



Development of a Science Process Skills-Based E-Worksheet to Enhance High School Students' Critical Thinking and Scientific Literacy

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Abstract: This study developed a science process skills-based electronic student worksheet (E-LKPD) for Grade XI biology and evaluated its validity, practicality, and effectiveness in improving students' critical thinking skills and scientific literacy. A Research and Development (R&D) approach using the 4-D model (*Define, Design, Develop, and Disseminate*) was employed. Product validity was assessed by subject-matter, instructional design, and layout design experts, while practicality was evaluated through individual ($n = 3$), small-group ($n = 9$), and limited-group ($n = 21$) trials. Effectiveness was tested using experimental and control groups, each consisting of 26 students. Validation scores were 87.5%, 92.8%, and 95.0% for subject matter, instructional design, and layout, respectively, all categorized as very good. Practicality scores were 90.0%, 91.7%, and 93.0% across the three trial stages. In the experimental group, the mean critical thinking and scientific literacy scores were 86.31 and 87.58, respectively. The N-Gain was 0.72 in the experimental group and 0.40 in the control group, indicating high and moderate improvement, respectively. The independent-samples t -test showed a significant difference between groups ($t = 5.80$, $p < 0.05$). These findings indicate that the developed E-LKPD is valid, practical, and effective in improving students' critical thinking skills and scientific literacy.

Keywords: E-LKPD; science process skills; critical thinking; scientific literacy; plant tissues

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INTRODUCTION

Biology education plays a strategic role in developing students who not only master biological concepts but are also able to understand natural phenomena through scientific processes. The structure and function of plant tissues is an important topic in senior high school biology because students are required to understand the relationship between microscopic tissue structures and the functions of plant organs. However, this topic is inherently abstract because many of the objects being studied cannot be directly observed without laboratory equipment, microscopic images, or digital visualization. Consequently, effective instruction on plant tissues should provide students with opportunities to observe biological structures, identify relevant characteristics, classify objects, analyze structure–function relationships, interpret evidence, and communicate their findings.

Science process skills provide an appropriate instructional foundation for such learning because they actively engage students in the processes through which scientific knowledge is constructed. These skills extend beyond the procedural ability to perform scientific activities; they also involve cognitive processes such as collecting evidence, interpreting information, analyzing data, evaluating observations, drawing conclusions, and communicating findings. These processes closely correspond to the competencies required for scientific literacy, particularly explaining phenomena scientifically, evaluating scientific inquiry, and interpreting data and evidence

scientifically (OECD, 2023). At the same time, engaging students in inquiry, evidence evaluation, interpretation, and reasoning provides opportunities to develop higher-order and critical thinking skills. Recent evidence indicates that inquiry-oriented science instruction can substantially support higher-order thinking and critical thinking by requiring learners to analyze information, evaluate evidence, and construct reasoned conclusions (Antonio & Prudente, 2023; Arifin et al., 2025). These competencies are also consistent with the demands of 21st-century learning, which emphasize critical thinking, problem-solving, communication, collaboration, and scientific literacy (Serly, 2018; Kemendikbudristek, 2022).

The learning conditions at SMA Negeri 1 Sungai Raya Aceh Timur indicate that the student worksheets currently used for the topic of plant tissue structure and function remain largely conventional. The worksheets primarily contain summaries of instructional content and discussion questions but do not systematically guide students through scientific activities. Observations and interviews showed that students rarely engage in structured experiments, data analysis, or inquiry activities that allow them to construct concepts from empirical evidence. Teachers also face limitations in providing digital practicum media and developing innovative student worksheets. Preliminary assessments further indicated that students' abilities to identify relevant information, analyze structure–function relationships, use evidence, draw conclusions, and provide scientific reasoning had not yet reached optimal levels. These findings suggest that the instructional problem involves not only limited learning resources but also insufficient opportunities for students to engage in scientific reasoning and evidence-based learning. As a result, instruction tends to remain teacher-centered, while students rely more heavily on memorizing terminology than on constructing conceptual understanding through scientific experience.

