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Mangrove-based discovery learning with JAS-integrated electronic worksheets: Impact on students' critical thinking and science literacy

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ABSTRACT

The development of students' critical thinking skills and scientific literacy remains a major challenge in biology learning, particularly when learning is not connected to real-world contexts. This study aimed to analyze improvement in critical thinking and scientific literacy among Phase E high school students through the implementation of an electronic worksheet (e-worksheet), based on Discovery Learning (DL) and integrated with the *Jelajah Alam Sekitar* (JAS) approach, utilizing the local potential of the Baros mangrove ecosystem. This study employed a pre-experimental one-group pretest–posttest design. The participants consisted of 36 tenth-grade students selected through cluster random sampling. The instruments included an essay test to measure critical thinking skills and a multiple-choice test to assess scientific literacy, both of which were validated and deemed reliable. Data were analyzed using N-Gain to determine the level of improvement in each aspect. The results showed that all aspects of critical thinking skills improved, with N-Gain scores in the medium-to-high categories: interpretation (0.71), analysis (0.76), inference (0.71), evaluation (0.77), explanation (0.69), and self-regulation (0.59). Similarly, scientific literacy skills showed great improvement across all aspects, including context (0.72), competence (0.73), and knowledge (0.71). These findings indicate that integrating e-worksheets, DL, and the JAS approach effectively creates contextual, active, and meaningful learning experiences, thereby enhancing students' critical thinking skills and scientific literacy. This study implies that integrating structured learning media with inquiry-based and environment-based approaches can support the development of higher-order thinking and scientific understanding.

INTRODUCTION

Dramatic changes in the economic, social, and technological landscapes have driven a transformation in the way individuals work, learn, and communicate. In this era of knowledge and a technology-based society, critical thinking skills are essential for students to possess because the creation and dissemination of knowledge are now the main drivers of socio-economic development (Leung, 2025).

Biology, as a branch of science concerned with natural phenomena and environmental issues, is highly relevant and prompts students to think critically about the material (Hoffman, 2025). Critical thinking is widely recognized as a metacognitive process that involves a set of skills and characteristics such as interpretation, analysis, inference, evaluation, explanation, and self-regulation that together allow for reflective assessment, self-regulation, logical problem-solving, and reasoned conclusions (Dwyer et al., 2023). Critical thinking plays a special role because science not only demands that students memorize facts but also analyze scientific evidence, evaluate claims, and engage in empirical, data-driven arguments.

However, important international assessments and research in Indonesia indicate that students' critical thinking skills remain underdeveloped. In Indonesia, several studies indicate that students often demonstrate low critical thinking proficiency, particularly in science and biology education, due to the dominance of rote learning, a lack of explicit instruction in critical thinking, and limited opportunities for inquiry-based learning (Zikrullah & Azhari, 2024; Rahmawati et al., 2025). A survey conducted in a public school in Indonesia, for example, showed that the average score of students' critical thinking skills was only 58.06%, which is relatively low, confirming the need for more innovative and contextual learning interventions.

Along with that, science literacy has become a major concern in science education as it refers to a person's ability to use scientific knowledge, interpret data/evidence, evaluate scientific claims, and make decisions relevant to real-life science issues. International studies show that Indonesian students are struggling in this area: based on the 2022 Programme for International Student Assessment (PISA) data, the average science literacy score of Indonesian students reached 383, below the OECD average, although the ranking has risen by five to six positions compared to 2018 (OECD, 2023). A literature analysis of a meta-study in Indonesia also found that students' science literacy is relatively low and shows a trend of stagnation and decline in recent years (Novita et al., 2021). At the school level, the survey showed an average science literacy score of 55.06% (low category), which shows that the challenge of science literacy still needs to be seriously addressed.

Critical thinking and science literacy are important 21st century competencies that must be developed through science learning in secondary schools. Science learning not only aims to help students understand concepts but also to enable them to analyze, evaluate, and apply that knowledge to solve real problems (Anderson & Krathwohl, 2001; National Research Council, 2012; Constantinou & Rybska, 2024). However, various factors are the causes of students' low critical thinking and science literacy in biology learning are complex, including: learning that is still teacher-centered, learning resources such as package books that do not encourage critical thinking, limited science literacy-based evaluation questions/tools, lack of inquiry-based activities or contextual exploration, and lack of use of innovative models and approaches that provide space for students' activities actively and contextual. To address this problem, one concrete solution is the use of innovative electronic student worksheets.

The use of electronic student worksheets allows for greater interactivity, access to digital learning resources, and the development of independent, discovery-centered student activities. The learning design in electronic student worksheets needs to be engaging, actively engage students, and provide meaningful learning experiences. One effective strategy is to integrate electronic student worksheets with constructivist-based learning models such as Discovery

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Learning. Recent research shows that implementing Discovery Learning effectively improves students' critical thinking and metacognitive skills (Kusniati, 2022).

