



PROMOTING SCIENTIFIC LITERACY FOR SUSTAINABLE DEVELOPMENT THROUGH SCRIBO WEB-BASED LEARNING ON ECOSYSTEMS AND ENVIRONMENTAL CHANGE

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ABSTRACT

Digital learning platforms have been widely implemented in science education; however, limited empirical evidence explains how specific web-based platforms support measurable scientific literacy competencies in learning about ecosystems and environmental change. Students require structured learning experiences to interpret environmental data, evaluate scientific evidence, and connect biological concepts with real-world environmental problems. Therefore, this study examined changes in students' scientific literacy after implementing SCRIBO web-based learning on ecosystem and environmental change topics. This study employed a quantitative approach with a one-group pretest–posttest design involving 80 tenth-grade students from two classes. Scientific literacy was measured with a test developed from scientific literacy indicators, while observations and student interviews provided supporting data on students' learning experiences. Instrument validity and reliability were examined using Pearson's Product-Moment correlation and Cronbach's Alpha, respectively. Quantitative data were analyzed using the Shapiro–Wilk normality test, paired-samples t-test, Cohen's d, and normalized gain (N-Gain). The results showed that the mean scientific literacy score increased from pretest to posttest, with a statistically significant difference. The within-group standardized change was large, while the N-Gain score indicated moderate improvement. Observation and interview findings also indicated that SCRIBO supported students in reading scientific texts, interpreting environmental data, evaluating evidence, and constructing evidence-based responses. The implementation of SCRIBO web-based learning was followed by higher scientific literacy scores in ecosystem and environmental change learning and showed potential to support students' scientific reasoning through structured digital learning activities. However, because this study used a one-group pretest–posttest design without a control group, the findings reflect within-group changes rather than definitive evidence of causal effectiveness. Further studies with comparison groups and broader samples are needed to strengthen evidence of SCRIBO's effectiveness in science learning.

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Keywords: scientific literacy; SCRIBO; web-learning; environment; ecosystem; technology; biology

INTRODUCTION

The rapid development of digital technology has transformed science education by expanding access to information, promoting interactive learning, and supporting data-driven inquiry. In 21st-century education, these transformations are closely linked to the need to strengthen students' scientific literacy. Scientific literacy is not limited

to understanding scientific concepts but also includes the ability to interpret evidence, analyze data, evaluate scientific information, and make responsible decisions in real-life contexts. These competencies are essential for preparing students to respond to complex socio-scientific issues, particularly those related to ecosystems, environmental degradation, climate change, and sustainable living (Effendi et al., 2021; Hartono et al., 2023; Valladares, 2021).

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The urgency of strengthening scientific literacy is also aligned with the Sustainable Development Goals (SDGs), especially SDG 4 on quality education, SDG 13 on climate action, SDG 14 on life below water, and SDG 15 on life on land. The SDGs emphasize the importance of education in developing knowledge, skills, values, and attitudes needed to promote sustainable development. Environmental issues cannot be solved through scientific knowledge alone; they require students to think critically, interpret environmental phenomena, and develop responsible behavior toward ecological sustainability. Therefore, science learning must be designed not only to improve conceptual understanding but also to develop students' ability to connect scientific concepts with sustainability problems in their surroundings (Jeronen & Jeronen, 2026; Mumthaza et al., 2026; Nurkanti et al., 2026; Ortega-Sánchez et al., 2020; Savelyeva & Park, 2024).

However, Indonesian students' scientific literacy remains a serious educational challenge. The OECD PISA 2022 report showed that only around 34% of Indonesian students reached at least Level 2 proficiency in science, while the OECD average was 76%. At this level, students are expected to recognize explanations for familiar scientific phenomena and use scientific knowledge to identify whether conclusions are valid based on available data. This condition indicates that many students still struggle to apply scientific reasoning, interpret evidence, and use science to solve contextual problems. These findings strengthen the need for learning innovations that can support inquiry, evidence-based reasoning, and contextual scientific understanding in biology education (Nurkanti et al., 2026; Valladares, 2021; Wibowo et al., 2026).

This problem is also reflected in the preliminary study conducted before implementing this research. Preliminary observations showed that students had difficulty interpreting environmental data, explaining ecosystem interactions, and constructing evidence-based arguments about environmental change. The initial diagnostic assessment also indicated that students' scientific literacy was still low, particularly in the indicators of explaining scientific phenomena, evaluating scientific evidence, and interpreting data scientifically. In addition, classroom learning was still dominated by teacher explanations and textbook-based activities, while students had limited opportunities to explore real environ-

mental problems through digital learning media. These preliminary findings indicate that students need a more contextual, interactive learning environment that supports scientific literacy development (Fitri & Wiyarsi, 2025; Irwandi et al., 2025; Jeronen & Jeronen, 2026).

