Jurnal Pustaka Indonesia (JPI)
2026, Vol. 6, No. 2, 452–472
https://doi.org/10.62159/jpi.v6i2.2586

OPEN ACCESS Research Article

Development of a Problem Based Learning Science E-Module Integrating *Ledre* Local Wisdom to Foster Junior High School Students' Critical Thinking Skills

Nofal Binti ali Mahfud[1], Sifak Indana[2*], Isnawati[3]
[1-3] Faculty of Mathematics and Natural Sciences, State University of Surabaya, Surabaya, Indonesia

Abstract
This study aimed to develop and evaluate a Problem-Based Learning (PBL)-based science e-module integrating the local wisdom of *Ledre* to support junior high school students' critical thinking skills on the topic of food additives. The study employed a Research and Development (R&D) approach using the 4D model consisting of the Define, Design, Develop, and Disseminate stages. The developed product was evaluated in terms of its validity, practicality, and its potential to support improvements in students' critical thinking skills. Product validity was assessed by subject-matter experts, instructional media experts, and science education practitioners using Aiken's V. Practicality was evaluated through learning implementation observations, teacher and student response questionnaires, and readability analysis. The potential improvement in students' critical thinking skills was examined using a one-group pretest-posttest design involving 64 eighth-grade students from two classes receiving the same instructional treatment. Students' critical thinking scores were analyzed using the Normalized Gain (N-Gain) and the Wilcoxon Signed-Rank Test. The developed science e-module achieved an average Aiken's V coefficient of 0.93, indicating high validity, while the assessment instrument demonstrated good reliability (Cronbach's Alpha = 0.815). Practicality evaluation showed highly positive classroom implementation and user responses, indicating that the e-module was feasible for classroom application. Students' mean critical thinking scores increased from 43.55 on the pretest to 83.73 on the posttest, with an average N-Gain score of 0.6965 (moderate category). The Wilcoxon Signed-Rank Test indicated a statistically significant difference between the pretest and posttest scores ($p < 0.001$), accompanied by a very large effect size ($r = 0.87$). These findings provide preliminary evidence that the developed science e-module may support improvements in junior high school students' critical thinking skills through contextual science learning integrating *Ledre* local wisdom. However, because the study employed a one-group pretest-posttest design without a comparison group, further studies using more rigorous experimental designs are recommended to confirm the effectiveness of the developed e-module.

ARTICLE HISTORY
Received : 29 March 2026
Revised : 25 June 2026
Accepted : 4 July 2026

KEYWORDS
Problem-Based Learning; critical thinking skills; digital learning materials; food additives; local wisdom

CORRESPONDING AUTHOR
*** Sifak Indana**, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya, Surabaya, Indonesia. Email: Sifakindana@unesa.ac.id

Introduction

Science education plays a fundamental role in developing students' scientific reasoning, problem-solving abilities, and evidence-based decision-making skills. In the twenty-first century, science learning is expected not only to promote conceptual understanding but also to foster higher-order thinking skills, particularly critical thinking. Critical thinking is recognized as one of the core competencies within the 4C framework (critical thinking, creativity, communication, and collaboration), enabling students to respond effectively to increasingly complex scientific and technological challenges (Zubaidah, 2018). Nevertheless, numerous studies have consistently

reported that Indonesian junior high school students continue to demonstrate relatively low levels of critical thinking in science learning. Musahrain et al. (2024) reported that junior high school students achieved an average critical thinking score of only 34.26%. Likewise, the Programme for International Student Assessment (PISA) has consistently shown that Indonesian students experience difficulties in interpreting scientific information, evaluating scientific evidence, and solving contextual scientific problems (OECD, 2019). Although these national findings illustrate the broader challenges of science education in Indonesia, improving students' critical thinking requires instructional approaches that address classroom realities and local educational needs.

One factor contributing to the limited development of students' critical thinking skills is the continued dominance of teacher-centered instructional practices. Science instruction in many Indonesian schools still relies heavily on lectures and printed textbooks, providing limited opportunities for students to investigate scientific phenomena, analyze evidence critically, and construct knowledge through authentic problem solving (Dewi et al., 2023; Ratna et al., 2025). This issue is particularly evident in the topic of food additives, which requires students not only to understand scientific concepts but also to evaluate the use of food additives, assess their potential health impacts, and make informed decisions based on scientific evidence. Consequently, food additives constitute an appropriate topic for fostering critical thinking when supported by contextual learning resources and inquiry-oriented instructional models.

To identify the instructional problems addressed in this study, a needs analysis was conducted among junior high school science teachers in Bojonegoro Regency, East Java, Indonesia. Online questionnaires were distributed to 33 teachers, of whom 22 completed the survey, yielding a response rate of 66.7%. The questionnaire explored four aspects, namely current instructional practices, the implementation of Problem-Based Learning, the availability of instructional materials, and the need for digital learning resources. The results revealed that instruction on food additives remained predominantly lecture- and textbook-oriented, while learning materials specifically designed to facilitate Problem-Based Learning and develop students' critical thinking skills were still limited. Furthermore, most teachers expressed a need for digital instructional resources, particularly science e-modules and electronic student worksheets (e-LKPD), to support more interactive and student-centered learning. These findings provided the empirical basis for developing the proposed science e-module.

Problem-Based Learning (PBL) has been widely recognized as an instructional model capable of fostering critical thinking by engaging students in authentic scientific problem solving. In PBL, learning begins with meaningful problems that encourage students to identify issues, collect relevant information, conduct investigations, and formulate evidence-based solutions (Arends, 2012; Barrows, 2002; Sari et al., 2021). Previous studies have consistently demonstrated that PBL contributes positively to students' critical thinking skills in science education (Hidayati & Purwaningsih, 2023; Suhirman & Khotimah, 2020). However, the effectiveness of PBL can be enhanced when learning activities are situated within contexts that are familiar and meaningful to students. Integrating local wisdom through ethnoscience provides opportunities for connecting scientific concepts with students' cultural experiences, thereby making science learning more contextual, relevant, and meaningful.

One form of local wisdom with considerable potential for contextual science learning is *Ledre*, a traditional snack originating from Bojonegoro Regency. Ledre is prepared from bananas, rice flour,

coconut milk, sugar, and salt, and its production process reflects several scientific concepts related to food additives, including the use of natural additives, physical and chemical changes during food processing, and the influence of ingredients on food quality. Investigating the preparation of Ledre enables students to compare natural and synthetic food additives, evaluate their functions and potential impacts, and formulate evidence-based conclusions. Consequently, the production process of Ledre provides an authentic scientific context through which students can develop the critical thinking skills of interpretation, analysis, evaluation, and inference.

Although numerous studies have demonstrated the effectiveness of Problem-Based Learning in promoting students' critical thinking skills, and others have emphasized the educational value of integrating local wisdom through ethnoscience, these approaches have generally been investigated independently. Most PBL studies have focused primarily on instructional strategies without systematically embedding local wisdom throughout each phase of learning. Conversely, ethnoscience-based studies have commonly used local wisdom merely as contextual enrichment rather than as authentic scientific inquiry that guides students through the complete Problem-Based Learning process. Furthermore, relatively few studies have developed digital science learning materials that simultaneously integrate Problem-Based Learning, local wisdom, and food additive content within a single instructional product specifically designed to foster critical thinking.