Previous research has demonstrated the potential of worksheets and digital learning materials to support active science learning. Hayati (2024), for example, reported that science process skills-based worksheets on plant tissue achieved a very high feasibility rating and received highly positive student responses. Research specifically involving electronic worksheets has also shown that E-LKPDs can support analytical skills and data interpretation in plant tissue learning. Rahmawati and Alimah (2022), for instance, developed a problem-solving-based E-LKPD on plant tissues and reported improvements in students' analytical and data-presentation abilities. Likewise, electronic worksheets designed around scientific approaches have been reported to support critical thinking in biology learning (Chaniago et al., 2022). These findings support the potential of electronic worksheets as learning environments that combine content presentation with structured scientific activities.

A number of studies have also specifically examined the integration of scientific literacy and critical thinking within E-LKPDs. Zahroh and Yuliani (2021) developed a scientific literacy-based E-LKPD on growth and development to train students' critical thinking skills. Their product positioned scientific literacy as the primary framework of the worksheet and critical thinking as the targeted learning outcome. Similarly, Widianingrum and Ducha (2023) developed a scientific literacy-based E-LKPD for Grade XI students studying the locomotor system and reported high levels of validity and practicality. More recent work has likewise shown that scientific literacy-based electronic worksheets can be designed to train critical thinking in biology topics such as bryophytes and pteridophytes (Fatika & Rahayu, 2024). However, these studies primarily positioned scientific literacy as the conceptual basis of the E-LKPD and did not specifically organize science process skills as the central instructional sequence through which both critical thinking and scientific literacy were developed.

Other studies have demonstrated that science process skills are conceptually and empirically associated with higher-order cognitive outcomes. Atmojo et al. (2024), for example, identified significant relationships among scientific literacy, science process skills, and higher-order thinking outcomes, supporting the view that engaging learners in scientific processes is closely related to the development of advanced cognitive abilities. Furthermore, biology learning that systematically incorporates inquiry, experimentation, evidence interpretation, and scientific discussion has been shown to promote both scientific literacy and critical thinking (Suwono et al., 2023). These findings provide a theoretical basis for designing learning materials in which science process skills function not merely as supplementary activities but as mechanisms through which students construct, evaluate, and communicate scientific understanding.

Despite the growing number of studies on E-LKPDs, science process skills, scientific literacy, and critical thinking, an important instructional gap remains. Existing scientific literacy-based E-LKPDs have generally focused on using literacy-oriented activities to train critical thinking, whereas science process skills-based worksheets have more commonly targeted critical thinking, science process performance, or general learning outcomes as separate outcomes. Few studies have systematically positioned science process skills as the organizing structure of an E-LKPD while explicitly linking each stage of scientific activity to both critical thinking and scientific literacy outcomes, particularly in the context of plant tissue structure and function. Thus, the research gap addressed in this study is not merely the absence of a product that combines several variables, but rather the limited development of an instructional design that connects science process activities, scientific evidence, critical reasoning, and scientific literacy within a coherent learning sequence.

Conceptually, science process skills can provide such a mechanism. Observation requires students to identify relevant information; classification enables them to detect similarities, differences, and patterns; experimentation provides opportunities to generate empirical evidence; data analysis requires interpretation and evaluation; conclusion drawing involves integrating evidence into reasoned judgments; and communication requires students to articulate evidence-based explanations. These activities closely align with scientific literacy competencies because scientifically literate students are expected to explain phenomena, evaluate scientific inquiry, and critically interpret data and evidence (OECD, 2023). At the same time, these processes engage students in analysis, evaluation, inference, and justification, which are central components of critical thinking. Therefore, improvements in critical thinking and scientific literacy should not be regarded merely as consequences of using digital media; rather, they should emerge from the structured scientific reasoning embedded within the learning activities.