Ecosystem and environmental change topics are highly relevant for strengthening scientific literacy because they are directly connected to students' daily lives and sustainability issues. These topics require students to understand relationships among living organisms, environmental factors, human activities, biodiversity loss, pollution, and ecological balance. Learning these topics should not focus only on memorizing definitions but also on training students to analyze causes, impacts, and possible solutions to environmental problems. Therefore, integrating digital learning media into ecosystem and environmental change topics can make biology learning more meaningful and better aligned with SDG-oriented education (Annuš et al., 2023; Hartono et al., 2023; Karyanto, 2019).

Previous studies have shown that digital learning media, web-based learning, and technology-enhanced instruction can improve student engagement, conceptual understanding, and learning independence in science education. Several studies have also emphasized the importance of scientific literacy in environmental education and sustainability-oriented learning. However, most previous studies focused on general digital media, mobile learning, e-modules, learning management systems, or environmental literacy. Few studies have specifically investigated the use of a web-based learning platform designed to strengthen scientific literacy through reading, analysis, digital interaction, and evidence-based assessment (Anwari et al., 2025; Delello et al., 2018; Suzuki et al., 2020). In particular, the use of SCRIBO as a web-based learning platform in biology learning has not been sufficiently examined, especially in relation to students' scientific literacy indicators in ecosystem and environmental change topics (Alharbi, 2023; Sofa et al., 2025; Tay, 2024).

Using SCRIBO in education can help develop students' science literacy skills. This tool supports higher-order thinking skills, such as interpreting information, evaluating evidence, and scientific communication, through AI-based assessment. In addition to measuring students' science literacy skills, integrating technology into

learning about ecosystems and environmental change helps students understand phenomena in a more contextual and data-driven way. This tool is expected to make learning more meaningful (Tay, 2024).

Research on technology-enhanced learning and the use of digital media has been extensively discussed (Hammad, 2024; Pan et al., 2023). However, no studies have specifically examined the effectiveness of web-based platforms such as SCRIBO in improving students' science literacy, particularly regarding ecosystem and environmental change topics. Furthermore, no in-depth study has examined the use of SCRIBO in relation to science literacy indicators (Tay, 2024).

This gap shows that further empirical research is needed to examine whether SCRIBO web-based learning can effectively enhance students' scientific literacy in SDG-related biology topics. The gap analysis indicates that previous studies have supported the importance of digital learning and sustainability education. However, they have not clearly explained how a specific web-based platform can support measurable scientific literacy indicators in the context of learning about ecosystem and environmental change. Therefore, this study aims to support and extend previous research by providing empirical evidence on the impact of SCRIBO web-based learning on students' scientific literacy.

This study's novelty lies in integrating SCRIBO web-based learning into ecosystem and environmental change topics as an SDG-oriented biology learning strategy. Scribo is an online learning platform developed by Marshall Cavendish that offers unique features compared to similar platforms. Unlike previous studies that generally examined digital learning media, this study focuses specifically on how SCRIBO sup-

ports scientific literacy through reading activities, information analysis, scientific reasoning, and digital-based assessment. This study also contributes to science education by offering a learning model that connects digital technology, scientific literacy, and sustainability-oriented biology learning (Tay, 2024).

Based on this research gap, this study aims to analyze changes in students' scientific literacy after implementing SCRIBO web-based learning in ecosystem and environmental change topics. Specifically, this study examines students' improvement in explaining scientific phenomena, interpreting scientific data, and evaluating evidence related to environmental problems. The findings are expected to contribute theoretically to the development of scientific literacy research and, practically, to the design of SDG-oriented digital learning in biology education.

METHODS

This study used a quantitative approach with a one-group pretest–posttest design to examine changes in students' scientific literacy before and after implementing SCRIBO web-based learning on ecosystem and environmental change topics. SCRIBO was selected because its web-based features support scientific reading, information analysis, evidence evaluation, and digital assessment, which are directly related to the scientific literacy competencies measured in this study. The design involved measuring students' scientific literacy before the intervention (pretest), implementing SCRIBO-based learning, and measuring the same competencies after the intervention (posttest). Figure 1 presents the research design.

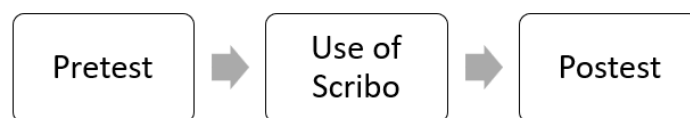


Figure 1. Research Process

This design allowed the researcher to compare students' scientific literacy scores before and after implementing SCRIBO. Although this design does not involve a control group, it is appropriate for evaluating learning improvement in

a classroom-based intervention. Science literacy regarding ecosystems and environmental change is divided into four main competency areas, as shown in Table 1 (Effendi et al., 2021).

