irawan et al., 2022). The color response of brazilein is influenced by pH, making secang extract relevant for demonstrating acid–base concepts through observable changes in color. This characteristic provides an opportunity for students to investigate the relationship between chemical conditions and visible changes in a natural material. Previous studies have also reported the potential of secang wood as a natural dye for food applications (Irawan et al., 2022; Septiyani et al., 2024, 2025), as well as its potential applications in textiles (Muslimin et al., 2024) and cosmetics (Septiyani et al., 2025). Its reported antioxidant, antibacterial, and anti-inflammatory properties have further supported interest in secang as a functional natural material (Septiyani et al., 2024; Vij et al., 2023). However, its use as a contextual learning material for integrating acid–base chemistry, chemical literacy, and food safety awareness in high-school chemistry remains limited. Recent analyses also document the chemical sensitivity and color stability of sappan pigments in beverages (Septiyani et al., 2024, 2025).

The use of secang wood as a learning context can be integrated with a Science, Technology, Engineering, and Mathematics (STEM) approach through project-based learning. STEM provides opportunities for students to integrate scientific concepts with technology, engineering processes, and mathematical reasoning while solving contextual problems and developing products. Project-based learning, meanwhile, provides students with opportunities to plan, investigate, develop, test, and communicate solutions to authentic problems. Previous studies

have reported that STEM-based project learning can support students' chemistry knowledge and awareness of food-related sustainability issues (Fitriyana et al., 2024; Hidayah et al., 2025). Studies involving STEM-PjBL in chemistry education have also reported improvements in students' science literacy and learning outcomes (Dibyantini et al., 2023; Wiyarsi et al., 2021). In the context of secang wood, students can investigate the extraction of a natural dye, examine its color response in different acid–base conditions, and apply the extract in a food product. Such activities provide opportunities to connect chemical concepts with experimentation, product development, interpretation of evidence, and real-life food applications. Thus, STEM-PjBL offers a pedagogically relevant framework for addressing the identified learning problem while utilizing an accessible natural material. Broader reviews identify project work as a promising context for chemistry reasoning and assessment (Ahmad et al., 2023; Cao et al., 2025; He et al., 2023; Santhosh et al., 2023).

Although previous studies have demonstrated the potential of natural dyes and STEM-based project learning in chemistry education, an important gap remains. Existing studies have generally examined natural dyes as materials for food, textile, or cosmetic applications, or have investigated STEM-PjBL as an approach for improving science or chemistry learning outcomes. Fewer studies have specifically integrated secang wood (*Caesalpinia sappan* L.) as a natural dye into a STEM-PjBL activity that simultaneously connects acid–base chemistry, chemical literacy, and food safety awareness in a high-school learning context. In addition, the limited laboratory facilities identified as a learning constraint create a need for project activities that can be implemented using simple and accessible materials without depending on a fully equipped laboratory. Therefore, the unresolved problem is whether a contextual STEM-PjBL project using secang wood can provide a feasible learning experience while improving students' chemical literacy and supporting their food safety awareness. Addressing this gap is particularly relevant for high-school chemistry learning in settings where practical resources are limited. Context-rich chemistry projects can be supported by locally available materials, but their learning effects require design-specific evidence (Barkah et al., 2025; Salelatu & Rohaeti, 2023).

Based on this gap, this study aims to examine changes following a STEM project using secang wood (*Caesalpinia sappan* L.) as a natural dye in improving high-school students' chemical literacy in acid–base chemistry and to describe students' food safety awareness following the learning activity. Chemical-literacy effectiveness is evaluated through students' performance on pretest and posttest essay questions, whereas food safety awareness is assessed separately using a questionnaire administered after the intervention. The study therefore focuses on the potential of a contextual STEM-PjBL activity to connect acid–base concepts with observable phenomena and food-related applications while providing evidence of changes in students' chemical literacy and their food safety awareness. Research on chemistry literacy and contextual teaching similarly emphasizes assessment of both knowledge and application (Minata et al., 2022; Ramadanty et al., 2025).

METHODS

Research Design

This study employed a quantitative approach with a pre-experimental one-group pretest–posttest design. The study was conducted at SMA Negeri 14 Pontianak during the even semester of the 2025/2026 academic year. The sampling frame consisted of 105 Grade XI students. Using purposive sampling, 35 students from Grade XI A were selected as participants based on the suitability of the class for the STEM-PjBL intervention and the research schedule. The study focused on acid–base chemistry and was conducted in a school setting with limited laboratory facilities. The intervention was implemented in two meetings, with the participating students attending both meetings. The research design is presented in Table 1. Similar classroom interventions highlight the need to interpret one-group pretest–posttest changes cautiously when no comparison group is available (Rediani, 2024; Yudiana et al., 2025).