The novelty of this study lies in the development of a Problem-Based Learning-based science e-module that systematically integrates *Ledre* local wisdom into every phase of the learning process. Rather than functioning merely as cultural enrichment, the production process of Ledre serves as an authentic scientific inquiry context that enables students to formulate scientific questions, investigate the use of natural and synthetic food additives, evaluate scientific evidence, compare alternative explanations, and construct evidence-based conclusions. Furthermore, all learning activities and assessment tasks were intentionally aligned with the four critical thinking indicators proposed by Facione (2015), namely interpretation, analysis, evaluation, and inference. Through this systematic integration of cultural context, instructional design, and critical thinking assessment, the developed science e-module offers a more comprehensive and contextual approach than conventional Problem-Based Learning materials.

Therefore, this study aimed to develop a Problem-Based Learning science e-module integrated with Ledre local wisdom on the topic of food additives that is valid, practical, and capable of supporting improvements in junior high school students' critical thinking skills. Specifically, the study aimed to determine the validity of the developed science e-module, evaluate its practicality in classroom implementation, and examine its effectiveness in improving junior high school students' critical thinking skills.

Method

This study employed a Research and Development (R&D) approach to develop a Problem-Based Learning (PBL)-based science e-module integrating the local wisdom of *Ledre* on the topic of food additives to support junior high school students' critical thinking skills. The study adopted the 4D development model proposed by Thiagarajan et al. (1974), which consists of four sequential stages: Define, Design, Develop, and Disseminate. The overall development procedure is illustrated in Figure 1.

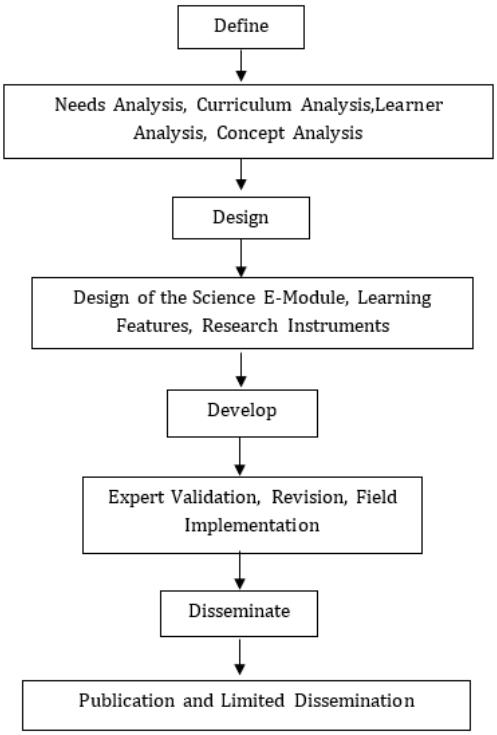

Figure 1. Development Process of the Problem-Based Learning Science E-Module Integrated with Ledre Local Wisdom (Adapted from Thiagarajan et al., 1974)

During the Define stage, a comprehensive preliminary analysis was conducted, including needs analysis, curriculum analysis, learner analysis, and concept analysis. The needs analysis involved distributing online questionnaires to 33 junior high school science teachers in Bojonegoro Regency, East Java, Indonesia, of whom 22 teachers completed the questionnaire, yielding a response rate of 66.7%. The analysis indicated that instruction on food additives remained predominantly lecture- and textbook-oriented, while digital instructional materials specifically designed to facilitate Problem-Based Learning and foster students' critical thinking skills were still limited. These findings served as the empirical foundation for developing the science e-module.

During the Design stage, the structure of the science e-module, learning activities, research instruments, and assessment procedures were systematically designed. The syntax of Problem-Based Learning was integrated with the local wisdom of *Ledre*, a traditional food originating from Bojonegoro Regency. The learning activities were intentionally organized to facilitate contextual scientific inquiry and develop students' critical thinking skills through authentic problem-solving experiences.

The Develop stage involved expert validation conducted by three validators representing a subject-matter expert, an instructional media expert, and a science education practitioner. Suggestions from the validators were incorporated through several revisions to improve instructional content, language clarity, media presentation, and the integration of local wisdom before the classroom implementation.

Finally, the Disseminate stage consisted of limited dissemination of the finalized science e-module through digital links and QR codes to participating science teachers and the partner school. Because this study primarily focused on product development and initial implementation, no large-scale dissemination evaluation was conducted.

The field implementation involved 64 eighth-grade students from two intact classes at SMP Negeri 1 Margomulyo, Bojonegoro Regency, East Java, Indonesia, during the 2025/2026 academic year. Both classes received the same instructional intervention using the developed Problem-Based Learning science e-module integrating *Ledre* local wisdom. To minimize instructional variation, both classes were taught by the same researcher using identical lesson plans, instructional procedures, learning materials, teaching duration, and assessment instruments. Consequently, data from both classes were pooled and analyzed as a single intervention group.

To examine changes in students' critical thinking skills following the implementation of the developed science e-module, this study employed a One-Group Pretest–Posttest Design, as illustrated below.

$$\mathbf{O_1 - X - O_2}$$

where:

- O_1 = Pretest
- X = Learning using the developed Problem-Based Learning science e-module integrated with *Ledre* local wisdom
- O_2 = Posttest

Students completed the pretest before the instructional intervention and the posttest after completing all learning activities. Because the study did not include a comparison group, changes observed between the pretest and posttest scores should not be interpreted as definitive causal evidence of the effectiveness of the developed e-module. Instead, the findings provide preliminary evidence regarding the feasibility of the developed instructional product and its potential to support improvements in students' critical thinking skills. Future studies employing controlled experimental designs are recommended to confirm these findings..

Several research instruments were employed to evaluate the quality of the developed science e-module in terms of validity, reliability, practicality, and students' critical thinking performance. Students' critical thinking skills were assessed using four contextual essay questions in the pretest and four parallel contextual essay questions in the posttest. The assessment measured four critical thinking indicators adapted from Facione (2015), namely:

- Interpretation
- Analysis
- Evaluation
- Inference

The parallel items were designed to minimize testing effects while maintaining equivalent cognitive demands. Each response was evaluated using an analytic scoring rubric ranging from 0 to 4 points. The critical thinking test consisted of four contextual essay items administered as the pretest and four parallel essay items administered as the posttest. The items were developed to assess four critical thinking indicators adapted from Facione (2015), namely interpretation, analysis, evaluation, and inference. Each item was scored using a five-level analytic rubric ranging from 0 (no response or scientifically incorrect answer) to 4 (complete, accurate, and well-reasoned response). Consequently, the maximum raw score was 16 points (4 items × 4 points), which was subsequently converted to a 100-point scale using the formula: Final Score = (Raw Score/16) × 100. All student responses were scored by the researcher using the validated analytic scoring rubric to ensure consistency in scoring. Responses that were incomplete or partially correct were evaluated according

to the rubric descriptors, with emphasis placed on the quality of scientific reasoning rather than linguistic expression.

Table 1. Specification of the Critical Thinking Test

Component	Description
Test format	Contextual essay questions
Pretest	4 essay items
Posttest	4 parallel items
Critical thinking indicators	Interpretation, Analysis, Evaluation, Inference
Scoring rubric	Analytic rubric (0–4 points per item)
Maximum raw score	16 points
Score conversion	Final Score = (Raw Score ÷ 16) × 100
Scorer	Researcher using a validated analytic scoring rubric

To evaluate the practicality of the developed science e-module, five instruments were employed:

1. Learning implementation observation sheet;
2. Student activity observation sheet;
3. Teacher response questionnaire;
4. Student response questionnaire; and
5. Readability analysis using the Fry Graph.