The use of local potential as a learning resource has significant added value in biology learning because it provides an authentic, contextual learning experience. One example is the Baros Mangrove ecosystem in Bantul Regency, Yogyakarta, which has unique characteristics such as the existence of five main species (*Bruguiera* sp., *Avicennia* sp., *Sonneratia* sp., *Nypa fruticans*, and *Rhizophora apiculata*), clear vegetation zoning, and diverse substrates and environmental conditions (Arianti & Satlita, 2018). This area has great potential to become a natural laboratory that supports learning based on local conditions, such as Mangrove Baros in biology, which allows students to connect ecosystem concepts with real phenomena in the surrounding environment, thereby strengthening the relevance of materials, increasing motivation, and fostering ecological awareness.

Exploration of the mangrove ecosystem as a learning resource will be more effective when implemented using an environment-based learning approach, such as the *Jelajah Alam Sekitar* (JAS) approach. The learning philosophy of the JAS approach is rooted in constructivist theory, emphasizing students' direct experience in exploring their physical, social, technological, and socio-cultural environments (Mulyani et al., 2008; Putra, 2021; Darwati et al., 2023). The JAS approach has been shown to increase motivation and interest in learning, foster cooperation and responsibility, and empower critical thinking skills and science literacy through direct observation activities (Ngabekti et al., 2017; Kurniyanti et al., 2019). Based on the background and literature review above, this study aims to analyze the improvement of each aspect of critical thinking skills and science literacy skills in Phase E High School after participating in learning using e-worksheets, based on the DL integrated with the JAS approach using the local potential of the Baros Mangrove in ecosystem materials.

METHODS

Research Design

This study employed a quantitative descriptive approach using a one-group pretest–posttest design. This design was used to examine students' critical thinking and scientific literacy skills before and after the implementation of the learning intervention, which used E-worksheets based on DL, integrated with the JAS approach.

Population and Samples

The population of this study consisted of all Grade 10 science-track students at a public high school in Bantul Regency, Indonesia, comprising four classes (Grades 10 Science 1-4), totaling 108 students. The sample consisted of 36 students from Grade 10 Science 4, selected using purposive sampling. The selection was based on several considerations, including relatively homogeneous academic ability, accessibility for implementing the intervention, and students' readiness to participate in outdoor learning activities integrated with the JAS approach, which utilizes the local potential of the Baros mangrove ecosystem.

Instruments

Two types of instruments were used in this study: a critical thinking test and a scientific literacy test. The critical thinking test consisted of 12 essay questions developed based on the Delphi Consensus (Facione, 2020), covering six aspects: interpretation, analysis, evaluation, inference, explanation, and self-regulation. The scientific literacy test consisted of 15 multiple-choice questions developed based on the PISA 2018 framework (OECD, 2023), covering three aspects: context, competence, and knowledge. Both instruments were initially validated through expert judgment involving university lecturers and biology teachers. The validation covered aspects of content, construction, and language. The results indicated that all items were categorized as

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"very good" and appropriate for use. Several revisions were made based on expert feedback, including improving cognitive levels from lower-order to higher-order thinking (e.g., C2 to C4), refining contextual problems, and clarifying scoring rubrics to better measure students' critical thinking processes.

Empirical validity and reliability were further examined through a pilot study involving 35 students using the Rasch Model with the QUEST program. The use of the Rasch Model enables a more robust evaluation of item fit and measurement consistency than classical test theory (Wright & Masters, 1982). Item fit was determined based on INFIT MNSQ values ranging from 0.77 to 1.33 and OUTFIT T values ≤ 2.00 (Adams & Khoo, 1996). The analysis results showed that, for the critical thinking test, 12 of 13 items met the Rasch model fit criteria, while 1 item was excluded due to misfit. Similarly, for the scientific literacy test, 15 of 16 items were declared valid, with 1 item excluded for failing to meet the fit criteria. These findings suggest that most items are empirically valid and suitable for measuring students' critical thinking and science literacy (Subali et al., 2018).

The reliability analysis using Cronbach's alpha yielded coefficients of 0.73 for the critical thinking test and 0.72 for the scientific literacy test, both categorized as high reliability. This shows that the instrument has good internal consistency and produces stable measurement results, making it reliable for assessing students' critical thinking and scientific literacy (Arikunto, 2018). Thus, the final instruments used in this study consisted of 12 essay items for critical thinking and 15 multiple-choice items for scientific literacy, which were considered valid and reliable for data collection.

