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Improving students' digital literacy in biology learning through a RICOSRE-based digital module

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Abstract: Digital literacy is essential in biology learning as students increasingly use digital sources to access scientific information. However, many students still struggle to evaluate online information, while digital platforms often emphasize content delivery rather than digital literacy development. This study examined the effectiveness of a Google Sites-based digital module integrated with RICOSRE in improving students' digital literacy. This study employed a quasi-experimental method by comparing two intact groups through pretest and posttest procedures. The participants involved 70 students: 34 in the experimental group and 36 in the control group. Data were collected through a test instrument that had been validated and developed with reference to Greenstein's framework, covering information finding, use of multiple sources, information selection, information evaluation, source and message consideration, and production of original work. Data were analyzed using ANCOVA, N-gain, and effect size. The analysis revealed a significant difference in digital literacy scores, with the experimental group outperforming the control group after controlling for pretest scores, $F = 128.008$, $p < 0.001$, partial $\eta^2 = 0.656$. The N-gain score was also higher in the experimental group, 0.57 versus 0.28. These findings indicate that the module effectively strengthens students' digital literacy in biology learning.

Keywords: Digital literacy, digital module, Google sites, RICOSRE, scientific information

Abstrak: Literasi digital menjadi kompetensi penting dalam pembelajaran biologi karena siswa semakin bergantung pada sumber digital untuk mengakses informasi ilmiah. Namun, banyak siswa masih kesulitan mengevaluasi kredibilitas informasi daring, sementara platform pembelajaran digital sering berfokus pada penyampaian materi, bukan pengembangan literasi digital secara eksplisit. Tujuan dari penelitian ini menguji efektivitas modul digital berbasis *Google Sites* yang terintegrasi dengan model RICOSRE dalam meningkatkan literasi digital siswa SMA. Penelitian menggunakan desain kuasi-eksperimen pretest-posttest dengan kelompok kontrol nonekuivalen, melibatkan 70 siswa: 34 siswa kelompok eksperimen dan 36 siswa kelompok kontrol. Data penelitian dihimpun melalui tes literasi digital tervalidasi berdasarkan kerangka Greenstein, mencakup pencarian informasi, penggunaan berbagai sumber, pemilihan informasi, evaluasi informasi, pertimbangan sumber dan efek pesan, serta penggunaan informasi untuk menghasilkan karya orisinal. Data dianalisis menggunakan ANCOVA, N-gain, dan ukuran efek. Hasil menunjukkan kelompok eksperimen memperoleh skor literasi digital lebih tinggi secara signifikan daripada kelompok kontrol setelah mengontrol skor pretest, $F = 128.008$, $p < 0.001$, partial $\eta^2 = 0.656$. Capaian N-gain kelompok eksperimen menunjukkan lebih tinggi daripada kelompok kontrol, sebesar 0.57 dibandingkan 0.28. Temuan ini mengindikasikan bahwa modul digital berbasis *Google Sites* terintegrasi RICOSRE efektif memperkuat literasi digital siswa dalam pembelajaran biologi secara lebih terstruktur.

Kata kunci: Literasi digital, modul digital, Google Sites, RICOSRE, informasi ilmiah

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INTRODUCTION

Digital transformation has changed the way students learn through the availability of abundant information and knowledge, as well as fast and relatively unrestricted access (Haleem et al., 2022; Hinostroza et al., 2024; Petchamé et al., 2023). The learning process has moved away from being predominantly led by the teacher, evolving instead into an approach that emphasizes student engagement within digital environments. In this context, students face both opportunities and challenges, particularly in identifying relevant and credible information (Jenkins, 2009). Therefore, students must both obtain information and apply it critically and meaningfully as part of digital literacy competencies (OECD, 2019).