Table 1. Operational Research Variables

Literacy Component	Core Competency	Description	Operational Variable
Science Literacy	Explaining Scientific Phenomena	Ability to understand and explain scientific concepts in real-world contexts	Identifying relevant scientific concepts Explaining ecosystem processes (food chains, energy cycles) Connecting theory with environmental phenomena Using concepts to predict events
	Interpreting Data and Scientific Evidence	Ability to read, analyze, and draw conclusions from data	Reading environmental tables/graphs. Identifying data patterns Drawing data-based conclusions Interpreting environmental changes from data
	Evaluating and Designing Scientific Inquiry	Ability to think critically about scientific methods and evidence	Evaluating the validity of information Distinguishing facts from opinions Assessing environmental information sources Proposing science-based solutions
	Communicating Scientific Information		Writing scientific arguments Data-based discussions

The test questions are based on PISA indicators, use Higher-Order Thinking Skills (HOTS), are context-based, and are tailored for the SCRIBO application. SCRIBO will use AI to analyze essays and multiple-choice questions using AI embedded within the tools. The assessment includes 20 questions, with correct answers worth 2 points and incorrect answers worth 0 points. Additionally, essays are scored out of 60 points.

This study included 10th-grade senior high school students who studied ecosystem and environmental change topics. A total of 80 students from two classes participated in this research. The researchers selected participants using purposive sampling because they had received basic biology instruction and were scheduled to study ecosystem and environmental change topics during the research implementation.

All participants were involved in three main activities: the pretest, SCRIBO-based learning activities, and the posttest. In addition, several students were randomly selected for short interviews to obtain supporting information about their learning experiences using SCRIBO.

The research stages were adapted from the one-group pretest–posttest procedure and educational research stages described by Creswell. The researcher modified the stages to suit the implementation of SCRIBO web-based learning in biology education. The stages of the research were as follows: 1) Preliminary Study, 2) Instrument Development, 3) Instrument Validation and Reliability Testing, 4) Pretest Implementation, 5) Scribo Web-Based Learning Intervention, 6) Posttest Implementation, 7) Observation and Student Interviews.

A preliminary study identified students' initial scientific literacy problems in ecosystem and environmental change topics. This stage involved classroom observation, analysis of students' learning difficulties, and discussion with the biology teacher. The findings showed that students had difficulties in interpreting scientific data, explaining environmental phenomena, and constructing evidence-based arguments. Based on these findings, the scientific literacy test was developed using PISA scientific literacy indicators, Higher-Order Thinking Skills principles, and

the learning objectives of ecosystem and environmental change topics. The instrument consisted of context-based multiple-choice and essay questions related to real environmental issues. Before implementation, experts in biology education and science assessment validated the instrument, and empirical validity and reliability were tested using Pearson's Product-Moment correlation and Cronbach's Alpha coefficient.

After validation, students completed a pretest to measure their initial scientific literacy before using the SCRIBO platform. The learning intervention was then implemented through SCRIBO web-based learning, in which students accessed digital materials, read environmental issue-based texts, answered analytical questions, and constructed written responses. SCRIBO supported students in reading, analyzing, evaluating, and communicating scientific information, including the use of AI-based assessment for essay responses. After the intervention, students completed a posttest with indicators equivalent to the pretest to measure improvement in scientific literacy. During the learning process, observations recorded students' participation and interaction with the platform, and short interviews with randomly selected students explored their experiences, challenges, and perceptions of SCRIBO web-based learning.

This study used a scientific literacy test, an observation sheet, and a student interview guide. The main instrument was a scientific literacy test on ecosystem and environmental change topics. The test was developed based on PISA scientific literacy competencies and adapted to the biology curriculum. The observation sheet recorded students' activities during SCRIBO-based learning. Observed aspects included students' participation, use of digital learning materials, ability to follow learning instructions, engagement in reading and analysis activities, and responses to scientific literacy tasks.

The interview guide was used to obtain supporting data regarding students' experiences using SCRIBO. The interview focused on students' perceptions of the platform, ease of use, learning motivation, challenges, and perceived benefits in understanding ecosystem and environmental change topics.

The data were collected through four techniques: scientific literacy tests, observation, documentation, and interviews. The pretest and posttest provided quantitative data on students' scientific literacy. The observation sheet recorded the implementation of SCRIBO-based learning.

Documentation collected students' learning outputs from the SCRIBO platform. Interviews were used to obtain supporting qualitative information regarding students' learning experiences.

The quantitative data were analyzed using SPSS software. The analysis included descriptive statistics, assumption tests, and hypothesis testing. First, descriptive statistics described students' pretest and posttest scores, including mean, minimum score, maximum score, standard deviation, and score improvement. Second, the Shapiro-Wilk test was used to assess whether the data were normally distributed. Third, because the study used the same group before and after treatment, the improvement in students' scientific literacy was analyzed using a paired-sample t-test when the data were normally distributed. If the data were not normally distributed, the Wilcoxon signed-rank test was used as a non-parametric alternative.

Data analysis techniques included normality tests, homogeneity tests, and paired-sample t-tests (Sugiyono, 2019; Arsyad, 2024). The Shapiro-Wilk test was used to assess data distribution. Instrument validity was assessed using Pearson's Product-Moment correlation, while reliability was tested using Cronbach's Alpha coefficient. All data analyses were conducted using the latest version of SPSS. The data were analyzed to support the discussion. Conclusions were then drawn from the results discussed.