Table 2. Research Instruments and Data Analysis Techniques

Aspect	Instrument	Data Analysis Technique
Validity	E-module validation sheet and instrument validation sheet	Aiken's V and validity percentage
Reliability	Critical thinking test	Cronbach's Alpha
Practicality	Learning implementation observation sheet, student activity observation sheet, teacher response questionnaire, student response questionnaire, and readability test	Percentage analysis and Fry Graph
Improvement in students' critical thinking skills	Pretest and posttest	N-Gain, normality test, Wilcoxon Signed-Rank Test, and effect size

Content validity was established through expert judgment to determine whether the developed science e-module and research instruments adequately represented the intended constructs. The Aiken's V coefficient (Aiken, 1985) was employed to quantify the degree of agreement among experts using the following equation::

$$V = \frac{\sum s}{n(c-1)}$$

where:

V = Aiken's validity coefficient;

s = the score assigned by each validator minus the lowest possible score;

n = the number of validators; and

c = the number of rating categories.

Values approaching 1.00 indicate stronger agreement among experts and higher content validity (Aiken, 1985).

The internal consistency of the critical thinking test was evaluated using Cronbach's Alpha (Cronbach, 1951), with a coefficient of 0.70 or higher considered acceptable for research purposes. Because the instrument consisted of constructed-response (essay) items, all student responses were scored by the researcher using the same validated analytic scoring rubric to ensure scoring consistency throughout the assessment process. The scoring rubric was developed based on the critical thinking indicators and was reviewed during the expert validation process to ensure that the scoring criteria were clear, consistent, and aligned with the intended constructs. Furthermore, the quality of the test items was supported through item validity analysis using Pearson's product-moment correlation and item sensitivity analysis, providing evidence that each item was capable of measuring and distinguishing improvements in students' critical thinking skills following the implementation of the developed science e-module. The item sensitivity analysis indicated that all test items demonstrated satisfactory sensitivity, confirming their ability to detect changes in students' critical thinking performance before and after the learning intervention.

The practicality of the developed science e-module was analyzed descriptively using percentage scores obtained from classroom implementation observations, student learning activities, teacher responses, student responses, and readability evaluation. Students' improvement in critical thinking skills was analyzed using the Normalized Gain (N-Gain) proposed by Hake (1999).

$$N\text{-}Gain = \frac{Posttest - Pretest}{Maximum\ Score - Pretest}$$

Table 3. Interpretation Criteria for Normalized Gain (N-Gain)

N-Gain Score	Interpretation
$g \geq 0.70$	High
$0.30 \leq g < 0.70$	Moderate
$g < 0.30$	Low

Before hypothesis testing, the normality of the paired differences between pretest and posttest scores was examined using the Kolmogorov–Smirnov and Shapiro–Wilk tests. Because the data were not normally distributed, the Wilcoxon Signed-Rank Test was employed to compare students' pretest and posttest scores at a significance level of 0.05. In addition, the effect size (r) was calculated to determine the magnitude of the observed changes.

The findings were interpreted based on the magnitude of the N-Gain score, the statistical significance of the Wilcoxon Signed-Rank Test, and the calculated effect size. Considering the one-group pretest–posttest design, these analyses provide preliminary evidence regarding changes in students' critical thinking skills following the implementation of the developed science e-module rather than definitive causal conclusions.

Permission to conduct the study was obtained from SMP Negeri 1 Margomulyo, Bojonegoro Regency, Indonesia, prior to data collection. Participation was voluntary, and all participants were informed about the purpose of the study. Students' identities were anonymized during data analysis, and all collected data were used exclusively for research purposes. The implementation of the study was coordinated with the school administration and the participating science teachers to ensure that all instructional activities were conducted according to the planned research procedures.

Result and Discussion

Development of the Problem-Based Learning Science E-Module Integrated with Ledre Local Wisdom

This study resulted in the development of a Problem Based Learning (PBL) based science e-module integrated with the local wisdom of *Ledre* on the topic of food additives for improving junior high school students' critical thinking skills. The product was developed using the 4D development model consisting of the Define, Design, Develop, and Disseminate stages (Thiagarajan et al., 1974).

The Define stage identified several instructional problems through needs analysis, curriculum analysis, concept analysis, and learner analysis. The results showed that science instruction on food additives was still dominated by lecture-based teaching and textbook-oriented learning, limiting students' opportunities to investigate scientific phenomena and solve authentic problems independently. These findings confirmed the need for developing a digital learning resource capable of facilitating student-centered learning and improving critical thinking skills.

During the Design stage, the science e-module was systematically designed by integrating the syntax of Problem Based Learning (PBL) with the local wisdom of *Ledre*, a traditional food originating from Bojonegoro Regency. The learning activities were organized to encourage students to investigate authentic problems related to food additives through contextual scientific inquiry.

The final product was developed as a Heyzine digital flipbook, enabling students to access the learning materials using smartphones or laptops. The science e-module consists of three major learning features, namely Exploration Zone, Science Investigation, and Self-Assessment. These features were specifically designed to facilitate the four critical thinking indicators adopted from Facione (2015), namely interpretation, analysis, evaluation, and inference.

A distinctive characteristic of the developed science e-module is the systematic integration of *Ledre* local wisdom throughout every stage of Problem-Based Learning. Rather than functioning merely as cultural enrichment, the production process of *Ledre* serves as an authentic learning context that enables students to investigate the use of natural food additives, compare them with synthetic additives, analyze scientific evidence, and formulate evidence-based conclusions.

Table 4. Characteristics of the Developed Science E-Module

Characteristic	Description
Format	Heyzine digital flipbook
Subject Matter	Food Additives
Learning Approach	Problem-Based Learning
Local Wisdom Integration	Ledre (Traditional Food of Bojonegoro)
Main Learning Features	Problem Orientation (Exploration Zone), Science Investigation (e-Presentation of Investigation Results, Self-Assessment
Supporting Media	Videos, QR Codes, Live Worksheets
Critical Thinking Skills	Interpretation, Analysis, Evaluation, Inference
Accessibility	Smartphones and Laptops
Integration within PBL	Ledre is used as an authentic problem context throughout every stage of Pr Based Learning to help students analyze the use of food additives in r situations.

The characteristics presented in Table 3 indicate that the developed e-module functions not only as a digital learning resource but also as a contextual instructional medium that promotes students' critical thinking through authentic scientific problem-solving activities.

Figure 2. Representative Pages of the Developed Problem-Based Learning Science E-Module Integrating *Ledre* Local Wisdom

Figure 2 presents representative pages of the developed Problem-Based Learning (PBL) science e-module integrating Ledre local wisdom. Figure 2(a) shows the cover page, which introduces the identity and theme of the instructional product. Figure 2(b) illustrates the *Problem Orientation* stage through the *Exploration Zone*, where students are introduced to authentic problems

related to the traditional food *Ledre* using videos and guiding questions. Figure 2(c) presents the *Science Investigation* section, in which students conduct inquiry activities using an electronic student worksheet (e-LKPD). Figure 2(d) demonstrates the stage where students develop and present the results of their investigations in the form of educational posters. Finally, Figure 2(e) presents the *Self-Assessment* feature, which enables students to evaluate their conceptual understanding through online formative assessments. Collectively, these features demonstrate the systematic integration of Ledre local wisdom into every phase of the Problem-Based Learning process while supporting the development of students' critical thinking skills through interactive digital learning.