Mastery of digital literacy is increasingly vital for students in 21st-century learning environments. This competency requires students to find, assess, produce, and share information using digital tools while applying critical thinking and ethical considerations (UNESCO, 2018). Digital literacy can be understood as a set of interrelated skills, including technical abilities, cognitive strategies, and socio-emotional competencies, applied when engaging with digital technology (Ng, 2012). Recent studies suggest that digital literacy involves more than just the basic ability to operate digital devices, but also involves critical evaluation of digital information, including the ability to asess credibility, validity, and potential misinformation (Bermes, 2021; McGrew & Breakstone, 2023; Polizzi, 2020).

Even though the current generation is often referred to as “digital natives,” the assumption that students automatically possess adequate digital literacy has been widely criticized (Kirschner & De Bruyckere, 2017). Experience in using technology does not always correlate directly with the ability to think critically, evaluate sources, and utilize technology for academic purposes (Selwyn, 2009). Empirical findings also show that students often struggle to assess the credibility of online information despite having broad access to digital technology. In Indonesia, The 2022 PISA assessment reveals that students still face difficulties in reading, interpreting, and evaluating complex information, which reflects a broader challenge in developing critical information-processing competencies. This condition highlights a gap between access to technology and students’ actual digital literacy competencies (Kominfo, 2023). This situation highlights a gap between technology access and actual digital literacy competencies.

Digital literacy is particularly relevant in biology education because biological knowledge is organized across multiple and interconnected levels, rom molecular and organelle levels to cells, tissues, and organs, then to organ systems and organisms, continuing to populations, and finally encompassing ecosystems (Schneeweiß & Gropengießer, 2019). Understanding biology therefore requires more than memorizing isolated concepts; students need to construct coherent explanations by relating structures, processes, including how biological components are connected, and how biological components influence one another across different levels. This demand is consistent with systems thinking in biology education, which emphasizes the ability to interpret biological phenomena as dynamic systems involving components, boundaries, interactions, feedback, and emergent patterns (Verhoeff et al., 2018). Many biological phenomena, however, are not directly observable and are commonly represented through diagrams, microscopic images, graphs, simulations, animations, databases, and other forms of scientific visualization (Gafur et al., 2024). Thus, digital literacy supports conceptual understanding in biology not merely by facilitating access to digital resources, but by enabling students to critically evaluate online scientific information, interpret digital visualizations and data, and integrate evidence into coherent explanations of biological phenomena (Vuorikari et al., 2022). From this perspective, strengthening students’ digital literacy through biology learning should not be treated as an additional or separate instructional goal but as an essential condition for helping students engage with biological knowledge in a critical, meaningful, and evidence-based manner.

Although digital technology has been widely integrated into biology education, previous implementations have rarely targeted the explicit development of students' digital literacy. Prior innovations in web-based learning media in science education have predominantly emphasized content delivery and accessibility, without systematically guiding students in acquiring, evaluating, integrating, and producing information from digital sources (Bedenlier et al., 2020; OECD, 2021). A digital module developed through Google Sites can effectively addressing this issue because it can organize biology content, multimedia resources, learning instructions, and evaluation activities within a single web-based learning environment, thereby supporting accessibility, multimedia integration, and ease of use in digital learning. This potential is also evident in studies using platforms such as Google Sites, which are flexible and capable of integrating various digital resources into biology content (Jayanti, 2023; Wulandari et al., 2024; Yusha & Risnani, 2023). However, digital modules developed in previous studies have often remained limited to the digitization of instructional materials and content repositories rather than being designed as structured learning environments that explicitly guide students' digital literacy practices (Fisher et al., 2017; OECD, 2021). Most previous research has not directly measured students' digital literacy development, focusing instead on engagement or general learning outcomes. This leaves a gap in understanding how digital modules can explicitly support students' digital literacy in biology learning. Addressing this gap requires an intervention that intentionally integrates digital literacy into the learning process by guiding students to search, evaluate, synthesize, and produce knowledge using digital resources. Therefore, the present study develops a Google Sites-based digital module designed around the RICOSRE model, with digital literacy positioned as a central learning objective. This approach aligns the affordances of digital platforms with the pedagogical goal of fostering students' ability to critically interact with digital information, transforming technology use from mere content delivery into a means of developing meaningful digital literacy (McGrew & Breakstone, 2023; OECD, 2019). This suggests that digital technology should not be treated merely as an instructional medium, but as a pedagogical space in which students are systematically guided to practice digital literacy in relation to biological knowledge.