Procedures

The study was conducted in three main stages: pretest, treatment, and posttest. In the first stage, students were given a pretest to measure their initial critical thinking and scientific literacy skills. In the second stage, the learning intervention was implemented using an e-worksheet based on the DL model, integrated with the JAS approach and the local potential of the Baros mangrove ecosystem. The e-worksheet functioned as a structured and interactive learning guide, developed using digital platforms (Canva and Liveworksheet), and included multimedia features such as videos, images, and scientific articles to support students' inquiry processes. The learning activities were organized according to the stages of DL, namely stimulation, problem identification, data collection, data processing, verification, and generalization. These stages were integrated with JAS principles, including exploration, constructivism, science process skills, learning community, and authentic assessment. Through this integration, students were actively involved in contextual and inquiry-based learning activities. During the learning process, students engaged in direct environmental observation in the Baros mangrove ecosystem, identified ecological problems, formulated hypotheses, collected and analyzed data, and participated in scientific discussions. The activities were designed to explicitly facilitate critical thinking skills (interpretation, analysis, inference, evaluation, explanation, and self-regulation) as well as scientific literacy competencies (explaining phenomena scientifically, interpreting data and evidence, and evaluating scientific investigations). In the final stage, a posttest is carried out to measure students' critical thinking skills and scientific literacy after learning.

Data Collection and Analysis

In this study, the analysis focuses on the achievement of student learning outcomes in general, as well as improvements in all aspects of critical thinking and science literacy, based on the results of the pretest, posttest, and N-Gain scores. The results of students' critical thinking and scientific literacy learning outcomes were then interpreted into the criteria for critical thinking and scientific literacy skills, as shown in Tables 1 and 2.

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Table 1
Criteria for students' critical thinking skills.

Percentage Value	Criterion
81.25 < x ≤ 100	Highly Critical
62.50 < x ≤ 81.24	Critical
42.75 < x ≤ 62.49	Moderately Critical
25.00 < x ≤ 42.74	Low Critical Thinking

Table 2
Criteria for students' scientific literacy skills.

Percentage Value	Criterion
86 - 100	Excellent
76 - 85	Good
60 - 75	Fair
55 - 59	Low
≤ 54	Very Low

Note: Adapted from Purwanto (2009)

Furthermore, to determine the category of improvement in each aspect of students' critical thinking and scientific literacy, the data were analyzed using the normalization gain score (N-Gain). The pretest and posttest scores in this study are total scores for each aspect, with maximum scores adjusted for the number of items. Thus, the N-Gain calculation reflects the normalized improvement relative to the maximum possible score for each aspect. The N-Gain values were then interpreted based on the criteria proposed by Hake (1998), as presented in Table 3.

Table 3
Interpretation of the N-Gain score.

Normalized gain score (g)	Criterion
g ≥ 0.7	High
0.3 ≤ g < 0.7	Medium
g < 0.3	Low

RESULTS AND DISCUSSION

Improvement of Critical Thinking Skills

In this study, students' critical thinking was measured before and after learning using an e-worksheet based on DL integrated with the JAS approach, which leverages the local potential of the Baros mangrove ecosystem. The results of the analysis of students' achievement in critical thinking skills are presented in Figure 1. Based on Figure 1, the distribution of students' critical thinking skills before the intervention was dominated by the moderately critical category (58%), followed by low critical thinking (33%) and critical (8%), while no students were categorized as highly critical (0%). This distribution indicates that, prior to the implementation of the learning intervention, students' critical thinking skills were generally at a low to moderate level.

Most students had not yet demonstrated the ability to engage in scientific reasoning, in-depth analysis, or evidence-based problem solving. After implementing the e-worksheets based on DL, integrating the JAS approach, and leveraging the local potential of the Baros mangrove

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ecosystem, a substantial improvement was observed. The posttest results show that the majority of students (83%) reached the highly critical category, while the remaining students (17%) were classified as critical. Notably, no students remained in the moderately critical or low-critical-thinking categories. This shift demonstrates that the learning intervention effectively enhanced students' critical thinking skills, particularly through activities involving exploration, direct observation in the mangrove environment, and scientific problem solving grounded in real-world contexts. The improvement in the critical thinking aspect of Phase E students after participating in e-worksheets based learning was assessed using the N-Gain score, as presented in Table 4.

Figure 1

Distribution of student critical thinking skills achievement before and after treatments (%).

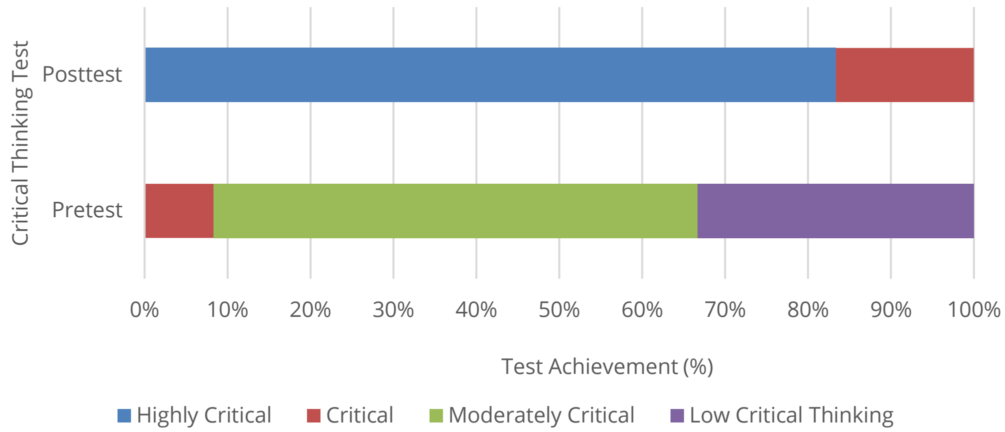

Table 4

N-Gain analysis results for each aspect of students' critical thinking skills.