The design of the developed e-module reflects the instructional characteristics of Problem-Based Learning by engaging students in authentic problem-solving activities from problem orientation to self-evaluation. In addition, the integration of multimedia components, such as videos, QR codes, electronic worksheets, and online assessments, enhances students' learning experiences and promotes independent learning. These features distinguish the developed product from conventional printed teaching materials by providing a more interactive, contextual, and technology-enhanced learning environment.

Validity of the Developed Science E-Module

The developed science e-module was evaluated by three validators representing a subject-matter expert, an instructional media expert, and a science education practitioner. The validation covered eight evaluation aspects, namely content feasibility, local wisdom integration, alignment with Problem-Based Learning, critical thinking development, interface design and layout, e-module features, instructional media and ease of use, and language.

Table 5. Validation Results of the Developed Science E-Module

Evaluation Aspect	Aiken's V	Validity (%)	Category
Content Feasibility	1.00	100.00	Highly Valid
Local Wisdom Integration	0.67	75.00	Valid
Alignment with Problem-Based Learning	1.00	100.00	Highly Valid
Critical Thinking Development	0.89	91.67	Highly Valid
Interface Design and Layout	1.00	100.00	Highly Valid
E-Module Features	0.89	91.67	Highly Valid
Instructional Media and Ease of Use	1.00	100.00	Highly Valid
Language	1.00	100.00	Highly Valid
Average	0.93	94.79	Highly Valid

As presented in Table 4, the developed science e-module achieved an average Aiken's V coefficient of 0.93 with an overall validity percentage of 94.79%, indicating that it belongs to the highly valid category. The high Aiken's V coefficient indicates strong agreement among experts regarding the relevance and appropriateness of the developed e-module. Similar findings have been reported in educational instrument development studies employing Aiken's V to establish content validity (An Nabil et al., 2022). These findings demonstrate that the developed e-module satisfies the essential quality requirements concerning instructional content, learning design, language, visual appearance, and alignment with the Problem-Based Learning model. Five evaluation aspects content feasibility, alignment with Problem-Based Learning, interface design, instructional media, and language obtained perfect validity scores (100%), indicating that the developed e-module fulfills the quality standards expected for digital instructional materials.

The critical thinking development aspect achieved a validity percentage of 91.67%, indicating that the learning activities were considered appropriate for facilitating the critical thinking indicators of interpretation, analysis, evaluation, and inference proposed by Facione (2015). The local wisdom integration aspect obtained the lowest validity percentage (75%), although it remained within the valid category. The validators recommended strengthening the relationship between the Ledre production process and the scientific concepts of food additives throughout each phase of the Problem-Based Learning activities. In response to these recommendations, the science e-module was revised by clarifying the scientific relevance of the Ledre production process, strengthening the contextual learning activities, and improving the integration of local wisdom across the learning sequence. The revised version was subsequently reviewed by the same validators, who confirmed that the recommended revisions had been adequately addressed and approved the revised product for field implementation. Because no second round of expert validation was conducted after the revisions, the validity percentages reported in Table 5 represent the initial expert evaluation. The local wisdom integration aspect obtained a validity score of 75%, indicating that although it met the minimum criteria for validity, it required further refinement based on the validators' recommendations. The suggested revisions focused on strengthening the integration of Ledre local wisdom within the learning activities and critical thinking tasks. These revisions were incorporated into the final version of the science e-module prior to classroom implementation. However, because no second round of expert validation was conducted after the revisions, the validity score reported in Table 5 represents the initial expert evaluation. Therefore, the post-revision improvements should be interpreted as revisions made in response to expert feedback rather than empirically verified improvements in validity.

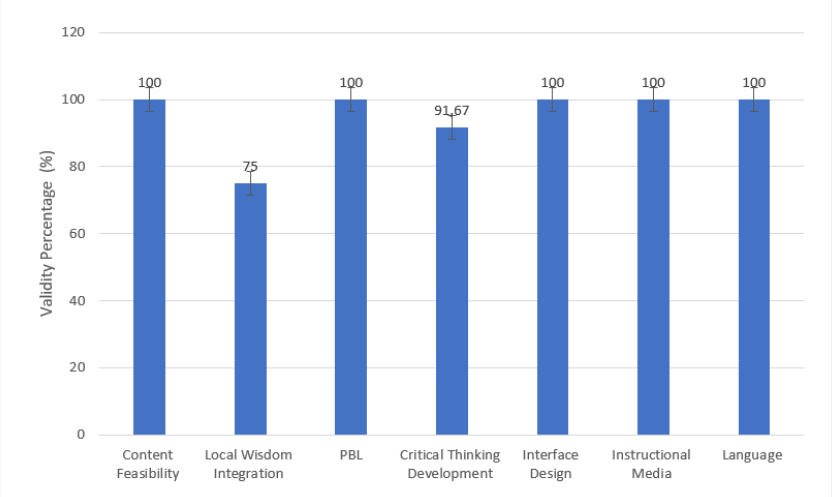

Figure 3. Validity Percentage of Each Evaluation Aspect of the Developed Science E-Module

Validity of the Critical Thinking Test Instrument

Prior to classroom implementation, the critical thinking assessment instrument was evaluated by three validators, consisting of a subject-matter expert, an educational assessment expert, and a science education practitioner. The evaluation focused on content relevance, item construction, and language.

Table 6. Validation Results of the Critical Thinking Test Instrument

Evaluation Aspect	Aiken's V	Validity (%)	Category
Content Relevance	0.93	95.00	Highly Valid
Item Construction	0.91	93.40	Highly Valid
Language	0.94	95.90	Highly Valid
Average	0.93	94.77	Highly Valid

The results presented in Table 5 indicate that the critical thinking assessment instrument achieved an average Aiken's V coefficient of 0.93 with an overall validity percentage of 94.77%, indicating excellent content validity. The language aspect obtained the highest score, demonstrating that the assessment items were scientifically accurate, linguistically appropriate, and readily understood by junior high school students. Likewise, the content relevance and item construction aspects achieved excellent agreement among the validators, confirming that the instrument appropriately measures the four targeted critical thinking indicators proposed by Facione (2015).

Reliability of the Critical Thinking Test Instrument

The reliability of the critical thinking assessment instrument was evaluated using Cronbach's Alpha to determine its internal consistency.

Table 7. Reliability Analysis of the Critical Thinking Test Instrument

Instrument	Cronbach's Alpha	Category
Critical Thinking Test	0.707	Reliable

As shown in Table 7, the critical thinking assessment instrument achieved a Cronbach's Alpha coefficient of 0.707, indicating acceptable internal consistency. According to Arikunto (2017), a reliability coefficient greater than 0.80 reflects excellent reliability. Therefore, the developed assessment instrument can be considered reliable and appropriate for evaluating students' critical thinking skills during the implementation of the developed science e-module. Overall, the validity and reliability findings demonstrate that both the developed science e-module and the critical thinking assessment instrument satisfy the quality standards required for educational research and classroom implementation.

Practicality of the Developed Science E-Module

The practicality of the developed science e-module was evaluated based on readability, learning implementation, student learning activities, teacher responses, and student responses during the classroom implementation. These aspects were used to determine the feasibility of the developed e-module for supporting science learning in junior high schools.

Table 8. Summary of the Practicality Evaluation of the Developed Science E-Module

Aspect	Result	Category
Readability (Fry Graph)	Level 9	Appropriate
Learning Implementation	96.04%	Highly Practical
Student Learning Activities	93.26%	Highly Practical
Teacher Responses	92.25%	Highly Practical
Student Responses	89.34%	Highly Practical

As presented in Table 8, the developed Problem-Based Learning science e-module integrated with *Ledre* local wisdom demonstrated an excellent level of practicality. The readability analysis using the Fry Graph indicated that the e-module corresponded to Grade Level 9, with an average of

6.38 sentences and 154.8 syllables per 100 words. These findings indicate that the language complexity of the e-module is appropriate for junior high school students, allowing them to understand the instructional content independently throughout the learning process.