In addition to the paired-sample t-test, the effect size was calculated using Cohen's *d* for paired samples to determine the magnitude of the difference between pretest and posttest scores. The normalized gain (N-Gain) was also calculated to measure students' improvement after implementing SCRIBO web-based learning. The N-Gain score was obtained by comparing the actual gain with the maximum possible gain based on the pretest score. N-Gain was interpreted as low, moderate, or high improvement.

This methodological design was developed to measure the impact of SCRIBO web-based learning on students' scientific literacy clearly and operationally. The combination of pretest-posttest scores, scientific literacy indicators, observation data, and student interviews provides comprehensive evidence regarding how SCRIBO supports students in understanding ecosystem and environmental change topics. Therefore, this method is expected to contribute to developing digital learning strategies in science education, especially learning models that integrate scientific literacy and sustainability-oriented biology

education. Observation and interview data were analyzed descriptively to support the interpretation of quantitative findings. The observation data were examined based on students' participation, engagement with digital materials, ability to follow learning instructions, interaction with SCRIBO features, and responses to scientific literacy tasks. Interview responses were grouped into several recurring themes, including ease of use, learning motivation, understanding of ecosystem and environmental change topics, data interpretation, and challenges in using SCRIBO. These qualitative findings helped explain the mechanisms underlying students' scientific literacy improvement.

RESULTS AND DISCUSSION

This study aims to determine whether implementing SCRIBO web-based learning improved students' scientific literacy in ecosystem and environmental change topics. The data were analyzed using descriptive statistics, normality testing, instrument validity and reliability testing, and a paired-sample t-test. Table 2 presents descriptive statistics for students' pretest and posttest scores. Table 2 shows that students' mean scientific literacy score increased from 55,08 in the pretest to 73,46 in the posttest.

Table 2. Data Description

Variables	N	Mean	Standard Deviation
Pretest	80	55,08	0,778
Posttest	80	73,46	0,997

The mean difference of 18,38 points indicates improved scientific literacy after implementing SCRIBO web-based learning. This result provides initial evidence that SCRIBO contributed positively to students' understanding of ecosys-

tem and environmental change topics. Before hypothesis testing, we conducted a Shapiro-Wilk normality test because the number of participants was fewer than 100. Table 3 presents the results.

Table 3. Normality Test Results

Variables	N	Statistic Shapiro-Wilk	Sig.	Interpretation
Pretest	80	0,985	0,469	Normally distributed
Posttest	80	0,982	0,342	Normally distributed

Data normality was assessed as a prerequisite for the t-test. The results, shown in Table 3, indicate that the data are normally distributed. The Shapiro-Wilk test was used to assess normality because the number of respondents was less than 100. A significance level >0.05 indicates that the data are normally distributed.

The results of the normality test using the Shapiro-Wilk test indicate that the pretest data (Statistic = 0,985) and posttest data (Statistic = 0,982) are normally distributed ($p > 0.05$). The Shapiro-Wilk test showed that the pretest sco-

re had a significance value of 0,469, while the posttest score had a significance value of 0,342. Both values were higher than 0,05, indicating that the data were normally distributed. Therefore, a paired-sample t-test was appropriate.

The validity test using Pearson's Product-Moment correlation, with a sample size of 80 students and $\alpha = 0.05$, yielded a value of 0,220. Since the calculated r value is greater than the table r value, the multiple-choice items are considered valid. Table 4 presents the item analysis results.

Table 4. Item Validity

No Item	r calculated	r table	Interpretation
S1	0,452	0,220	Valid
S2	0,487	0,220	Valid
S3	0,503	0,220	Valid
S4	0,436	0,220	Valid
S5	0,468	0,220	Valid

S6	0,521	0,220	Valid
S7	0,498	0,220	Valid
S8	0,476	0,220	Valid
S9	0,512	0,220	Valid
S10	0,459	0,220	Valid
S11	0,533	0,220	Valid
S12	0,471	0,220	Valid
S13	0,446	0,220	Valid
S14	0,489	0,220	Valid
S15	0,507	0,220	Valid
S16	0,462	0,220	Valid
S17	0,495	0,220	Valid
S18	0,478	0,220	Valid
S19	0,441	0,220	Valid
S20	0,466	0,220	Valid

The data analysis results indicate that all items 1–20 on the posttest have a calculated r value greater than the table r value (0.220) at the 5% significance level. Thus, all items in the instrument are deemed valid and suitable for measuring students' science literacy.

Reliability was assessed using Cronbach's Alpha. The reliability values indicate that the research data are consistent, stable, and reliable even when measured repeatedly. Data are considered reliable if they have a Cronbach's Alpha value greater than 0,5. The data analysis results align with Table 5.