To operationalize the intervention, the present study adopts the RICOSRE learning model as a pedagogical framework for structuring students' digital literacy practices. RICOSRE is relevant for this purpose because its six stages (1) reading, (2) identifying a problem, (3) constructing the solution, (4) solving the problem, (5) reviewing the problem solving, and (6) extending the problem solving provide a sequential framework for guiding students from information acquisition to knowledge construction and extension (Mahanal et al., 2019). Previous studies have shown that RICOSRE supports students' thinking processes, particularly in problem-solving and higher-order thinking, by engaging them in reading, analysing problems, developing solutions, evaluating ideas, and extending their understanding (Mahanal et al., 2022; Ramdani et al., 2025). However, these strengths do not automatically address digital literacy unless the model is implemented through learning activities that require students to search, evaluate, integrate, and communicate information using digital resources. In conventional implementation, RICOSRE may guide students' problem solving processes, but it does not necessarily provide a structured digital environment where students can critically interact with online scientific information, visual representations, and evidence based resources. Therefore, integrating RICOSRE into a Google Sites-based digital module is necessary to align each stage of the model with digital literacy practices. Through this integration, the digital module can support students in reading digital biology resources, identifying problems based on scientific information, constructing and solving problems using credible digital evidence, reviewing the validity of their understanding, and extending their knowledge through digital learning activities. Thus, the integration of RICOSRE and a Google Sites based digital module functions beyond a simple technological adaptation and serves as a pedagogical strategy to transform the stages of RICOSRE into structured digital literacy practices in biology learning.

Conceptually, each stage of the RICOSRE framework is linked to part of digital literacy competence. The "reading" and "identifying" stages develop the capability to access and select information; the stages of "constructing" and "solving" develop the ability to evaluate information and draw connections among ideas; and the stages of "reviewing" and "extending" develop the ability to evaluate and produce knowledge (Mahanal et al., 2019). This alignment is consistent with the digital competency framework, which emphasizes the ability to critically access, evaluate, and create information (UNESCO, 2018). Therefore, RICOSRE provides a pedagogical sequence through which digital literacy can be explicitly practiced in biology learning.

Considering the above, there is a need for educational innovations that integrate digital literacy, instructional models, and digital media. Previous research has been limited in examining the integration of the RICOSRE model with a digital module developed through Google Sites and tailored to strengthen learners' digital literacy in biology education. As a result, this study aims to test the effectiveness of a Google Sites-based digital module integrated with the RICOSRE model in enhancing students' digital literacy in biology learning.

METHOD

The research was conducted quantitatively by comparing two intact groups through pretest and posttest procedures within a quasi-experimental framework. This design was used to compare the effects of two instructional treatments on students' digital literacy. In this research, the instructional treatment served as the independent variable, while the dependent variable was students' digital literacy. Two groups participated in this research: an experimental group taught using the RICOSRE model supported by a Google Sites-based digital module and a control group taught using the RICOSRE model without digital module support. The research design is presented in Table 1.