The observation of learning implementation achieved a percentage of 96.04%, categorized as highly practical. This finding indicates that all stages of Problem Based Learning, including problem orientation, organizing students, guiding investigations, developing and presenting solutions, and evaluating the problem-solving process, were successfully implemented during classroom instruction. Furthermore, the integration of *Ledre* local wisdom into each learning stage effectively connected scientific concepts with students' real-life experiences.

Student learning activities obtained a percentage of 93.26%, indicating that students actively participated throughout the instructional process. Students were engaged in identifying scientific problems, collecting and analyzing information, evaluating scientific evidence, discussing alternative solutions, and drawing evidence-based conclusions. These learning activities directly supported the development of the four critical thinking indicators proposed by Facione (2015).

Teacher responses reached 92.25%, indicating highly positive perceptions toward the developed science e-module. Teachers considered the instructional materials easy to implement, systematically organized, and well aligned with the principles of Problem Based Learning. In addition, teachers acknowledged that integrating *Ledre* local wisdom made science learning more contextual and meaningful. Similarly, student responses achieved 89.34%, indicating that students perceived the science e-module as attractive, easy to use, and helpful for understanding the topic of food additives through authentic real-world situations. The integration of local wisdom also enhanced students' motivation by connecting scientific concepts with familiar cultural experiences.

These findings are consistent with those reported by Nurmasitoh et al. (2025), who concluded that ethnoscience-based digital learning materials are highly practical and capable of increasing students' participation and engagement during science learning. Likewise, Sari et al. (2021) emphasized that integrating local wisdom into science instruction enhances students' learning experiences by connecting scientific concepts with their sociocultural environment. Overall, the practicality evaluation demonstrates that the developed science e-module is highly practical and suitable for supporting contextual, student-centered science learning.

Observed Changes in Students' Critical Thinking Scores

Changes in students' critical thinking scores following the implementation of the developed science e-module were examined using descriptive statistics, the Normalized Gain (N-Gain), and the Wilcoxon Signed-Rank Test. The N-Gain analysis was used to describe the magnitude of students' score improvement, whereas the Wilcoxon Signed-Rank Test was employed to examine whether the observed changes between the pretest and posttest scores were statistically significant.

Table 9. Descriptive Statistics of Students' Critical Thinking Scores and N-Gain Results

Parameter	Value
Number of Students	64
Mean Pretest Score	54,59
Mean Posttest Score	85,35
Mean N-Gain	0.70
N-Gain Category	High

As shown in Table 9, the mean critical thinking score increased from 54.59 on the pretest to 85.35 on the posttest. The average N-Gain score was 0.70, which falls within the high improvement category according to Hake (1999). This finding indicates that students experienced substantial improvement in their critical thinking skills following the implementation of the developed science e-module. The mean increase in students' critical thinking scores was 30.76 points, demonstrating a meaningful improvement in learning outcomes across the sample. Although these findings suggest that the developed science e-module has the potential to support students' critical thinking skills, the results should be interpreted with caution because the study employed a one-group pretest-posttest design without a comparison group. Therefore, the observed improvement represents preliminary evidence of learning gains rather than conclusive evidence of the causal effectiveness of the intervention.

Table 10. Distribution of Students' N-Gain Categories

Category	Number of Students	Percentage (%)
High ($g \geq 0.70$)	32	50.00
Moderate ($0.30 \leq g < 0.70$)	32	50.00
Low ($g < 0.30$)	0	1.56
Total	64	100.00

As presented in Table 10, students demonstrated varying levels of improvement in their critical thinking skills following the implementation of the developed science e-module. Of the 64 participating students, 32 students (50.00%) achieved a high level of improvement ($g \geq 0.70$), while the remaining 32 students (50.00%) demonstrated a moderate level of improvement ($0.30 \leq g < 0.70$). No students were classified in the low improvement category ($g < 0.30$). These findings indicate that all students experienced meaningful learning gains, with half of the participants achieving high improvement and the other half demonstrating moderate improvement. The absence of students in the low N-Gain category further suggests that the developed science e-module consistently supported improvements in students' critical thinking skills across the entire sample.

Normality Test

Before conducting hypothesis testing, the pretest and posttest scores were examined for normality using the Kolmogorov–Smirnov test.

Table 11. Results of the Normality Test

Variable	Significance	Interpretation
Pretest	< 0.05	Not Normally Distributed
Posttest	< 0.05	Not Normally Distributed

The results presented in Table 10 indicate that both the pretest and posttest scores were not normally distributed ($p < 0.05$). Therefore, a non-parametric statistical analysis was considered appropriate, and the Wilcoxon Signed-Rank Test was employed to examine the difference between pretest and posttest scores.

Wilcoxon Signed-Rank Test

Following the normality assessment, the paired differences between students' pretest and posttest critical thinking scores were analyzed using the Wilcoxon Signed-Rank Test. This non-parametric test was selected because the paired differences were not normally distributed. The results of the analysis are presented in Table 12.

Table 12. Wilcoxon Signed-Rank Test Results for Students' Critical Thinking Scores

Parameter	Result
Negative Ranks	0
Positive Ranks	64
Ties	0
Asymp. Sig. (2-tailed)	< 0.001
Decision	Significant Difference

The Wilcoxon Signed-Rank Test yielded Z = -7.128 with $p < 0.001$, indicating a statistically significant difference between students' pretest and posttest scores. Consequently, the null hypothesis was rejected, confirming that the implementation of the developed science e-module significantly improved students' critical thinking skills. Interestingly, all 64 students demonstrated higher posttest scores than pretest scores (positive ranks = 64), while no student experienced a decrease or maintained the same score. This result provides strong evidence regarding the effectiveness of the developed instructional product.

Magnitude of the Observed Score Changes

To describe the magnitude of the observed differences between students' pretest and posttest scores, an effect size (r) was calculated based on the Wilcoxon Signed-Rank Test statistic.

Table 13. Magnitude of the Observed Changes in Students' Critical Thinking Scores

Parameter	Value
Z	-7.128
N	64
Effect Size (r)	0.87
Category	Very Large

The calculated effect size (r = 0.87) indicates that the observed difference between students' pretest and posttest critical thinking scores was large according to the conventional interpretation of effect size proposed by Cohen (1988). This finding suggests that the magnitude of the observed score changes was substantial. Similar large score differences have also been reported in previous studies implementing Problem-Based Learning to support students' critical thinking development (Hidayati & Purwaningsih, 2023; Suhirman & Khotimah, 2020). However, because the present study employed a one-group pretest-posttest design without a comparison group, the effect size should be interpreted as describing the magnitude of the observed score changes rather than providing definitive evidence of the causal effectiveness of the developed science e-module. Therefore, the findings should be interpreted as preliminary evidence that students demonstrated substantial improvements in their critical thinking scores following implementation of the developed science e-module. Future studies employing controlled experimental designs are recommended to verify these findings under more rigorous conditions.