Aspects	Maximum Score	Pretest Score	Posttest Score	N-Gain	Criterion
Interpretation	288	139	245	0,71	High
Analysis	432	221	381	0,76	High
Inference	288	143	246	0,71	High
Evaluation	144	69	127	0,77	High
Explanation	432	197	359	0,69	Medium
Self-regulation	144	80	118	0,59	Medium

Based on the results of the analysis of the N-Gain score in Table 4, it shows that students' critical thinking skills in all aspects of critical thinking, namely interpetation, analysis, conclusion, evaluation, explanation and self-regulation obtained different average scores with each experiencing an increase classified as a medium and high criterion after following the learning using e-worksheets based on DL integrated with the JAS approach using the local potential of the Baros mangrove ecosystem. The differences in the improvement of each aspect of students' critical thinking are more clearly shown in Figure 2. Figure 2 shows that the highest improvement in students' critical thinking skills occurred in the evaluation aspect, with an N-Gain score of 0.77 (high category). The improvement in students' critical thinking skills observed in this study is not attributable to a single instructional component, but rather to the synergistic interaction of e-worksheets as a structured learning medium, the DL model as a cognitive inquiry framework, the JAS approach as a contextual learning strategy, and the utilization of local environmental potential in the form of the Baros mangrove ecosystem. This integrated design ensures that

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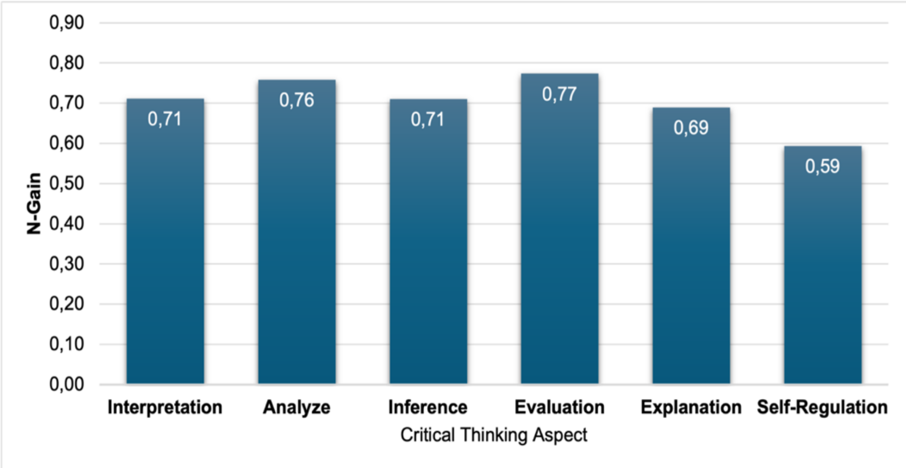
each aspect of critical thinking is systematically activated through structured, contextual, and inquiry-based learning experiences.

Figure 2

N-Gain scores for students' critical thinking skills in each aspect.



E-worksheet plays a central role as a scaffolding tool, organizing learning activities into structured stages aligned with critical-thinking indicators, including interpretation, analysis, inference, evaluation, explanation, and self-regulation. Through guided instructions, embedded tasks, and interactive features, students are encouraged to actively analyze data, construct arguments, and reflect on their thinking processes. The DL model contributes by providing a systematic cognitive process, consisting of stimulation, problem identification, data collection, data processing, verification, and generalization, which encourages students to construct knowledge independently through inductive and deductive reasoning. Meanwhile, the JAS approach situates learning in authentic environmental contexts, enabling students to observe, explore, and analyze real ecological phenomena directly. The integration of local potential strengthens contextual relevance, allowing students to connect scientific concepts with real-world environmental issues, thereby enhancing engagement and depth of understanding.

This significant increase is closely related to students' intensive engagement in evaluating the credibility of claims and the quality of arguments through structured, contextual activities. Within e-worksheets, students are guided to assess data obtained from observations, interviews, and scientific articles. They evaluate the reliability, accuracy, and relevance of evidence, and examine whether empirical data logically support arguments. DL strengthens this process during the verification stage, in which students must justify their conclusions with evidence. The JAS approach contributes by providing authentic data from the mangrove ecosystem, requiring students to critically assess real environmental information rather than abstract examples. According to Facione (2020), evaluation involves assessing the credibility of claims, the quality of arguments, and the accuracy of inferences based on empirical evidence.