Table 5. Data Reliability

Numbers Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted	Interpretation
S1	0,45	0,86	Reliable
S2	0,48	0,86	Reliable
S3	0,50	0,86	Reliable
S4	0,44	0,86	Reliable
S5	0,47	0,86	Reliable
S6	0,52	0,86	Reliable
S7	0,49	0,86	Reliable
S8	0,47	0,86	Reliable
S9	0,51	0,86	Reliable
S10	0,46	0,86	Reliable
S11	0,53	0,86	Reliable
S12	0,47	0,86	Reliable
S13	0,44	0,86	Reliable
S14	0,49	0,86	Reliable
S15	0,50	0,86	Reliable
S16	0,46	0,86	Reliable
S17	0,49	0,86	Reliable
S18	0,48	0,86	Reliable
S19	0,44	0,86	Reliable
S20	0,47	0,86	Reliable

The reliability test showed a Cronbach's alpha of 0,87, indicating high internal consistency. This indicates that the instrument exhibits excellent data consistency. After confirming that the data were normally distributed and that

the instrument was valid and reliable, a paired-sample t-test was conducted to determine whether students' pretest and posttest scores differed significantly. Table 6 presents the results.

Table 6. Paired Samples Statistics

Variable	Mean	N	Std. Dev.	Std. Error Mean
Pretest	55,08	80	6,10	0,778
Posttest	73,46	80	6,80	0,997

The paired-sample t-test (Table 7) showed a significant difference between students' pretest and posttest scores, with $t = -27,58$ and $p < 0,001$. Since the significance value was lower than 0,05,

the null hypothesis was rejected. This result indicates that SCRIBO web-based learning had a statistically significant effect on improving students' scientific literacy.

Table 7. Paired Samples Correlation

Pair	N	Correlation	Sig.
Pretest-Posttest	80	0,721	0,00

Table 7 does not report the paired-samples correlation between pretest and posttest scores, which was not used to determine the effectiveness or magnitude of students' scientific literacy improvement. Therefore, the paired-samples correlation analysis was excluded from the main analysis. Changes in students' scientific literacy were evaluated using the paired-samples t-test, accompanied by Cohen's d and N-Gain to describe the magnitude and level of improvement.

Statistically, a t-value of -27,58 was obtained with a significance level of 0,000 ($p <$

0,05). These results indicate a significant difference between the pre- and post-treatment scores. This study shows that using SCRIBO effectively improves students' science literacy. A correlation coefficient of 0,721 indicates a strong relationship between pretest and posttest scores. These results also suggest that integrating digital learning platforms into biology education can help students interpret scientific information, analyze environmental issues, and develop evidence-based reasoning.

Table 8. Paired Samples Test

Pair	Mean Difference	Std Dev	t
Pretest-Posttest	-18,20	5,9	-27,58

The paired-sample t-test results (Table 8) indicate a significant difference between the pretest and posttest scores. The mean pretest score of 55,20 increased to 73,40 on the posttest. The mean difference of 18,20 indicates substantial

improvement after implementing learning using the SCRIBO platform. To strengthen the statistical interpretation, we calculated Cohen's d and N-Gain in Table 9.

Table 9. Effect Size and N-Gain Analysis

Analysis	Formula	Result	Interpretation
Cohen's d	Mean difference / SD difference	3,08	Very large effect
N-Gain	(Posttest - Pretest) / (Maximum score - Pretest)	0,41	Moderate improvement
N-Gain percentage	N-Gain $\times$ 100	40,63%	Moderate improvement
Analysis	Formula	Result	Interpretation

Table 9 shows that the increase in students' posttest scores was not only statistically significant but also practically meaningful. The Cohen's d value was 3,08, indicating a very large effect of SCRIBO web-based learning on students' scientific literacy. The N-Gain value was 0,41, or 40,63%, which falls into the moderate improvement category. This indicates that SCRIBO web-based learning produced a meaningful increase in students' scientific literacy, although further instructional support is still needed to achieve a higher level of learning gain.

The most notable improvement was students' ability to interpret data and evaluate scientific evidence. This indicates that the ability to read, analyze, and draw conclusions from data can be developed through repeated practice. This suggests that using SCRIBO is more effective for developing analytical skills than expressive skills (Alharbi, 2023).

The results indicate that using the SCRIBO platform significantly improves students' science literacy. These findings align with the framework of technology-enhanced learning. This approach emphasizes that integrating digital technology into learning can enrich the learning experience and enhance students' cognitive engagement (Hammad, 2024; Muñoz-Galván & Padilla, 2024; Wibowo et al., 2026).

Several instructional mechanisms embedded in SCRIBO web-based learning explain improvements in students' scientific literacy. First, SCRIBO provided structured exposure to scientific texts and environmental data, which helped students connect biological concepts with real ecosystem and environmental change issues. This mechanism strengthened students' ability to explain scientific phenomena because they not only received information but also interpreted it in a contextual learning situation. Second, SCRIBO required students to analyze tables, graphs, and case-based environmental problems. This repeated analytical activity trained students to identify data patterns, compare evidence, and draw data-based conclusions. Third, AI-assisted assessment and feedback helped students review their answers and improve the quality of their reasoning. These mechanisms explain why improvement was highest in data interpretation and scientific evidence evaluation (Hammad, 2024; Tay, 2024).