Table 1. One-group pretest-posttest design

Group	Pretest	Treatment	Posttest
Experiment	O_1	X	O_2

Notes:

O_1 = pretest measurement of students' chemical literacy
X = STEM-PjBL intervention using secang wood (*Caesalpinia sappan L.*) as a natural dye and acid–base indicator
O_2 = posttest measurement of students' chemical literacy

The chemical literacy test consisted of five essay questions covering acid–base concepts and their application in food-related contexts. The same five questions were administered as the pretest and posttest to maintain item equivalence and enable direct comparison of students' performance before and after the intervention. Each question was scored using a predetermined scoring rubric, with a maximum score of 20 points per item and a total possible score of 100. The pretest was administered before the STEM-PjBL intervention, while the posttest was administered after the intervention was completed. The interval between the pretest and posttest corresponded to the two-meeting STEM-PjBL intervention. Related work emphasizes the alignment of project activities, evidence-based explanation, and assessment tasks (S. A. Sari et al., 2025; Suryawan & Mitarlis, 2024).

Validation of Learning Materials and Research Instruments

Validation was conducted before the learning intervention to determine the content appropriateness of the learning materials and research instruments. The materials and instruments subjected to validation consisted of the lesson plan (RPP), pretest and posttest questions, project assessment rubric, and food-safety concern questionnaire. Thus, the validation process covered both learning-material validation and research-instrument validation, rather than serving as an outcome measure of the intervention. Three validators were involved in the validation process, consisting of two chemistry lecturers and one high-school chemistry teacher. The validators assessed the materials and instruments using validation sheets covering relevant aspects of content, language, and presentation. The percentage score for each validated component was calculated by comparing the score obtained with the maximum possible score and multiplying the result by 100%. The interpretation of the validation percentage followed the criteria presented in Table 2 below. Content and reliability evidence provide complementary information when evaluating chemistry learning instruments (Febriningtyas & Dwiningsih, 2024; Zakariya, 2022).

Table 2. Classification of Validation Results

Percentage (%)	Validation Criteria
76-100	Valid
56-75	Fairly Valid
40-55	Less Valid
0-39	Invalid

(based on the study's validation classification).

Food-Safety Concern Questionnaire

Students' food safety awareness was measured separately from chemical literacy using a 10-item questionnaire administered after the STEM-PjBL intervention. The questionnaire was intended to obtain students' responses concerning food-safety issues related to the use of coloring substances in food. The questionnaire consisted of positively and negatively worded statements. Negative statements were reverse-scored before the total questionnaire score was calculated. Educational interventions that combine demonstrations and accessible visual cues offer relevant, although indirect, pedagogical comparisons (Ahmadi et al., 2025; Rasyid et al., 2025).

The questionnaire used a four-point Likert scale. A response of 1 represented "Strongly Disagree," while a response of 4 represented "Strongly Agree." The complete response scale used in the questionnaire is presented in Table 3 below.

Table 3. Food Safety Awareness Rating Scale

Rating	Criteria
Strongly Disagree	1
Disagree	2
Agree	3
Strongly Agree	4

For negatively worded items, the scoring direction was reversed before the total score was calculated. The total questionnaire score was obtained by summing the scores of all 10 items after reverse scoring. The obtained score was then compared with the maximum possible score and converted into a percentage.

In the original study, this percentage was subsequently interpreted using a practicality classification. To avoid conflating the constructs of food safety awareness and practicality, the questionnaire is treated in this study as the instrument for measuring students' food safety awareness, whereas the resulting percentage classification is reported only as the interpretation category used in the original scoring procedure. The practicality criteria are presented in Table 4 below.

Criterion score = highest score × number of aspects × number of respondents

Table 4. Practicality Assessment Criteria

Persentage	Criteria
0 % - 20 %	Impractical
21 % - 40 %	Less Practical
41 % - 60 %	Fairly Practical
61 % - 80 %	Practical
81 % - 100 %	Very Practical

The formula used to calculate practicality is as follows:

$$P\ (\%) = \frac{\text{total score}}{\text{criterion score}} \times 100\ \%$$

Reliability of the Research Instrument

Reliability testing was conducted to examine the internal consistency of the research instrument before its use in the main study. The reliability testing involved the essay instrument used to assess students' chemical literacy. The instrument consisted of five essay questions covering the acid–base topic. The reliability test was conducted with students who had previously studied the acid–base material at SMA Taman Mulia. Reviews of inquiry-based chemistry learning underline the importance of linking hands-on activities with explanations of chemical phenomena (Jegstad, 2024; Varadarajan & Ladage, 2024).