Based on this gap, the novelty of the present study lies in the instructional architecture of the E-LKPD, which positions science process skills as the primary learning sequence for the topic of plant tissue structure and function. Rather than merely converting a printed worksheet into an electronic format, the E-LKPD organizes learning through sequential activities involving observation of tissue visualizations or specimens, use of tools and materials, classification of tissue characteristics, experimentation, analysis of observational data, evidence-based conclusion drawing, and communication of findings. Each activity is intentionally linked to indicators of critical thinking and scientific literacy, thereby creating an explicit instructional pathway from scientific activity to evidence-based reasoning and scientific understanding. Thus, the contribution of the study lies not simply in the use of digital technology or the

combination of multiple variables, but in the systematic integration of science process skills, scientific evidence, critical thinking, and scientific literacy within a single E-LKPD.

The product was developed using the 4-D model, which consists of the *Define*, *Design*, *Develop*, and *Disseminate* stages. Through this model, user needs and learning conditions are first analyzed before the product is designed, developed, validated, revised, tested, and disseminated. This approach enables the E-LKPD to be developed according to actual classroom needs and the characteristics of plant tissue content, which is largely microscopic and abstract. By combining digital visualization with structured scientific activities, the E-LKPD is expected to provide more meaningful learning experiences and reduce students' dependence on memorization-based learning.

Accordingly, this study aimed to develop a science process skills-based E-LKPD for the topic of plant tissue structure and function, determine its validity and feasibility based on expert evaluation, assess its practicality based on student responses, and evaluate its effectiveness in improving students' critical thinking skills and scientific literacy. The science process skills integrated into the E-LKPD include observing, using tools and materials, classifying, conducting experiments, drawing conclusions, and communicating findings. Critical thinking skills focus on identifying problems, analyzing arguments, providing clarification, evaluating observations, drawing conclusions, and considering reasons rationally (Ennis, 2017; Niken et al., 2020).

METHOD

Research Design and Development Procedures

This study employed a Research and Development (R&D) approach to develop an electronic student worksheet (E-LKPD) based on science process skills. The development process followed the 4-D model, which consists of four stages: *Define*, *Design*, *Develop*, and *Disseminate*. This model was selected because it provides a systematic framework for conducting needs analysis, designing the product, validating and revising the product, conducting field trials, and disseminating the final product. The study was conducted at SMA Negeri 1 Sungai Raya Aceh Timur beginning in November 2025. The E-LKPD was developed for Grade XI biology instruction on the structure and function of plant tissues.

The *Define* stage involved preliminary analysis, student analysis, task analysis, concept analysis, and curriculum analysis. The findings indicated that the existing instructional materials did not provide students with sufficient opportunities to engage in scientific inquiry. During the *Design* stage, the structure of the E-LKPD was developed to include instructions for use, learning objectives, instructional content, science process skills activities, observation tables, analytical questions, concept-application tasks, evaluation activities, reflection, a glossary, and references. The *Develop* stage comprised product development, expert validation, revision, and field testing. Product effectiveness was also evaluated during this stage by implementing the E-LKPD in the experimental class and comparing the learning outcomes with those of a control class using a pretest-posttest control group design. The *Disseminate* stage was conducted after the product had been judged feasible and effective. At this stage, the E-LKPD was introduced to the school as an alternative instructional resource and distributed digitally to teachers and other relevant users. Thus, effectiveness testing was conducted as part of the *Develop* stage, whereas the *Disseminate* stage focused on distributing the finalized product after it had undergone development and evaluation.

Research Participants

The participants consisted of expert validators, a biology teacher, and Grade XI students at SMA Negeri 1 Sungai Raya Aceh Timur. Product validation involved two experts: Dra. Cucik Suriani, M.Si., as the subject-matter expert, and Dr. Widya Arwita, S.Pd., M.Pd., as the media/layout design expert. The subject-matter expert held a master's degree in science, whereas the media expert held doctoral and master's degrees in education. The specific areas of expertise, academic positions, and institutional affiliations of both validators should be reported in accordance with their official professional profiles. The instructional design aspect was also evaluated by a biology teacher acting as a practitioner, who provided feedback on the alignment of the E-LKPD with the learning objectives, student characteristics, and actual classroom implementation.