Discussion

The present study developed and evaluated a Problem-Based Learning (PBL)-based science e-module that systematically integrates Ledre local wisdom into the topic of food additives to support junior high school students' critical thinking skills. The findings addressed the three research objectives concerning product validity, practicality, and the observed improvement in critical thinking performance. First, the e-module achieved an average Aiken's V coefficient of 0.93 and an overall validity percentage of 94.79%, indicating strong expert agreement regarding its instructional

content, PBL alignment, critical-thinking orientation, language, interface, and usability. Second, its practicality was supported by appropriate Grade 9 readability, learning implementation of 96.04%, student activity of 93.26%, teacher responses of 92.25%, and student responses of 89.34%. Third, students' mean critical thinking score increased from 54.59 on the pretest to 85.35 on the posttest, resulting in an N-Gain of 0.70. The Wilcoxon Signed-Rank Test confirmed a statistically significant difference between the paired scores, $Z = -7.128$, $p < .001$, while the effect size of $r = .87$ indicated a substantial magnitude of observed change. Collectively, these results suggest that the e-module is a valid and practical instructional product with considerable potential to support interpretation, analysis, evaluation, and inference. Nevertheless, the score improvement should be interpreted as preliminary evidence rather than a definitive causal effect because the study did not employ a comparison group.

The observed improvement is broadly consistent with contemporary international evidence concerning PBL and critical thinking. Liu and Pásztor's (2022) meta-analysis demonstrated that PBL interventions generally exert positive effects on critical thinking, although their magnitude varies according to educational level, intervention design, measurement, and implementation quality. Similarly, Yu and Zin (2023) found that PBL becomes more effective when it is deliberately adapted through critical-thinking questions, digital technologies, metacognitive activities, authentic tasks, peer interaction, and teacher scaffolding. These characteristics are evident in the present e-module, in which students encounter a culturally authentic problem, investigate evidence, discuss possible explanations, evaluate food additives, and construct conclusions. The results also correspond with the second-order meta-analysis by Koçoğlu and Kanadlı (2025), which concluded that PBL positively influences cognitive and affective learning outcomes. Moreover, Xu et al. (2023) reported that collaborative problem solving produces a substantial overall effect on critical thinking, particularly when learners receive appropriate scaffolding and work in manageable groups. The present findings reinforce these conclusions by showing that digitally structured PBL can facilitate active investigation and collaborative reasoning in junior high school science. However, the effect size observed in this study was larger than the average effects commonly reported in meta-analytical research. This discrepancy may reflect the culturally familiar Ledre context, the alignment between learning activities and test indicators, or students' initial unfamiliarity with contextual PBL. It may also have been amplified by the one-group design, short intervention period, repeated measurement, and absence of controls for maturation, teacher influence, or testing effects.

Beyond the general influence of PBL, the findings support global arguments for connecting formal science with local and Indigenous knowledge. Sotero et al. (2020) concluded that articulating local and scientific knowledge can promote culturally sensitive science education, especially when teachers and communities participate in contextualizing school science. Similarly, Zidny et al. (2020) argued that Indigenous knowledge should not be treated as decorative cultural content but should be positioned alongside scientific perspectives to facilitate sustainability-oriented reasoning. The present study operationalized this principle by using Ledre production as the central scientific problem rather than merely presenting Ledre as an illustrative example. Students were required to examine ingredients, distinguish natural and synthetic additives, evaluate their functions and implications, and formulate evidence-based decisions. This instructional organization is also compatible with Wiyarsi et al. (2021), who demonstrated that familiar socio-scientific contexts can support scientific habits of mind and chemical literacy. Wiyarsi et al. (2024) further showed that

familiarity with local issues influences how Indonesian learners apply scientific reasoning. Compared with studies addressing broader environmental or sustainability issues, the current study used a highly specific traditional-food practice. Its familiarity may have reduced the cognitive distance between abstract scientific concepts and students' everyday experiences, thereby enabling them to allocate more cognitive resources to interpretation and evaluation. At the same time, cultural familiarity alone cannot guarantee critical thinking; the local context must be accompanied by explicit questions, evidence evaluation, conceptual scaffolding, and opportunities to justify conclusions.

The findings also align with Indonesian research conducted between 2020 and 2026. Suciyati et al. (2021) concluded that ethnoscience can be integrated into PBL to improve the contextuality and meaningfulness of biology learning while contributing to cultural preservation. Sholahuddin et al. (2021) similarly reported that project-based learning situated in ethnoscience contexts supported students' scientific literacy. Ariyatun (2021) found that Ethno-STEM project activities were relevant to the development of critical and creative thinking, while Pohan et al. (2020) emphasized that science teaching materials must explicitly provide opportunities for higher-order reasoning rather than merely present scientific information. More directly, Kusuma and Sumarni (2024) developed an ethnoscience-integrated electronic worksheet for acid–base learning that obtained high validity and practicality and was associated with increased critical thinking performance. Pitorini et al. (2025) also demonstrated that a PBL e-module combined with Socratic dialogue facilitated interpretation, analysis, evaluation, and self-regulation by requiring students to articulate and reconsider their reasoning. These studies provide a strong national foundation for the present findings. Nevertheless, the current study differs in its systematic use of a specific Bojonegoro culinary tradition throughout the complete PBL sequence. The Ledre production process served simultaneously as a cultural resource, an authentic food-additive problem, a stimulus for scientific inquiry, and a context for critical-thinking assessment. This integration is particularly relevant in Indonesian classrooms, where abstract science content, unequal access to laboratory resources, teacher-centered instruction, and variations in digital infrastructure may limit the implementation of inquiry-oriented learning.

The novelty of this study lies in the convergence of four elements within one instructional product: the 4D development framework, digital modular learning, the complete PBL syntax, and systematic integration of Ledre local wisdom with Facione's critical-thinking indicators. Existing studies have often developed digital materials, implemented PBL, or introduced local culture as separate innovations. In contrast, this e-module aligns problem orientation, investigation, presentation, and evaluation with interpretation, analysis, evaluation, and inference. Its contribution is therefore not limited to producing another digital module; it offers a replicable design logic for transforming a local cultural practice into an epistemically productive science-learning context. This contribution is consistent with Koderi et al. (2023), whose development of a Lampung local-wisdom film demonstrated that culturally situated digital media can strengthen learning relevance and learner identity. It also resonates with Al Khansa et al. (2024), who emphasized that connecting learning content to real-life and cultural contexts can enhance engagement and meaningful understanding at the junior high school level. From a methodological perspective, the iterative validation and revision process reflects the educational-product development principles used by Rokhman et al. (2024) and Erlina et al. (2025). Furthermore, the findings complement the classroom-

based evidence of Erlina et al. (2025), who reported that PBL can facilitate active participation and contextual reasoning when instructional problems are meaningfully connected to learners' social experiences.

Theoretically, the findings support a synthesis of constructivist learning, situated cognition, ethnoscience, and critical-thinking theory. PBL assumes that knowledge is actively constructed through engagement with meaningful and insufficiently structured problems, while situated cognition emphasizes that reasoning is influenced by the social and cultural contexts in which knowledge is applied. Ledre provided a familiar cultural anchor, whereas the digital investigation tasks required students to reconstruct everyday understanding through formal scientific concepts. The alignment of the activities with interpretation, analysis, evaluation, and inference also suggests that critical thinking is more likely to develop when its constituent processes are embedded explicitly within the learning sequence rather than treated as an incidental outcome. Pedagogically, teachers should therefore avoid using local wisdom merely as introductory decoration. Cultural practices should be translated into investigable questions, relevant data, competing explanations, and decision-making tasks. Teachers should additionally provide progressive scaffolding, distribute group responsibilities, facilitate respectful argumentation, and use formative feedback to identify misconceptions. The e-module may also support engagement by offering interactive activities and familiar examples; however, educators should balance digital interaction with discussion, hands-on observation, and reflection to prevent passive screen-based completion.