Internal consistency was evaluated using Cronbach's alpha. This coefficient was selected because the five essay items were intended to assess related aspects of the same chemical-literacy construct. The resulting coefficient was interpreted using the reliability criteria presented in Table 5 below.

$$r_{11} = \left(\frac{n}{n-1}\right)\left(1 - \frac{\Sigma ó_i^2}{ó_i^2}\right) (1)$$

Table 5. Reliability Criteria

Coefficient Interval	Criteria
0.800–1.000	Very High
0.600–0.799	High
0.400–0.599	Moderate
0.200–0.399	Low

0.000–0.199	Very Low

Data Analysis

Data were analyzed to answer the research questions and test the research hypothesis. The analysis proceeded in the following sequence: (1) content validity analysis of the learning materials and instruments; (2) reliability analysis of the chemical literacy test; (3) a normality test (Shapiro–Wilk, appropriate for n < 50) on the pretest and posttest scores; (4) based on the normality result, a nonparametric Wilcoxon signed-rank test on the paired pretest–posttest difference scores, with the hypotheses stated as H0: there is no significant difference between pretest and posttest chemical literacy scores, and H1: there is a significant difference between pretest and posttest chemical literacy scores, evaluated at a 95% confidence level (α = .05); (5) N-gain calculation using the formula N-gain = (posttest score − pretest score) / (maximum possible score − pretest score); (6) effect size calculation using $r = Z / \sqrt{N}$, where Z is the Wilcoxon test statistic and N is the number of paired observations; and (7) descriptive analysis of the food safety awareness questionnaire. No missing data were recorded, as all 35 students completed both the pretest and posttest. Recent research stresses the importance of aligning assessment instruments with the intended learning constructs (Sulastri et al., 2025; Suryawan & Mitarlis, 2024).

RESULTS AND DISCUSSION

Results

The learning materials and research instruments were validated by three validators, comprising two Chemistry Education lecturers and one chemistry teacher. The validation results showed that the lesson plan, project assessment rubric, chemical literacy test, and student practicality questionnaire obtained scores of 95%, 100%, 93%, and 98%, respectively. Based on the validation criteria, all components were categorized as valid and suitable for use in the study.

The reliability test was conducted using the five-item chemical literacy test with students who had previously studied acid–base concepts. The instrument obtained a Cronbach's alpha coefficient of **0.80**, indicating good internal consistency. Therefore, the chemical literacy test was considered reliable for measuring students' chemical literacy. The coefficient describes the essay test only; it should not be assumed to establish the questionnaire's reliability (Zakariya, 2022). The Shapiro–Wilk results showed that the pretest scores were normally distributed (W = .943, p = .067), whereas the posttest scores were not (W = .873, p = .001). The results are presented in Table 6.

Table 6. Shapiro–Wilk Normality Test Results

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	w	df	p
Pretest	.165	35	.017	.943	35	.067
Posttest	.196	35	.002	.873	35	.001

The Shapiro–Wilk test results presented in Table 6 indicated that the pretest scores were normally distributed, $W(35)$ = .943, p = .067, whereas the posttest scores significantly deviated from normality, $W(35)$ = .873, p = .001. Because the posttest scores did not meet the normality assumption, a nonparametric Wilcoxon Signed-Rank test was used to examine the difference between pretest and posttest chemical literacy scores.

The Wilcoxon Signed-Rank Test was used to examine the paired difference between pretest and posttest chemical literacy scores. The null hypothesis stated that there was no difference between the scores, while the alternative hypothesis stated that a difference existed. The results are presented in Table 7.

Table 7. Wilcoxon Signed-Rank Test Results

	Posttest - Pretest
Z	-5.193[b]
Asymp. Sig. (2-tailed)	< .001

The test showed a statistically significant difference between pretest and posttest scores (Z = -5.193, p < .001). The rank results are presented in Table 8.

Table 8. Wilcoxon Signed-Rank Test Ranks

		N	Mean Rank	Sum of Ranks
Posttest – Pretest	Negative Ranks	0[a]	.00	.00
	Positive Ranks	35[b]	18.00	630.00
	Ties	0[c]		
	Total	35		

The results in Table 8 show that all 35 students had positive ranks, with no negative ranks or ties, indicating that posttest scores were higher than pretest scores for all students.