The individual trial involved three students, the small-group trial involved nine students, and the limited-group trial involved 21 students. During the effectiveness test, the experimental class consisted of 26 students and the control class consisted of 18 students, resulting in a total of 44 students. Both groups comprised Grade XI students with relatively comparable academic characteristics in terms of grade level, learning content, curriculum, and initial ability, as indicated by their pretest performance. The experimental class received instruction using the science process skills-based E-LKPD, whereas the control class received instruction using the instructional materials and teaching strategies routinely employed in regular classroom practice.

The experimental and control classes were selected using purposive sampling based on class characteristics, number of students, initial academic ability, and recommendations from the subject teacher. Students participating in the individual, small-group, and limited-group trials were selected progressively to represent different levels of student ability. Grade XI students were selected because they were studying the structure and function of plant tissues. Student characteristics were an important consideration in the development of the E-LKPD because plant tissue concepts are relatively abstract and require visualization and observational experience. Feedback obtained at each trial stage was used as the basis for product revision before the E-LKPD proceeded to the subsequent stage.

Research Instruments and Data Collection Procedures

The research instruments consisted of expert validation sheets, student response questionnaires, observation sheets, and student competency tests. The expert validation sheets were used to assess the feasibility of the E-LKPD in terms of content, instructional design, visual presentation, language, and overall presentation. Subject-matter validation covered content feasibility, conceptual depth, content accuracy, language, presentation, and the alignment of evaluation activities with the learning objectives. Instructional design validation assessed the alignment of learning objectives, the sequence of activities, clarity of instructions, integration of activities with science process skills, and the extent to which the intended learning objectives could be achieved. Layout design validation assessed display size, cover design, internal layout, writing conventions, readability, and the suitability of the digital presentation.

The student response questionnaire was used to assess attractiveness, ease of use, perceived conceptual understanding, and learning motivation after students used the E-LKPD. The individual trial was conducted with three students, followed by a small-group trial with nine students and a limited-group trial with 21 students. The assessment results and student comments obtained at each stage were used to refine the product before its implementation in the effectiveness test.

The competency tests were designed to measure two major outcomes: critical thinking skills and scientific literacy. The critical thinking test consisted of items developed according to critical thinking indicators, including identifying problems, analyzing arguments, providing explanations, evaluating evidence or observations, and drawing and evaluating conclusions. Each response was assessed using a scoring rubric developed in accordance with the characteristics of the items and the indicators being measured.

The scientific literacy test was developed based on the scientific literacy framework of the Programme for International Student Assessment (PISA), which encompasses the ability to explain phenomena scientifically, evaluate and design scientific inquiry, and interpret scientific data and evidence. The test items were contextualized within the topic of plant tissue structure and function, for example through the analysis of microscopic images, observational results, tables, graphs, and phenomena related to plant tissue functions. The final item format, number of items, source of adapted instruments, and scoring procedures were determined according to the instruments actually used in the study.

Before data collection, the critical thinking and scientific literacy instruments were evaluated through content validation and empirical testing. Content validity was assessed by experts with competence in biology education or educational assessment, with particular attention to item-indicator alignment, conceptual accuracy, clarity of language, and appropriateness of item difficulty. Empirical testing was subsequently conducted with students who had characteristics similar to those of the research participants but were not included in the effectiveness test. Item validity was analyzed using statistical procedures appropriate to the item format, whereas instrument reliability was assessed using Cronbach's alpha for instruments that met the assumptions for its application. The validity and reliability coefficients should be reported according to the actual results obtained from the instrument testing.

Effectiveness data were collected using a pretest-posttest control group design. Before the intervention, students in both the experimental and control classes completed a pretest to assess their initial critical thinking skills and scientific literacy. The experimental class then received instruction using the science process skills-based E-LKPD, whereas the control class received instruction without the developed E-LKPD. After completion of the instructional period, both groups completed a posttest using instruments that had been judged suitable for use. Changes in pretest and posttest scores were used to evaluate improvements in students' critical thinking skills and scientific literacy.