At the policy level, the findings support investment in culturally responsive digital resources, teacher professional development, equitable access to devices, and school-level mechanisms for evaluating the scientific and cultural accuracy of locally developed materials. Curriculum authorities could encourage schools to map local foods, crafts, ecological practices, and production processes that are relevant to science competencies without romanticizing or accepting all traditional claims as scientifically valid. Collaboration among teachers, scientists, cultural practitioners, and local communities is therefore essential. Although the present study did not directly measure emotional well-being, media literacy, online behaviour, or digital identity, its digital format carries relevant educational implications. Teachers should guide students to assess the credibility of online information about food additives, distinguish scientific evidence from unsupported health claims, cite digital sources responsibly, and communicate respectfully in collaborative platforms. Schools should also establish reasonable screen-time practices, accessible interface standards, data-privacy safeguards, and support mechanisms for students who experience digital fatigue or unequal access. The findings do not provide direct evidence for social-media regulation or mental-health intervention; nevertheless, they indicate that digital-learning policies should integrate media literacy, psychological safety, cultural responsiveness, and equitable participation rather than focus exclusively on technological availability.

Several limitations constrain the interpretation and generalizability of the findings. The participants were 64 students from two intact classes in a single junior high school, and both classes received the same intervention and were analyzed as one group. Consequently, the study could not separate the influence of the e-module from maturation, repeated testing, teacher effects, classroom interaction, or other contextual variables. The researcher's involvement in instruction and scoring may also have introduced expectancy and scoring biases, particularly because inter-rater reliability was not examined. Critical thinking was measured using only four parallel essay items, while delayed

retention, transfer to unfamiliar scientific problems, engagement, emotional well-being, digital literacy, and cultural identity were not assessed. Moreover, the local-wisdom integration aspect initially obtained a lower validity score than the other dimensions, and the revised product was not subjected to a second quantitative validation round. Future research should employ randomized or quasi-experimental designs with active comparison groups, multisite samples, independent instructors and scorers, inter-rater reliability analysis, delayed posttests, and more comprehensive critical-thinking instruments. Mixed-method investigations should examine how students use cultural knowledge during argumentation, which e-module features generate cognitive engagement, and whether engagement mediates critical-thinking development. Further studies should also compare different local-wisdom contexts, investigate accessibility across socioeconomic and geographic groups, and determine whether the design framework can be transferred to other science topics without weakening either scientific integrity or cultural authenticity.

Conclusion

This study developed and evaluated a Problem-Based Learning science e-module that systematically integrates Ledre local wisdom into the teaching of food additives to support junior high school students' critical thinking skills. The findings demonstrate that the developed e-module fulfilled the established criteria of validity and practicality, as reflected in the strong agreement among subject-matter, instructional media, and science education experts, as well as its appropriate readability, high level of classroom implementation, active student participation, and positive responses from teachers and students. The observed increase in students' critical thinking scores, supported by the normalized gain analysis, the statistically significant difference between pretest and posttest performance, and the substantial magnitude of score change, provides preliminary evidence that the e-module may facilitate the development of interpretation, analysis, evaluation, and inference skills. These findings answer the research questions by confirming that the instructional product is valid, practical, and potentially beneficial for supporting critical thinking within contextual science learning. Theoretically, this study extends the conceptual integration of Problem-Based Learning, ethnoscience, and culturally responsive pedagogy by positioning local wisdom not merely as supplementary cultural information but as an authentic scientific inquiry context embedded throughout the instructional process. Practically, the e-module offers science teachers an accessible digital resource for connecting scientific concepts with students' sociocultural experiences, promoting active investigation, evidence-based reasoning, and meaningful problem solving. Nevertheless, the findings should be interpreted cautiously because the study involved a limited sample from a single school, employed a one-group pretest–posttest design without a comparison group, relied on researcher-scored essay responses, and conducted only limited dissemination. These methodological constraints prevent definitive conclusions regarding the causal effectiveness and broader generalizability of the intervention. Future research should therefore employ randomized or quasi-experimental designs, involve larger and more diverse samples, examine long-term knowledge retention and transfer, establish inter-rater scoring reliability, and investigate the applicability of the instructional framework to other scientific topics and forms of local wisdom. Overall, this study provides a substantive foundation for developing culturally grounded digital science instruction and demonstrates the potential of systematically integrating local knowledge with inquiry-oriented pedagogy to advance meaningful, relevant, and intellectually rigorous science learning.

References

Aiken, L. R. (1985). Three coefficients for analyzing the reliability and validity of ratings. *Educational and Psychological Measurement, 45*(1), 131–142. https://doi.org/10.1177/0013164485451012

Al Khansa, E., Pahrudin, A., Jatmiko, A., Sufian, M., & Azad, I. (2024). The integrated learning model in Islamic religious education in junior high school. *Southeast Asian Journal of Islamic Education, 7*(2), 69–85. https://doi.org/10.21093/sajie.v7i2.9356

Almanasreh, E., Moles, R., & Chen, T. F. (2019). Evaluation of methods used for estimating content validity. *Research in Social and Administrative Pharmacy, 15*(2), 214–221. https://doi.org/10.1016/j.sapharm.2018.03.066

An Nabil, N. R., Wulandari, I., Yamtinah, S., Ariani, S. R. D., & Ulfa, M. (2022). Analisis indeks Aiken untuk mengetahui validitas isi instrumen asesmen kompetensi minimum berbasis konteks sains kimia. *Paedagogia, 25*(2), 184–191. https://doi.org/10.20961/paedagogia.v25i2.64566

Arends, R. I. (2012). *Learning to teach* (9th ed.). McGraw-Hill.

Ariyatun, A. (2021). Analysis of Ethno-STEM integrated project-based learning on students' critical and creative thinking skills. *Journal of Educational Chemistry, 3*(1), 35–44. https://doi.org/10.21580/jec.2021.3.1.6574

Barrows, H. S. (2002). Is it truly possible to have such a thing as dPBL? *Distance Education, 23*(1), 119–122. https://doi.org/10.1080/01587910220124026

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika, 16*(3), 297–334. https://doi.org/10.1007/BF02310555

Dewi, P., Romadhana, A., Muzaki, M., & Ati MZ, A. F. S. (2023). Pengembangan perangkat pembelajaran IPA berbasis project-based learning (PjBL) di sekolah dasar. *Jurnal Ilmiah PENDAS: Primary Educational Journal, 4*(1), 61–68. https://doi.org/10.29303/pendas.v4i1.3164

Erlina, E., Hijriyah, U., Ghazi, F., Syahril, S., & Sufian, M. (2025). Arabic problem-based learning for religious moderation: Classroom action research in Islamic education. *JPI: Jurnal Pustaka Indonesia, 5*(3). https://doi.org/10.62159/jpi.v5i3.1806

Erlina, E., Koderi, K., & Sufian, M. (2025). Designing a gender-responsive qira'ah learning module: Bridging equality and inclusivity in Islamic higher education. *Jurnal Ilmiah Islam Futura, 25*(1), 239–262. https://doi.org/10.22373/jiif.v25i1.29305

Ge, W.-L., Zhu, X.-Y., Lin, J.-B., Jiang, J.-J., Li, T., Lu, Y.-F., Mi, Y.-F., & Tung, T.-H. (2025). Critical thinking and clinical skills by problem-based learning educational methods: An umbrella systematic review. *BMC Medical Education, 25*, Article 455. https://doi.org/10.1186/s12909-025-06951-z

Hake, R. R. (1999). *Analyzing change/gain scores*. Indiana University.