The normalized gain (N-Gain) was calculated to assess the improvement in students' chemical literacy from pretest to posttest. The mean N-Gain was 0.7796, indicating a high level of improvement following the STEM-based PjBL intervention using secang wood natural dye. This finding should be interpreted cautiously because N-Gain is bounded between 0 and 1, while the posttest scores were relatively high. As only the mean N-Gain was available, individual N-Gain distributions were not reported. Prior studies of project-based science learning likewise report potential literacy gains, while emphasizing variations in study design and implementation (Alfiah et al., 2025; Desyafrianti & Aini, 2024).

The effect size was calculated from the Wilcoxon Signed-Rank Test using the formula $r = |Z|/\sqrt{N}$. The obtained effect size was r = 0.878, indicating a large effect. This result indicates that the observed pretest–posttest difference was substantial following the STEM-based PjBL intervention. The effect size is reported as an absolute value; therefore, the negative sign of the Wilcoxon Z statistic is not retained. A confidence interval was not estimated because individual-level effect-size data were not available.

The STEM-based PjBL intervention was implemented over two days, on May 21 and 22, 2026, with the learning activities conducted according to the planned instructional stages. The activities integrated science, technology, engineering, and mathematics through the extraction and application of secang wood natural dye. The implementation stages and corresponding STEM components are presented in Table 9. The inclusion of an applied food product provides a local context; related studies discuss the value of experiential product making and context-rich project work (Barkah et al., 2025; Hidayah et al., 2025).

Table 9. Implementation of STEM-Based PjBL using Secang Wood Natural Dye on Acid–Base Material

PjBL Stage	STEM Stage	STEM Component	PjBL-STEM Outcome
Formulating the essential question	Reflection	Science: Understanding the acid–base concept and the color change of secang wood at various pH levels. Technology: Identifying problems related to the use of synthetic dyes in food. Engineering: Determining the requirements for the secang wood natural dye project. Mathematics: Determining the variables and quantities of materials used.	Students are able to identify problems, formulate questions, and establish the objectives of the secang wood natural dye project as an acid–base indicator and food colorant.

PjBL Stage	STEM Stage	STEM Component	PjBL-STEM Outcome
Designing the project plan	Research	Science: Gathering information on secang wood, natural indicators, and the acid–base concept. Technology: Analyzing extraction methods and the utilization of natural dyes. Engineering: Developing a design for producing the natural dye. Mathematics: Calculating the tools and materials needed.	Students are able to develop a project design based on scientific information obtained from various sources.
Creating a project schedule	Discovery	Science: Determining the stages of the experiment. Technology: Preparing tools and materials. Engineering: Developing the project work procedure. Mathematics: Allocating time for each stage of the project..	Students are able to systematically develop a schedule and work procedure for the project.
Monitoring project implementation	Application	Science: Extracting secang wood and testing color changes in acidic and basic solutions. Technology: Using laboratory equipment correctly. Engineering: Producing the natural dye and applying it to jelly (agar-agar). Mathematics: Processing and presenting observation results in the form of simple tables or graphs.	Students are able to carry out the project, test the results, and apply the acid–base concept in everyday life.
Testing the results and evaluating the experience	Communication	Science**:** Drawing conclusions from the experiment results. Technology: Presenting the results using presentation media. Engineering: Evaluating the resulting product. Mathematics: Interpreting the observation data.	Students are able to present the project results, evaluate the process and product produced, and relate the benefits of natural dyes to food safety.

The project performance scores were assessed using the project rubric covering project planning, project implementation, and observation of experimental results. The average scores of the three student groups are presented in Table 10.

Table 10. Average Project Assessment Scores by Student Group

Assessment Aspect	Group 1	Group 2	Group 3
Assessment Aspect	95	90	100
Project Planning	90	95	95
Project Implementation	100	95	100
Observation of Experimental Results	95	85	90
Average	**95.00**	**91.25**	**96.25**

As presented in Table 10, Group 3 obtained the highest average score (96.25), followed by Group 1 (95.00) and Group 2 (91.25). All groups achieved scores above 90, indicating a high level

of performance across the assessed project domains. These project scores were used descriptively to evaluate project implementation and were not included in the inferential analysis. Students' food safety awareness was assessed using a 10-item questionnaire after the intervention. The questionnaire used a Likert scale, and the results are presented in Table 11.