Data Analysis

The data were analyzed using both quantitative descriptive and qualitative approaches. Expert validation scores and student response data were converted into percentages by dividing the obtained score by the maximum possible score and multiplying the result by 100%. The assessment scale comprised five categories: very good, good, fair, poor, and very poor. Scores of 81-100% were categorized as very valid or very good, 61-80% as valid, 41-60% as moderately valid, 21-40% as less valid, and 0-20% as invalid. Comments and suggestions from the validators were analyzed qualitatively and used as the basis for product revision.

Effectiveness analyses were conducted separately for critical thinking skills and scientific literacy. The analysis began with a normality test to determine whether the data were normally distributed and a homogeneity test to assess the equality of variances between the experimental and control groups. After the assumptions for parametric analysis had been satisfied, differences in improvement between the two

groups were analyzed using an independent-samples *t*-test. Hypothesis testing was conducted at a significance level of 5% ($\alpha = 0.05$). The product was considered effective when a statistically significant difference was found between the experimental and control groups, as indicated by a *p*-value < 0.05 .

Improvements in student performance were also calculated using normalized gain (N-Gain) scores based on the differences between pretest and posttest performance. N-Gain was calculated separately for critical thinking skills and scientific literacy so that improvement in each outcome could be examined independently. The resulting N-Gain values were interpreted according to the gain categories adopted in the study. The findings were subsequently interpreted in relation to the research objectives and relevant previous studies.

Research Ethics

The study was conducted after obtaining permission from the relevant authorities and approval from SMA Negeri 1 Sungai Raya Aceh Timur. Before data collection, the researchers explained the objectives and procedures of the study to the school and the biology teacher. Student data were collected in accordance with the approval requirements of the school, the students, and their parents or guardians where required. All student data were used exclusively for research purposes and reported in aggregate form to protect participants' identities and confidentiality. The study procedures were also designed to avoid disrupting regular classroom activities and were implemented in accordance with the applicable regulations and policies of the school.

RESULTS AND DISCUSSION

Development of the Science Process Skills-Based E-LKPD

The development process resulted in an E-LKPD specifically designed for the topic of plant tissue structure and function. During the *Define* stage, the worksheets previously used in the classroom were found to focus primarily on content presentation and discussion questions, with limited opportunities for students to engage in observation, experimentation, data analysis, and communication of scientific findings. Based on these conditions, the E-LKPD was developed to incorporate science process skills involving observation, classification, the use of tools and materials, experimentation, conclusion drawing, and communication of findings. The instructional content covered meristematic, epidermal, parenchymal, supporting, vascular, and cork tissues. The material was supplemented with visual representations and structured activities that enabled students to relate tissue structure to the functions of plant organs.

During the *Design* and *Develop* stages, the E-LKPD was constructed as a digital learning resource incorporating visualizations, observation activities, analytical questions, observation tables, case studies, evaluation tasks, and reflective activities. The product was therefore designed not merely as a digital source of biological information but also as a guide for conducting structured scientific activities. The learning sequence required students to obtain information through observation, classify the information, analyze the findings, connect evidence with relevant biological concepts, draw conclusions, and communicate their results.

This sequence positioned science process skills as the central mechanism of learning rather than as supplementary activities. Dewi et al. (2023) similarly reported that worksheets incorporating a scientific approach can facilitate science process skills and improve learning outcomes. Widanti et al. (2023) also demonstrated that inquiry-based worksheets on plant tissue structure and function can promote active student

engagement. These findings support the use of structured scientific activities as an instructional framework for biology learning.

The pedagogical value of the developed E-LKPD lies in the way it organizes students' interaction with scientific evidence. Observation activities provide students with empirical information, classification activities help them identify similarities, differences, and patterns, and analytical questions encourage them to connect evidence with biological concepts. This instructional sequence is consistent with inquiry-based science learning, in which students construct understanding through observation, investigation, interpretation, and evidence-based reasoning (Urdanivia Alarcon et al., 2023).