Hidayati, T., & Purwaningsih, D. (2023). The effect of applying problem-based learning model on students' critical thinking ability in science subjects in grade V elementary school. *JPI (Jurnal Pendidikan Indonesia), 12*(3), 576–585. https://doi.org/10.23887/jpiundiksha.v12i3.55235

Koderi, K., Sufian, M., & Erlina, E. (2023). Developing Lampung local wisdom film of Arabic communication skills for Madrasah Tsanawiyah students. *International Journal of Information and Education Technology, 13*(12), 2004–2013. https://doi.org/10.18178/ijiet.2023.13.12.2015

Koçoğlu, A., & Kanadlı, S. (2025). The effect of problem-based learning approach on learning outcomes: A second-order meta-analysis study. *Educational Research Review, 48*, Article 100690. https://doi.org/10.1016/j.edurev.2025.100690

Kusuma, I. A., & Sumarni, W. (2024). Development of ethnoscience integrated e-worksheet in acid–base materials to improve critical thinking skill. *EDUSAINS, 16*(2), 97–109. https://doi.org/10.15408/es.v16i2.34136

Liu, Y., & Pásztor, A. (2022). Effects of problem-based learning instructional intervention on critical thinking in higher education: A meta-analysis. *Thinking Skills and Creativity, 45*, Article 101069. https://doi.org/10.1016/j.tsc.2022.101069

Musahrain, Ainurrahmi, Ferniawan, & Sabrina, A. (2024). Analisis kemampuan berpikir kritis pada mata pelajaran IPA SMP kelas IX di Kabupaten Sumbawa. *Jurnal PIPA: Pendidikan Ilmu Pengetahuan Alam, 5*(2), 152–159. https://doi.org/10.56842/jp-ipa.v5i2.439

Nurmasitoh, Q. A., Sudarmin, S., Ngabekti, S., Irsadi, A., & Sutopo, A. (2025). Development of a problem-based learning (PBL) ethnoscience e-module on the biodiversity of herbal plants to enhance junior high

school students' critical thinking and environmental literacy. *Unnes Science Education Journal, 14*(2), 204–210. https://doi.org/10.15294/usej.v14i2.25904

Pitorini, D. E., Suciati, S., & Harlita, H. (2025). Using an e-module based on problem-based learning combined with Socratic dialogue to develop students' critical thinking skills: A qualitative study. *Journal of Educators Online, 22*(1), 52–65. https://doi.org/10.9743/JEO.2025.22.1.18

Pohan, L. A., Maulina, J., & Hardianti, T. (2020). Students' critical thinking: A study on science teaching material based on the scientific approach. *Universal Journal of Educational Research, 8*(12B), 8129–8136. https://doi.org/10.13189/ujer.2020.082615

Ratna, L., Pada, A. U. T., Samingan, S., Rahmatan, H., Safrida, S., & Fuadi, T. M. (2025). Ethno-PjBL: A pedagogical strategy to foster students' critical thinking skills on environmental science topics. *Biosfer: Jurnal Pendidikan Biologi, 18*(2), 190–201. https://doi.org/10.21009/biosferjpb.54197

Rokhman, R., Diana, N., Etek, Y., Koderi, K., & Sufian, M. (2024). The development of a scientific-based academic supervision management model. *AL-ISHLAH: Jurnal Pendidikan, 16*(2), 1383–1398. https://doi.org/10.35445/alishlah.v16i2.4626

Sari, S. P., Mapuah, S., & Sunaryo, I. (2021). Pembelajaran ilmu pengetahuan alam berbasis etnosains untuk mengembangkan kemampuan berpikir kritis siswa sekolah dasar. *EduBase: Journal of Basic Education, 2*(1), 9–18. https://doi.org/10.47453/edubase.v2i1.284

Sholahuddin, A., Hayati, N., Iriani, R., Saadi, P., & Susilowati, E. (2021). Project-based learning on ethnoscience setting to improve students' scientific literacy. *AIP Conference Proceedings, 2330*(1), Article 020051. https://doi.org/10.1063/5.0043571

Sotero, M. C., Alves, Â. G. C., Arandas, J. K. G., & Medeiros, M. F. T. (2020). Local and scientific knowledge in the school context: Characterization and content of published works. *Journal of Ethnobiology and Ethnomedicine, 16*, Article 23. https://doi.org/10.1186/s13002-020-00373-5

Suciyati, A., Suryadarma, I. G. P., & Paidi, P. (2021). Integration of ethnoscience in problem-based learning to improve contextuality and meaning of biology learning. *Biosfer: Jurnal Pendidikan Biologi, 14*(2), 201–215. https://doi.org/10.21009/biosferjpb.18424

Suhirman, S., & Khotimah, H. (2020). The effects of problem-based learning on critical thinking skills and student science literacy. *Lensa: Jurnal Kependidikan Fisika, 8*(1), 31–38. https://doi.org/10.33394/j-lkf.v8i1.2794

Thiagarajan, S., Semmel, D. S., & Semmel, M. I. (1974). *Instructional development for training teachers of exceptional children: A sourcebook*. Leadership Training Institute/Special Education, University of Minnesota.

Wiyarsi, A., Çalik, M., Priyambodo, E., & Dina, D. (2024). Indonesian prospective teachers' scientific habits of mind: A cross-grade study in the context of local and global socio-scientific issues. *Science & Education, 33*, 1257–1283. https://doi.org/10.1007/s11191-023-00429-4

Wiyarsi, A., Prodjosantoso, A. K., & Nugraheni, A. R. E. (2021). Promoting students' scientific habits of mind and chemical literacy using the context of socio-scientific issues on inquiry learning. *Frontiers in Education, 6*, Article 660495. https://doi.org/10.3389/feduc.2021.660495

Xu, E., Wang, W., & Wang, Q. (2023). The effectiveness of collaborative problem solving in promoting students' critical thinking: A meta-analysis based on empirical literature. *Humanities and Social Sciences Communications, 10*, Article 16. https://doi.org/10.1057/s41599-023-01508-1

Yu, L., & Zin, Z. M. (2023). The critical thinking-oriented adaptations of problem-based learning models: A systematic review. *Frontiers in Education, 8*, Article 1139987. https://doi.org/10.3389/feduc.2023.1139987

Yulanda, V., Hamidah, A., & Anggereini, E. (2023). Development of electronic student worksheets (E-LKPD) based on problem-based learning as an effort to improve critical thinking of grade VIII middle school students on respiratory system material. *Jurnal Penelitian Pendidikan IPA, 9*(9), 7326–7332. https://doi.org/10.29303/jppipa.v9i9.4144

Zidny, R., Sjöström, J., & Eilks, I. (2020). Integrating perspectives from Indigenous knowledge and Western science in secondary and higher chemistry learning to contribute to sustainability education. *Sustainable Chemistry and Pharmacy, 16*, Article 100229. https://doi.org/10.1016/j.scp.2020.100229

Zubaidah, S. (2018, October 13). *Mengenal 4C: Learning and innovation skills untuk menghadapi era Revolusi Industri 4.0* [Paper presentation]. 2nd Science Education National Conference, Universitas Trunojoyo Madura, Bangkalan, Indonesia. https://www.researchgate.net/publication/332469989