The analysis aspect obtained an N-Gain score of 0.76 (high category), indicating a substantial improvement in students' ability to break down problems and identify relationships among variables. The synergistic role of the instructional components supports this improvement. DL plays a key role in encouraging students to explore problems systematically and identify cause-and-effect relationships. The e-worksheet provides structured guidance through prompts and analytical tasks, helping students organize their thinking as they identify variables and relationships. Additionally, the JAS approach combined with local potential enables students to directly observe interactions between biotic and abiotic components in the mangrove ecosystem, making abstract concepts more concrete and analyzable. Learning

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activities such as analyzing videos, conducting field observations, and participating in group discussions further strengthen students' analytical reasoning. This is consistent with Facione (2020) and Dewey (1938), who emphasize that analysis involves identifying relationships between elements of information, while Chan et al. (2018) highlight that active engagement in scientific data analysis enhances critical thinking and evidence-based decision-making.

The interpretation aspect showed an N-Gain score of 0.71 (high category), indicating that students improved in their ability to understand and organize information meaningfully. This improvement can be explained through the interaction of structured guidance and contextual learning experiences. The e-worksheet plays a crucial role in facilitating interpretation by guiding students to systematically code, categorize, and represent data. At the same time, DL encourages students to construct meaning independently from the data they collect. The JAS approach and the integration of local potential provide rich contextual experiences, allowing students to connect theoretical knowledge with real-world ecological phenomena. Activities such as transforming observational data into tables, diagrams, and food web schemas help students visualize relationships among ecosystem components. According to Gagné (1985) and Bruner (1966), organizing and encoding information enhances conceptual understanding and long-term memory. Furthermore, Ennis (2018) explains that categorizing and interpreting data are fundamental processes in scientific critical thinking.

The inference aspect also showed a great improvement, with an N-Gain score of 0.71. This indicates that students became more capable of drawing logical conclusions based on empirical evidence. DL engages students in processes such as data collection, verification, and generalization, which require both inductive and deductive reasoning. The e-worksheet supports this process by providing guiding questions and structured tasks that help students formulate evidence-based conclusions. Meanwhile, the JAS approach and local potential exposure enable students to gather authentic data from the mangrove ecosystem, strengthening the validity of their reasoning. Through these integrated learning experiences, students learn to connect observations with scientific concepts and construct logical conclusions. This finding aligns with Ennis (2018), who emphasizes that the ability to evaluate evidence and draw conclusions is central to critical thinking. Thus, integrating exploratory activities and empirical evidence analysis in the field can strengthen students' inference skills in logically connecting ecological data, concepts, and phenomena.

The explanation aspect obtained an N-Gain score of 0.69 (medium category), indicating moderate improvement in students' ability to communicate their reasoning. This relatively modest improvement suggests that explanatory skills require more sustained practice than other aspects. The e-worksheet plays an important role by providing students with opportunities to document and present their findings systematically. DL supports this process by encouraging students to articulate their reasoning during discussions and presentations. In addition, the JAS approach and local context enrich students' explanations by providing real and meaningful phenomena to describe. Activities such as presenting findings, writing reports, and participating in discussions help students construct evidence-based arguments. According to Zohar and Nemet (2022) and Osborne (2023), engaging students in scientific argumentation is essential for developing reasoning and communication skills. Therefore, although the improvement is moderate, integrating structured guidance, inquiry processes, and contextual experiences contributes to the development of students' explanatory abilities.

The self-regulation aspect showed the lowest increase with an N-Gain score of 0.59 (medium category). Nevertheless, this achievement still reflects the development of students' ability to monitor, correct, and evaluate their own thought processes. Self-regulation increases more slowly because these skills require metacognitive awareness and sustained reflective habituation. Through reflection activities, teacher feedback, and self-evaluation in e-worksheets, students learn to recognize their strengths and weaknesses in thinking. According to Flavell (1979) and Zimmerman (2020), metacognition and self-regulated learning are important

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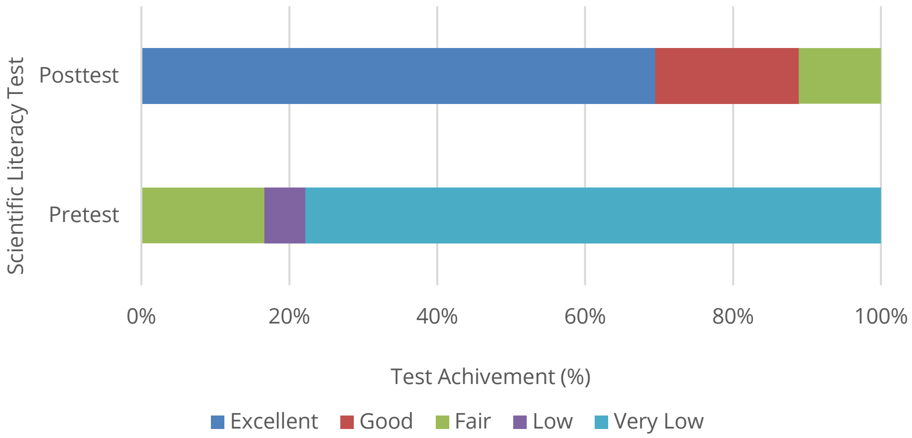
components in the development of deep critical thinking. Moon's research (2021) also confirms that active reflection and self-examination help students correct thinking errors and increase awareness of independent learning. Therefore, although the increase is moderate, the self-regulation aspect still shows an important contribution in shaping the independence of scientific critical thinking.