The observation data supported the quantitative findings. During SCRIBO-based learning, students actively engaged in reading digital materials, exploring environmental information, and completing analysis-based tasks. Students were more involved when the learning activities

required them to interpret environmental graphs, examine ecosystem-related cases, and discuss possible solutions to environmental problems. The observation also showed that students gradually became more confident in using evidence to support their answers. This finding indicates that SCRIBO created a learning environment that encouraged active reading, data interpretation, and evidence-based reasoning.

SCRIBO is a web-based learning platform designed to support the development of student literacy. SCRIBO's features enhance student literacy by analyzing, providing feedback on, and measuring the depth of students' literacy using AI-powered tools. In this study, science literacy was assessed through activities such as reading, analyzing information, and connecting scientific data to solutions relevant to ecosystems and environmental changes. This study uses SCRIBO exclusively as a learning medium for ecosystem and environmental change content to support a more interactive, data-driven learning process. Additionally, the platform encourages active student engagement in understanding scientific phenomena and interpreting environmental data. SCRIBO serves as a digital learning medium and a tool to enhance students' critical thinking skills and science literacy.

Based on observations, the SCRIBO platform is beneficial for 1) improving science literacy through understanding scientific concepts, analyzing data, and drawing evidence-based conclusions with the help of AI and assessment rubrics, thereby making the process more focused, 2) helping to improve critical thinking skills through the understanding of scientific concepts and scaffolding critical thinking efforts, 3) helping to understand complex topics such as ecosystems and environmental change due to contextual and visual presentation, 4) helping to increase learning motivation through the use of digital technology and intense student engagement in the learning process, 5) helping to promote active learning, as students must be involved in the process of exploring knowledge.

The interview results also strengthened this interpretation. Several students stated that SCRIBO helped them understand ecosystem and environmental change topics because the platform presented learning materials in a more structured, contextual, and accessible format. Students also reported that the data-based questions encouraged them to think more carefully before answering. They felt that the platform helped them relate biological concepts to real environmental problems, such as pollution, biodiversity

loss, and changes in ecosystem balance. One student stated, "SCRIBO helped me understand environmental data because I could see the problem and answer the questions step by step." However, some students also mentioned that they still needed teacher guidance when interpreting complex data or formulating scientific explanations. This suggests that SCRIBO was useful as a digital learning tool, but teacher facilitation remained

important to support deeper scientific reasoning.

The relationship between SCRIBO features and scientific literacy competencies was further analyzed to clarify how the platform supports students' learning activities. Each SCRIBO function was connected to specific learning activities, scientific literacy indicators, and skills developed during ecosystem and environmental change learning. Table 10 and Figure 2 present this mapping.

Table 10. Mapping of SCRIBO Functions, Learning Activities, and Scientific Literacy Indicators

No	SCRIBO Function	Learning Activities	Science Literacy Indicators	Skills Developed
1	Presentation of scientific text-based material	Students read materials on ecosystems and environmental change	Explaining scientific phenomena	Conceptual understanding, connecting theory to real-world phenomena
2	Presentation of data (environmental graphs/tables)	Students observe and analyze data	Interpreting scientific data and evidence	Data analysis, pattern recognition
3	Analysis-based question features	Students answer interpretive questions	Interpreting scientific data and evidence	Critical thinking and drawing evidence-based conclusions
4	Access to structured digital information	Students explore and compare various sources of scientific information	Evaluating scientific evidence	Information evaluation and source verification
5	Independent reading activities	Students independently explore scientific materials through the platform	Students independently explore scientific materials through the platform	Students independently explore scientific materials through the platform
6	Integration of real-world environmental contexts	Students connect biological concepts with environmental issues	Explaining scientific phenomena	Contextual scientific reasoning and problem-solving
7	Case-based exercises	Students analyze environmental problems and propose possible solutions	Evaluating and designing scientific inquiry	Scientific reasoning, problem-solving
8	Reflection and discussion	Students discuss and communicate the results of their analysis	Students discuss and communicate the results of their analysis	Students discuss and communicate the results of their analysis
9	Digital interaction	Students actively interact with scientific content and learning tasks	Interpreting and evaluating scientific information	Active engagement and analytical thinking
10	Platform-based assessment	Students complete scientific literacy assessment tasks and receive feedback	Integrated scientific literacy competencies	reinforcement of scientific literacy competencies

Table 10 shows that SCRIBO functions are not limited to presenting digital learning materials but are systematically connected to scientific literacy activities. Scientific texts and contextual environmental content primarily support students in explaining scientific phenomena, while graphs, tables, and analysis-based questions facilitate interpreting data and scientific evidence. Structured information, case-based activities, reflection, and discussion give students opportunities to evaluate evidence and communicate scientific reasoning. Therefore, the SCRIBO framework used in this study connects digital learning activities with

the scientific literacy competencies measured in ecosystem and environmental change topics.

The learning process in this study utilized the SCRIBO platform integrated with the Problem-Based Learning (PBL) model. PBL was chosen, in part, to support conceptual understanding by allowing sufficient time to cover the material. Additionally, PBL addresses ecosystems and environmental change more effectively. As shown in Figure 2, the learning process begins with a problem-orientation phase through the presentation of relevant environmental issues, followed by material exploration activities via SCRIBO.