A key characteristic of the developed product was therefore the transformation of the worksheet from a predominantly informational resource into an instructional tool that systematically guided students through scientific processes. Visual representations of plant tissues facilitated the interpretation of microscopic structures, while observation tables and classification activities helped students organize the information they obtained. Analytical questions and case studies further encouraged students to compare information, identify structure-function relationships, evaluate evidence, and justify conclusions. Thus, each component of the E-LKPD served a specific pedagogical function in supporting conceptual understanding and scientific reasoning.

Validity and Feasibility of the E-LKPD

The validation results indicated that the developed E-LKPD had a very high level of feasibility. The subject-matter expert assigned an average score of 87.5%, the instructional design expert assigned 92.8%, and the layout design expert assigned 95.0%. All three scores were classified as very good. In the subject-matter validation, language and the integration of evaluation and reflection received particularly high ratings. The instructional design validation showed very good results for content accuracy, presentation techniques, sentence clarity, completeness of presentation, and language. Similarly, the layout validation yielded high scores for display dimensions, cover design, writing conventions, and overall presentation feasibility.

Table 1. Validation results of the E-LKPD

Validator	Percentage	Category
Subject-matter expert	87.5%	Very Good
Instructional design expert	92.8%	Very Good
Layout design expert	95.0%	Very Good

The high validation scores indicate that the E-LKPD met the expected criteria for content, instructional presentation, language, and visual design. This finding is consistent with Hayati (2024), who reported a feasibility score of 83.5% for a science process skills-based worksheet on plant tissues. Aynani (2024) likewise reported that a scientific approach-based E-LKPD demonstrated high validity and supported scientific literacy.

The validity findings are important not only as indicators of technical product quality but also because they demonstrate alignment among scientific content, instructional activities, and intended learning outcomes. The plant tissue content was presented by linking structural characteristics with biological functions rather than by providing isolated definitions. In addition, the science process skills activities were systematically organized from observation to communication of findings. Such

alignment is important in inquiry-oriented learning because scientific activities are most meaningful when they are directly connected to conceptual understanding and scientific reasoning (Urdanivia Alarcon et al., 2023).

The high layout validation score further suggests that the organization and visual presentation of the E-LKPD supported readability and navigation. Therefore, the validation results indicate that the product was considered appropriate not only in terms of visual and technical presentation but also in terms of its instructional suitability for the intended biology learning objectives.

Practicality and Student Responses

The practicality of the E-LKPD was evaluated progressively through individual, small-group, and limited-group trials. The individual trial involving three students produced an average score of 90.0%. The visual appearance aspect received 95%, perceived conceptual understanding 85%, and learning motivation 90%. The small-group trial involving nine students yielded an average score of 91.7%, with scores of 92% for visual appearance, 90% for perceived conceptual understanding, and 93% for learning motivation. The limited-group trial involving 21 students produced an average score of 93.0%, with scores of 93% for visual appearance, 94% for perceived conceptual understanding, and 92% for learning motivation.

Table 2. Practicality test results of the E-LKPD

Trial Stage	Number of Students	Percentage	Category
Individual trial	3	90.0%	Very Good
Small-group trial	9	91.7%	Very Good
Limited-group trial	21	93.0%	Very Good

These results indicate that the E-LKPD received consistently positive responses across the three stages of testing. However, the increase from 90.0% in the individual trial to 93.0% in the limited-group trial should not be interpreted as a progressive increase in practicality because the number and characteristics of participants differed across trial stages. A more appropriate interpretation is that the product consistently received very good ratings from different groups of users.

Students responded positively to the visual appearance, ease of use, learning activities, and motivational aspects of the E-LKPD. The inclusion of visualizations, observation activities, structured working tables, analytical questions, and reflection tasks provided students with a clear sequence for completing learning activities. This structured guidance may help students focus on observation, analysis, and interpretation rather than merely on task completion.

The practicality of the E-LKPD also appears to be related to the integration between its digital features and its instructional structure. The product does not function simply as an electronic replacement for a printed worksheet. Instead, the digital format supports a sequence of activities involving observation, evidence interpretation, analytical questioning, and communication. Therefore, the positive student responses are more appropriately interpreted as evidence that the product was both usable and instructionally accessible.