Improving Science Literacy Skills

In this study, students' science literacy skills were also assessed before and after learning using an e-worksheet based on DL, integrated with the JAS approach, which leverages the local potential of the Baros mangrove ecosystem. The results of the analysis of students' science literacy achievement category are presented in Figure 3.

Figure 3

Distribution of students' scientific literacy before and after treatments (%).



According to Figure 3, the distribution of students' scientific literacy skills before the learning intervention was dominated by the very poor category (78%), followed by the fair (17%) and poor (6%), while no students were classified as good or very good. This indicates that, prior to the learning intervention, students' scientific literacy was generally very low, with most demonstrating limited ability to understand scientific concepts, interpret data, and apply scientific knowledge in real-world contexts. After the implementation of the DL-based e-worksheets integrated with the JAS approach utilizing the Baros mangrove ecosystem, significant improvements were observed. Posttest results showed that the majority of students achieved the excellent category (69%), followed by the good category (19%) and the fair category (11%), with no students remaining in the poor or very poor categories. This shift indicates that the learning intervention effectively improved students' scientific literacy, particularly in understanding scientific concepts in context, interpreting environmental phenomena, and applying scientific reasoning grounded in real-world experiences.

The improvement in the science literacy of Phase E students after participating in e-worksheets-based learning was determined by calculating the N-Gain score presented in Table 5. Based on the N-Gain analysis presented in Table 5, students' scientific literacy improved across all aspects, namely context, competence, and knowledge. These aspects refer to the PISA framework, in which each assessment item integrates real-world context, scientific competencies, and knowledge simultaneously. However, for analytical purposes, the results were grouped based on the dominant aspect represented in each item. The results show that all aspects experienced improvement, with N-Gain values categorized as high. The competence aspect demonstrated the highest improvement (g = 0.73), followed by the context aspect (g = 0.72) and the knowledge aspect (g = 0.71). This indicates that the implementation of e-

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worksheets based on DL integrated with the JAS approach effectively enhances students' scientific literacy across multiple aspects.

Table 5
N-Gain analysis results for each aspect of students' science literacy skills.

Aspects	Indicators	Maximum Score	Pretest Score	Posttest Score	N-Gain	Criterion
Context	Personal	152	81	131	0.70	Medium
	Local	190	69	156	0.72	High
	Global	228	103	195	0.74	High
Total Context		570	253	482	0.72	High
Competency	Explain the phenomenon scientifically	190	85	147	0.73	High
	Evaluating and designing scientific questions	228	73	125	0.71	High
	Interpreting data and evidence scientifically	152	82	143	0.74	High
Total Competency		570	240	415	0.73	High
Knowledge	Content knowledge	266	104	224	0.74	High
	Procedural knowledge	152	96	139	0.77	High
	Epistemic knowledge	152	65	120	0.63	Medium
Total Competency		570	265	483	0.71	High

Note: Each test item integrates aspects of context, competence, and knowledge based on the PISA 2018 framework. The N-Gain score for each aspect is calculated based on the total score.

This finding is consistent with previous studies. Muthalib et al. (2024) found that DL-based worksheet facilitates students' active construction of their understanding of scientific concepts, thereby improving scientific literacy. DL has been proven to improve students' science literacy (Rahman et al., 2022; Karimah et al., 2023; Sulaihah et al., 2024). In addition, Ahmadi (2021) showed that the JAS approach enhances students' understanding of scientific concepts in context and in an engaging way through the exploration of real-world objects, such as mangrove ecosystems, thereby fostering collaborative learning environments. Furthermore, Dewi et al. (2024) emphasized that e-worksheets based on local potential, when combined with appropriate learning models, positively impacts students' scientific literacy.

A more detailed analysis at the indicator level reveals variation in the magnitude of improvement. Within the knowledge aspect, procedural knowledge showed the highest increase ($g = 0.77$), followed by content knowledge ($g = 0.74$), while epistemic knowledge showed a moderate increase ($g = 0.63$). This suggests that while students improved significantly in understanding and applying scientific procedures and concepts, their ability to reflect on the nature of scientific knowledge (epistemic understanding) developed at a relatively lower level, as it requires higher-order thinking processes such as evaluation, justification, and reflection, which typically develop through more sustained and explicit instructional support.

These findings indicate that the learning process not only improves students' conceptual understanding but also strengthens their ability to apply scientific reasoning in real-world

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contexts. The integration of local environmental resources, such as the Baros mangrove ecosystem, provides meaningful, context-rich learning experiences that support the development of scientific literacy. The differences in the improvement of each aspect of students' scientific literacy are presented in more detail in Figure 4.