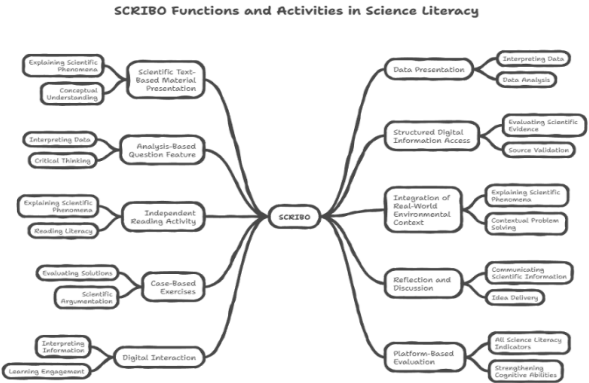


Figure 2. Framework of SCRIBO Functions

Students then analyze and interpret data-based information available on the platform and discuss their findings in groups. The teacher acts as a facilitator, reinforcing concepts and clarifying misconceptions. The study was conducted over several sessions, including a pretest, a treatment using SCRIBO, and a posttest to measure improvements in students' science literacy.

SCRIBO's characteristics can explain the improvement in science literacy found in this study, as it is a web-based platform that provides reading, analysis, and interaction activities based on scientific content. These activities sup-

port constructivist learning. This learning process aligns with constructivist principles, in which students actively construct knowledge through interaction with information and the learning environment. SCRIBO facilitates this process by providing access to learning resources, offering AI-based assessments, and encouraging students to explore, analyze, and evaluate information independently (Mikhailova et al., 2022; Lytras, 2023; Boateng, 2024; Nurkanti et al., 2026). The SCRIBO-based learning process is presented in Figure 3.

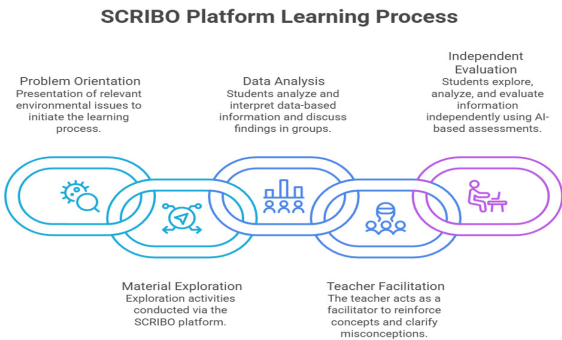


Figure 3. Learning Process Using SCRIBO

The findings of this study are also consistent with the scientific literacy framework. This concept supports the idea that scientific literacy encompasses the ability to explain scientific phenomena, interpret data, and evaluate evidence. This concept also emphasizes four aspects: Contexts, Competencies, Knowledge, and Attitudes. The significant improvement in the data interpretation and evidence evaluation indicators in this study indicates that SCRIBO can support the development of higher-order thinking skills (Shukshina et al., 2021; Tay, 2024; Widyastuti et al., 2026).

SCRIBO's interactive AI features show that digital learning can present information in a multidisciplinary, multi-contextual way. This will help students understand complex concepts, including contextual and dynamic topics such as ecosystems and environmental change. Additionally, a facilitator—namely, the teacher—can guide socio-scientific topics and democratic participation. This provides teachers with the opportunity to explore issues more deeply and foster students' metacognition in the classroom Rangkuti et al., 2024; Rusydiyah et al., 2024; Safkolam et al., 2024; (Guerrero & Sjöström, 2025).

In environmental education, SCRIBO adds value by helping students connect scientific concepts with real-world phenomena. This is important because science literacy is not merely about understanding concepts; the ability to apply knowledge in daily life—particularly when addressing global environmental issues—must be practiced repeatedly (Cuong et al., 2024; Pitiyorntapin et al., 2024; Hikmah et al., 2025; Ardianto et al., 2026; Jeronen & Jeronen, 2026; Nurkanti et al., 2026).

This study also found that improvements in scientific communication were lower than those in other indicators. This may be due to limitations in SCRIBO's features, which focus more on reading and analysis than on the written production or expression of ideas. Additionally, the SCRIBO platform has not yet integrated image inputs generated by students. This is because the Vision feature recognizes only handwriting and other characters. The developers still plan to develop the vision feature in the future. Therefore, teachers can implement additional learning strategies. For example, discussions or project-based assignments can help optimize all aspects of science literacy, as shown in Figure 4.