The "conceptual understanding" component of the questionnaire was interpreted as students' perceptions of how easily they understood the material rather than as objective evidence of cognitive achievement. Objective learning outcomes were assessed through the critical thinking and scientific literacy tests during the

effectiveness stage. Accordingly, the questionnaire data were used to evaluate product practicality and user responses rather than to establish cognitive improvement.

Effectiveness of the E-LKPD in Supporting Critical Thinking Skills and Scientific Literacy

The effectiveness of the E-LKPD was evaluated by comparing learning outcomes between the experimental and control groups. The data met the assumptions required for parametric analysis based on normality and homogeneity testing. Hypothesis testing using an independent-samples *t*-test yielded a calculated *t* value of 5.80, whereas the critical *t* value was 1.671. Because the calculated *t* value exceeded the critical value, a statistically significant difference was found between the experimental and control groups. This result indicates that students who learned using the science process skills-based E-LKPD achieved better learning outcomes than those in the control group.

Table 3. N-Gain results

Group	N-Gain	Percentage	Category
Experimental	0.72	72%	High
Control	0.40	40%	Moderate

The N-Gain analysis further showed a greater improvement in the experimental group. The experimental group obtained an N-Gain of 0.72, categorized as high, whereas the control group obtained an N-Gain of 0.40, categorized as moderate. Together with the *t*-test result, these findings indicate that the E-LKPD provided a more favorable learning environment for developing the targeted competencies.

The improvement can be explained by the cognitive demands embedded in the science process skills activities. Observation required students to identify relevant information, while classification encouraged them to recognize similarities, differences, and patterns among tissue characteristics. During data analysis, students were required to relate observational findings to concepts concerning plant tissue structure and function. Analytical questions and case studies further encouraged them to evaluate information, consider evidence, formulate explanations, and draw conclusions.

These activities are closely related to critical thinking because students are required not merely to recall biological concepts but also to analyze information, evaluate evidence, draw inferences, and justify their conclusions. Atmojo et al. (2024) reported significant relationships among science process skills, scientific literacy, and higher-order thinking outcomes, supporting the view that engagement in scientific processes can contribute to advanced cognitive performance. Inquiry-oriented learning has likewise been associated with scientific reasoning, analysis, experimentation, and conclusion drawing (Urdanivia Alarcon et al., 2023).

Accordingly, the improvement observed in the experimental group should not be attributed solely to the electronic format of the worksheet. Rather, the instructional mechanism lies in the structured activities that repeatedly require students to interpret information, analyze evidence, evaluate relationships, and construct reasoned conclusions.

The same instructional structure also provides a strong basis for developing scientific literacy. Microscopic images and observational findings provide scientific information that students must interpret. Classification activities require them to identify patterns, while analytical and experimental activities require them to relate evidence to

biological functions. Conclusion-drawing and communication activities further require students to use evidence to construct scientific explanations.

These activities are consistent with the scientific literacy competencies emphasized in the PISA framework. Scientific literacy involves the capacity to explain phenomena scientifically, evaluate and design scientific inquiry, and interpret data and evidence scientifically (OECD, 2023). Thus, the activities incorporated into the E-LKPD provide opportunities for students to engage directly with the processes underlying scientific literacy rather than simply acquire factual biological knowledge.

The present findings are also consistent with Suwono et al. (2023), who showed that inquiry-oriented biology learning can enhance scientific literacy, biological knowledge, and critical thinking. Their findings support the assumption that instructional environments requiring students to engage with evidence, scientific problems, and inquiry processes can simultaneously support several dimensions of scientific reasoning.

Discussion of the Effectiveness of the E-LKPD

Overall, the findings indicate that science process skills function as an important instructional mechanism supporting both critical thinking and scientific literacy. Although these two competencies represent distinct learning outcomes, they can be developed through overlapping scientific activities.

In relation to critical thinking, science process skills provide opportunities for students to analyze information, evaluate evidence, identify relationships, draw inferences, and justify conclusions. In relation to scientific literacy, the same activities provide opportunities to obtain, interpret, and use scientific evidence to explain biological phenomena. Thus, a single sequence of activities can support different cognitive outcomes through related but distinct processes.