Figure 4

N-Gain scores for students' science literacy skills in each aspect.

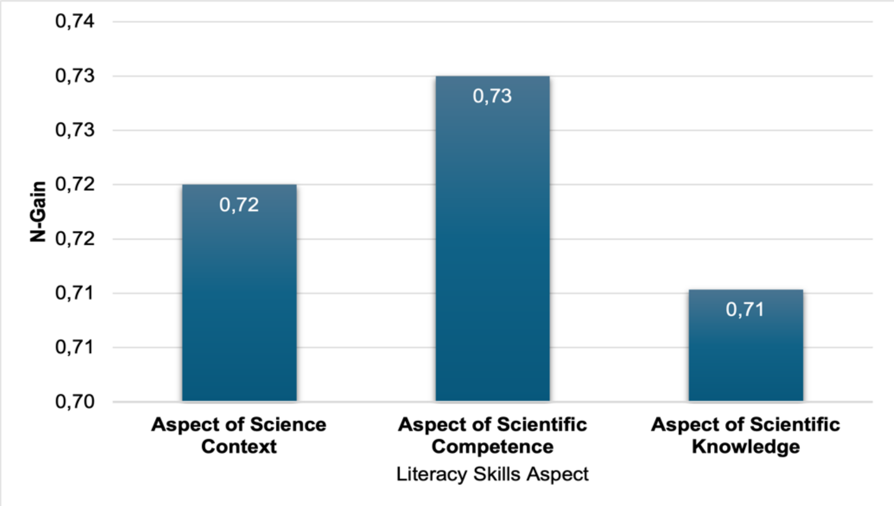

Figure 4 shows that the highest increase in students' science literacy occurred in the competency aspect, with an N-Gain score of 0.73 (high category). This indicates that students can explain scientific phenomena, evaluate, and design scientific questions logically, based on evidence obtained from field activities in the Baros mangrove ecosystem. Overall, students' scientific literacy improved after implementing e-worksheet-based learning using the DL approach, integrated with the JAS approach, which leverages the local potential of the Baros mangrove ecosystem. The improvement in students' scientific literacy is not attributable to a single instructional component, but rather to the synergistic integration of e-worksheets, DL, the JAS approach, and the use of local environmental potential. E-worksheet provides structured guidance that supports students in interpreting data, analyzing information, and constructing scientific explanations. DL facilitates inquiry-based processes that engage students in problem identification, data collection, analysis, and conclusion drawing. Meanwhile, the JAS approach situates learning in real-world environmental contexts, while integrating local potential enhances relevance and meaningful learning experiences.

The increase in the aspect of competence is higher than in other aspects because learning using e-worksheets based on DL, integrated with the Jelajah Alam Sekitar approach, using the local potential of the Baros mangrove ecosystem, directs students to make direct observations, identify environmental problems, formulate hypotheses, interpret empirical data, and draw scientific conclusions. These activities require the application of complex and integrative scientific thinking skills. In line with Yuliati (2020), strengthening science competence occurs when students engage in contextual investigations that require the integrated application of scientific knowledge and skills. In this activity, students actively collect data through observation and interviews, then interpret the results as tables, graphs, or schemas, and compare empirical data with ecological concepts, such as the relationship between pollution and mangrove damage. The ability to interpret data and design scientific questions is a key component of science literacy because it helps students come to conclusions based on scientific evidence (OECD, 2023). In addition, presentation activities and class discussions train students' ability to explain scientific phenomena and present arguments based on field data. This is in line with

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Piaget's constructivist view that knowledge is built through direct experience and social interaction (Alamiah & Marianti, 2016). According to Osborne (2023), environmental exploration-based learning deepens the understanding of scientific concepts while developing critical thinking skills and scientific argumentation. Thus, a significant improvement in scientific competence indicates that the implementation of e-worksheets based on DL, integrated with the Jelajah Alam Sekitar (JAS) approach, effectively encourages students to think scientifically, reflectively, and contextually through authentic learning experiences in real-world environments.

Furthermore, in the scientific context, an N-Gain score of 0.72 (high category) was obtained. This improvement shows that students can connect scientific concepts to personal, local, and global contexts more meaningfully. In a personal context, students discuss the impact of human activities, such as waste disposal and mangrove logging, on environmental health. These activities foster environmental awareness and an understanding of the relationship between individual actions and ecosystem balance. Personal context is important in developing scientific responsibility and environmental awareness because it helps students relate science knowledge to everyday life (Orlich et al., 2010; Puspitasari et al., 2020). In the local context, learning about the potential of the Baros mangrove ecosystem helps students understand environmental issues around them, such as coastal abrasion, water pollution, and microclimate change. Environmental exploration activities allow students to identify real-world problems and relate them to scientific concepts. Local problem-based learning can foster scientific thinking skills and sensitivity to environmental issues relevant to students' lives. Meanwhile, in the global context, students are invited to study major issues such as climate change, resource sustainability, and biodiversity loss. This activity helps them understand the relationship between local events and global phenomena. According to Alamiah & Marianti (2016), the global context in science literacy broadens students' perspectives on the global impact of local actions. Learning that connects local topics with global issues increases global awareness and a sense of responsibility for the environment. Thus, the improvement in the science context shows the success of learning in fostering ecological awareness and cross-context understanding.