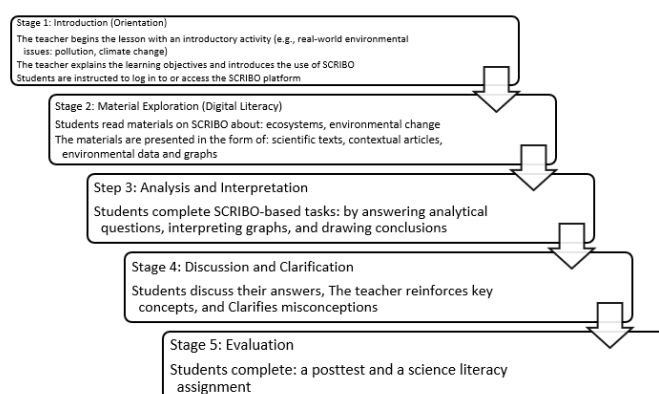


Figure 4. PBL activity plan using SCRIBO

Another important finding is that improvement in scientific communication was relatively lower than improvement in data interpretation and evidence evaluation. This indicates that SCRIBO was more effective in developing analytical literacy than expressive literacy. One possible explanation is that the platform provides stronger support for reading, analyzing, and answering structured questions than for producing extended scientific explanations or multimodal communication products. Therefore, although SCRIBO can improve students' scientific literacy, additional learning strategies are still needed to optimize students' scientific communication skills. Class-

room discussion, peer feedback, oral presentation, project-based assignments, and student-generated reports may be integrated to strengthen this aspect (Chan et al., 2020; Shukshina et al., 2021; Van Der Merwe et al., 2023; Darussyamsu et al., 2024; Haviz et al., 2024).

This finding contributes to the development of science education. It shows that students' scientific literacy can improve when digital platforms engage them in reading scientific information, interpreting data, evaluating evidence, and relating concepts to real environmental problems. The study also extends previous research by showing that web-based learning can be aligned with

Sustainable Development Goals-oriented biology education. In this context, SCRIBO contributes to SDG 4 by supporting quality science learning and to SDG 13, SDG 14, and SDG 15 by helping students understand environmental issues through scientific reasoning (Bilici et al., 2016; Ortega-Sánchez et al., 2020; Savelyeva & Park, 2024; Sumarni et al., 2025; Anwar et al., 2025; Sari et al., 2025; Jeronen & Jeronen, 2026).

The findings also have practical implications for biology teachers. Teachers can use SCRIBO to design more analytical, contextual, and data-driven learning activities. However, teacher facilitation remains essential. Teachers need to guide students in interpreting data, clarifying misconceptions, connecting environmental issues with biological concepts, and encouraging students to communicate their reasoning. Thus, SCRIBO's effectiveness depends not only on the technology itself but also on how the teacher integrates it into a meaningful learning design (Artayasa et al., 2024; Sapriati et al., 2024; Majid et al., 2024; Rosyidah et al., 2025; Nurkanti et al., 2026).

Despite these positive findings, this study has several limitations. First, the study used a one-group pretest-posttest design without a control group. Therefore, the improvement in students' scientific literacy cannot be attributed solely to SCRIBO with full experimental certainty. Other factors, such as teacher explanation, students' prior knowledge, repeated exposure to similar test formats, and classroom interaction, may also have contributed to the observed improvement. Second, the study involved 80 students from two classes, so the findings should be generalized with caution to broader educational contexts. Third, the study used observation and interview data as supporting evidence, but it did not analyze them through a fully developed qualitative design. Future studies should apply a control-group experimental design, involve larger and more diverse samples, and use more systematic qualitative analysis to examine how students interact with SCRIBO during scientific literacy learning.

Overall, this study confirms that SCRIBO web-based learning can enhance students' scientific literacy in ecosystem and environmental change topics. More importantly, the study explains that the improvement occurred because SCRIBO provided structured opportunities for students to engage in reading, data interpretation, evidence evaluation, and contextual scientific reasoning. The novelty of this research lies in integrating SCRIBO, scientific literacy indicators, AI-assisted assessment, and SDG-oriented envi-

ronmental biology learning. Therefore, this study contributes to the development of digital science learning models that are relevant to 21st-century education and sustainability-oriented biology instruction.

CONCLUSION

This study concludes that the implementation of SCRIBO web-based learning significantly increased posttest scores compared with pretest scores. These findings suggest that SCRIBO has potential to support scientific literacy learning in ecosystem and environmental change topics. The key result showed an increase in students' mean score from 55,20 in the pretest to 73,40 in the posttest, with a significant difference based on the paired-sample t-test result ($p < 0.001$). The effect size showed a very large effect (Cohen's $d = 3,08$), indicating that the improvement was not only statistically significant but also practically meaningful. The N-Gain score of 0,41, or 40,63%, showed a moderate level of improvement in students' scientific literacy. This improvement indicates that SCRIBO effectively supports students in developing scientific literacy skills, particularly in interpreting scientific data, evaluating evidence, and connecting biological concepts with real environmental issues. The application of SCRIBO also has a significant impact on biology learning by creating a more interactive, contextual, and analysis-based learning environment that encourages students to think critically and draw evidence-based conclusions. Therefore, SCRIBO can serve as an alternative digital learning platform to strengthen scientific literacy and support sustainability-oriented science education, especially for topics related to ecosystems and environmental change. However, because this study did not include a control group, future research should use a stronger experimental design or a mixed-methods approach to provide deeper, more comprehensive evidence of SCRIBO's effectiveness.

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