For example, when students observe and classify plant tissues, they practice identifying relevant information, comparing characteristics, and recognizing patterns. These processes contribute to critical analysis. When students subsequently use those observations to explain the relationship between tissue structure and biological function, they engage in scientific literacy by interpreting evidence and constructing scientific explanations. This interaction demonstrates that critical thinking and scientific literacy need not be treated as isolated competencies.

The findings are consistent with Rahma (2022), who reported that E-LKPD can support critical thinking across the dimensions of interpretation, analysis, evaluation, inference, explanation, and self-regulation. Similarly, Aynani (2024) reported improvements in scientific literacy through an E-LKPD incorporating a scientific approach. However, the contribution of the present study extends beyond demonstrating the potential effectiveness of electronic worksheets.

The distinctive contribution of the developed E-LKPD lies in the use of science process skills as the organizing structure of the learning sequence. Observation, classification, experimentation, analysis, conclusion drawing, and communication are not presented as isolated activities. Instead, they form a coherent sequence through which students first obtain evidence, organize and interpret information, connect evidence with biological concepts, formulate conclusions, and communicate scientific explanations.

This structure is consistent with the broader principles of inquiry-oriented science learning. Urdanivia Alarcon et al. (2023) emphasized that inquiry-based instruction supports knowledge construction through investigation, experimentation, analysis, and scientific reasoning. Similarly, Suwono et al. (2023) demonstrated that inquiry-oriented biology instruction can simultaneously promote scientific literacy and critical thinking.

The findings therefore suggest that the effectiveness of the E-LKPD is more appropriately explained by its instructional architecture than by digitalization alone. The digital format provides the platform, whereas the learning mechanism is established through the systematic interaction of observation, evidence, analysis, explanation, and communication. In this sense, the E-LKPD functions as an evidence-oriented learning environment rather than merely as an electronic worksheet.

Visualizations also contribute to this instructional mechanism by making microscopic plant structures more accessible for observation and comparison. However, their pedagogical value emerges primarily when students are required to interpret what they observe, connect visual information with biological concepts, and use the evidence to construct explanations. The combination of visualization and structured science process activities therefore helps bridge the gap between abstract plant tissue concepts and observable scientific evidence.

Taken together, the validation, practicality, and effectiveness results indicate that the developed science process skills-based E-LKPD is feasible for use in Grade XI biology learning and provides a structured instructional environment that supports scientific reasoning. The high validation scores, consistently positive student responses, higher N-Gain in the experimental group, and statistically significant difference between groups collectively support the instructional potential of the developed product.

CONCLUSION

The science process skills-based E-LKPD developed for the topic of plant tissue structure and function was found to be valid, practical, and effective for supporting Grade XI biology learning. The validity assessment showed that the product met the required criteria in terms of subject matter, instructional design, and layout, indicating that its content, presentation, language, and visual design were appropriate for instructional use. The practicality trials also yielded consistently very positive responses, suggesting that the E-LKPD was easy to use, engaging, and able to guide students through learning activities in a structured manner. Its implementation was associated with improvements in students' critical thinking skills through activities involving observation, classification, data analysis, evidence evaluation, conclusion drawing, and communication, while scientific literacy was supported through opportunities to interpret data, use scientific evidence, explain phenomena scientifically, and formulate evidence-based conclusions. Nevertheless, the study was limited to a single school and a single biology topic; therefore, the findings should be interpreted within this context, and further research involving broader student populations, multiple schools, and other biology topics is recommended to strengthen the generalizability of the results.

RECOMMENDATION

Based on the findings and limitations of this study, future research should evaluate the implementation of science process skills-based E-LKPDs across different schools and among students with more diverse characteristics, apply the approach to other biology topics, and involve larger samples. Such studies would provide broader evidence regarding the practicality and effectiveness of E-LKPDs in supporting students' critical thinking skills and scientific literacy. Future development could also incorporate more interactive features and a wider range of science process skills activities to optimize the use of E-LKPDs in biology instruction.

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