Table 11. Summary of Students' Food Safety Awareness Questionnaire

Respondents	Total	Maximum Score	Average	Criteria
35 Students	1194	1400	85.29	Very Practical

The questionnaire yielded a total score of 1,194 out of 1,400, corresponding to 85.29%, which fell within the highest category of the original practicality scale, although that scale does not directly classify food safety awareness. This result describes students' reported responses regarding food safety awareness following the intervention and does not directly indicate changes in food safety behavior.

Discussion

The improvement in students' chemical literacy can be related to the learning activities implemented through STEM-based PjBL using secang wood natural dye. The project required students to identify problems, formulate questions, design procedures, and conduct experiments. During the extraction and acid–base testing activities, students observed changes in the color of secang wood extract under different conditions. These activities provided direct experiences for explaining chemical phenomena and interpreting experimental results. The application of the extract as a natural food colorant also enabled students to relate acid–base concepts to an everyday context. Furthermore, presenting and evaluating the project results supported students' ability to communicate scientific information and draw conclusions from experimental evidence. Contemporary research identifies connections among contextual tasks, student inquiry, and practical science knowledge as important components of chemistry learning (Beskara & Wiyarsi, 2024; Setiawan et al., 2025).

Related chemistry education studies have examined PjBL-oriented worksheets for chemical literacy (Suryawan & Mitarlis, 2024) and STEM-PjBL modules for scientific literacy and learning motivation (Dibyantini et al., 2023). The present study extends these findings by applying STEM-based PjBL to acid–base learning through a project involving secang wood natural dye. However, the present intervention involved 35 students and was conducted over two days. Differences in sample characteristics, intervention duration, and learning context should therefore be considered when comparing the findings. The results should be interpreted within the context of the present study rather than generalized to other populations. Other relevant studies discuss project-based learning in chemistry and its relationship with students' scientific literacy (Halimatuzzahra & Louise, 2025; S. A. Sari et al., 2025; Sulistina et al., 2024).

Students' responses to the 10-item food safety awareness questionnaire produced a score of 85.29%, indicating a high level of reported awareness according to the predetermined criteria. The use of secang wood as a natural food colorant provided a contextual connection between chemistry learning and food safety issues. Through the project, students were exposed to the consideration of materials used in food products and the relevance of natural colorants. This finding is consistent, who emphasized the need to strengthen students' food safety knowledge and awareness through contextual educational approaches. Nevertheless, the present study did not include a baseline measurement of food safety awareness. Therefore, the 85.28% result should not be interpreted as evidence of an increase in awareness. Responses may also have been influenced by social-desirability bias, particularly because the questionnaire was administered after the intervention. School-based food-safety education can support awareness, but self-reported perceptions should not be equated with observed safer practices (Limon, 2022; Sameshima & Akamatsu, 2023). The post-intervention score must not be interpreted as a measured increase because no pre-intervention awareness questionnaire was administered.

The integration of science, technology, engineering, and mathematics provided a contextual learning environment in which students could apply chemical concepts through practical activities. The extraction process involved scientific observation, the preparation and use of equipment involved technology, the development and application of the natural dye involved engineering, and the measurement and interpretation of experimental results involved mathematical reasoning. These integrated activities may have supported students' active engagement with chemical concepts and their application in a real-world context. This interpretation is consistent with Cao et al. (2025), who found that STEM-based PjBL supports active and contextual learning. However, the present study did not directly measure whether students transferred their reported food safety awareness into safer food-selection or food-handling behavior. Future research should therefore include behavioral measures, longer intervention periods, and comparison groups to examine the sustainability and transferability of the observed outcomes. Related findings on learning engagement and project approaches have also been reported in different subjects and student populations (Rasyid et al., 2025; Y. P. Sari et al., 2025; Sidik et al., 2025).

CONCLUSION

STEM-based Project-Based Learning (PjBL) using secang wood natural dye demonstrated positive outcomes in students' chemical literacy on acid–base material. The contextual project activities supported students in explaining chemical phenomena, interpreting experimental results, applying chemical concepts, and communicating scientific findings. The Wilcoxon Signed-Rank Test showed a significant difference between pretest and posttest scores, with the N-Gain value indicating a high level of improvement. Students also reported a high level of food safety awareness following the learning intervention.

Overall, STEM-based PjBL using secang wood natural dye provides a meaningful contextual approach that connects acid–base concepts with practical applications in food-related contexts. The findings were obtained from a single-group design without a comparison group and a short two-day intervention, defining the scope of the present study. Within this context, the learning approach demonstrated positive outcomes in students' chemical literacy and reported food safety awareness.

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