As for the science knowledge aspect, it obtained an N-Gain score of 0.71 with a relatively high increase. This increase occurs because, through learning with e-worksheets, students are trained to understand the three main dimensions of scientific knowledge, namely content, procedural, and epistemic. In content knowledge, students can explain the results of observations of the components of the mangrove ecosystem, such as relationships among organisms, food chains, and the material cycle. Students also analyze the factors that destroy mangrove ecosystems and offer science-based solutions. This activity helps students understand ecological concepts in depth and their applicability. According to deBoer (2020), understanding of science content is strengthened when students learn in real-world natural contexts, as they can relate theories to empirical phenomena. In procedural knowledge, students are trained to understand scientific methods, including measuring environmental variables (pH, temperature, light, and wind speed) and processing observational data. According to Fadilah et al. (2020), mastery of procedural knowledge helps students design and carry out valid scientific experiments and analyze data objectively. In epistemic knowledge, students learn about how scientific knowledge is constructed through observation, experimentation, and logical analysis. Students also learn to distinguish among facts, theories, and hypotheses and to understand the importance of collaboration in ensuring the validity of scientific data. According to Sari (2022) and Muis et al. (2021), epistemic understanding supports the development of critical thinking and the ability to assess scientific claims objectively. Thus, the improvement in scientific knowledge indicates that the use of e-worksheets based on DL, integrated with the Baros mangrove-based JAS approach, not only improves conceptual understanding but also strengthens students' scientific ways of thinking through direct and reflective experiences.

Overall, students' scientific literacy improved across all assessed aspects after learning using the e-worksheets based on DL integrated with the Jelajah Alam Sekitar approach, which

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utilizes the local potential of the Baros mangrove ecosystem. This learning design effectively supported the development of students' scientific thinking skills, ecological awareness, and conceptual understanding through contextual and experience-based learning.

The implementation of e-worksheets based on DL, integrated with the JAS approach, enhances both critical thinking skills and scientific literacy by providing authentic learning experiences in which the natural environment serves as the primary learning resource. The mechanism of this integration can be understood through several interconnected processes. First, direct interaction with real environmental phenomena enables students to observe authentic conditions in the Baros mangrove ecosystem, making abstract scientific concepts more concrete and meaningful. Second, guided exploration through e-worksheets and DL stages directs students to systematically identify problems, formulate hypotheses, collect and analyze empirical data, and draw conclusions. Third, reflective and collaborative activities, such as group discussions and presentations, encourage students to evaluate evidence, justify their reasoning, and refine their understanding based on scientific arguments.

Through these processes, students engage in higher-order thinking activities, including data interpretation, causal analysis, evaluation of scientific evidence, and evidence-based decision making. As students observe mangrove conditions, measure environmental variables, and analyze the impacts of human activities on the ecosystem, they are trained to assess data validity, compare empirical findings with ecological concepts, and reflect on their own thinking processes. These skills are essential components of critical thinking (Sari, 2022).

Furthermore, the JAS approach supports the development of scientific literacy by explicitly connecting scientific knowledge with personal, local, and global contexts. Students not only understand ecosystem concepts but also relate them to real environmental issues, such as coastal erosion, pollution, and mangrove degradation, as well as broader global sustainability challenges. This contextual integration strengthens students' ability to explain scientific phenomena, formulate scientific questions, and use evidence in decision-making, which are core components of scientific literacy. This learning process aligns with the view that contextual exploration and scientific investigation enhance conceptual understanding and scientific reasoning skills (Fadilah et al., 2020). Thus, integrating the Jelajah Alam Sekitar (JAS) approach into learning not only improves conceptual understanding but also systematically develops students' critical, scientific, and reflective thinking skills, resulting in more meaningful and holistic development of scientific literacy.

CONCLUSION

This study analyzed improvements in critical thinking skills and scientific literacy among Phase E high school students through e-worksheets based on Discovery Learning (DL), integrated with the Jelajah Alam Sekitar (JAS) approach using the local potential of the Baros mangrove ecosystem. Results show that the synergy of e-worksheets, DL, and JAS effectively improved all aspects of both skills by facilitating meaningful, inquiry-based learning rooted in authentic environmental contexts. This integration supports active knowledge construction, analytical thinking, and conceptual understanding linked to real-world phenomena.

The study contributes an integrated instructional framework for contextual, environment-based learning, suggesting that educators combine structured media, inquiry models, and local environmental contexts for comprehensive student development. However, findings are limited to a specific context, so future research should examine each component independently and explore broader applications, while also considering additional variables such as problem-solving, creativity, environmental awareness, and pro-environmental behavior.

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