Table 1. Overview of the quasi-experimental procedure

Pretest	Treatment Group	N	Posttest
Q1	Experimental group (RICOSRE assisted by a Google Sites-based digital module)	34	Q2
Q3	RICOSRE	36	Q4

This research identified all Grade 11 students at the selected high school during the 2025/2026 academic year as its population, comprising five biology classes. The sampling units were whole classes because the students had already been organized into fixed classroom groups, making individual randomization impractical. Sampling was conducted at the class level by drawing lots. Of the five available classes, two were selected as the study sample consisting of one treatment group and one comparison group. Before the treatment was administered, both groups were tested for equivalence to ensure that the students' initial abilities were relatively comparable. The participants were between 16 and 17 years old. The experimental group consisted of 34 students who received RICOSRE instruction supported by a Google Sites-based digital module, whereas the comparison class included 36 learners who participated in RICOSRE-based learning without digital module support.

The research instrument for assessing students' digital literacy took the form of a digital literacy test developed based on Greenstein's digital literacy framework. The instrument consisted of 27 items covering six indicators: 3 items for "finds," 6 items for "uses multiple sources," 5 items for "selects," 4 items for "evaluates," 5 items for "considers source and message effect," and while 4 items focused on "uses information to produce original work." These six indicators were used to measure students' ability to find information, use multiple sources, select relevant information, evaluate information, consider source and message effects, and use information to produce original work in the context of biology learning. The instrument was scored using a five-point scale to indicate the level of students' digital literacy achievement.

The instrument was first reviewed by experts to assess the alignment of the items with Greenstein's digital literacy indicators, their relevance to the biology context, the clarity of the language, and the appropriateness of the cognitive level. This expert review was conducted as a way to confirm the instrument's content validity and construct validity.. Subsequently, the instrument was pilot-tested with students beyond the selected sample. On the basis of the pilot test findings, the item validity was analyzed using SPSS to perform Pearson's product-moment correlation analysis, while Cronbach's alpha was used to evaluate the reliability of the instrument. The analysis results revealed that every item was valid and that the instrument achieved a very high reliability level, indicated by a Cronbach's alpha coefficient of 0.932. Therefore, the instrument was considered suitable for use in this study.

This study began with the administration of an initial test in both the treatment and comparison groups to assess learners' baseline digital literacy prior to the implementation of the intervention. Subsequently, instruction was conducted in accordance with the research design. The treatment group participated RICOSRE model supported by a Google Sites-based digital module, whereas the comparison group learned through the RICOSRE model without support from the digital module. The implementation of instruction in both groups followed the six stages of the RICOSRE model: Reading, Identifying Problem, Constructing Solution, Solving Problem, Reviewing, and Extending, as presented in Table 2. In the experimental group, the Google Sites-based digital module served as the primary medium to support information-seeking, information evaluation, and information-processing activities at each stage of instruction. During the learning process, the implementation of the RICOSRE stages was observed using an observation sheet to ensure implementation fidelity across both groups. After all treatments were completed, both groups were administered a posttest to measure students' digital literacy after instruction.

The sequence of the research procedures consisted of pretest administration, treatment implementation, observation of implementation fidelity, and posttest administration.

Table 2. RICOSRE model syntax

	The Steps	Student Activity
1	Read	Students read and understand the text describing the problem presented
2	Identifying the problem	Students identify and formulate the problem to be solved
3	Construction the Solution	Students design appropriate problem-solving strategies or steps
4	Solving the Problem	Students conduct research and collect data to arrive at a solution
5	Reviewing the Problem Solving	Learners review and assess whether the proposed solution is appropriate.
6	Extending the Problem Solving	Learners use the proposed solution to address comparable problems in new contexts.

The data were examined using descriptive and inferential statistics. Descriptive analysis was used to summarize the pretest and posttest mean scores and the development of students' digital literacy in both groups. Before hypothesis testing, the data were examined to verify their suitability for ANCOVA analysis by checking several requirements: normal distribution through the Shapiro-Wilk test, variance homogeneity through Levene's test, linearity between the covariate and dependent variable, and homogeneity of regression slopes. Hypothesis testing was carried out through ANCOVA, in which pretest results were treated as the covariate for adjusting differences in students' initial abilities. This analysis was used to determine how the instructional treatment influenced learners' digital literacy scores in the posttest. The strength of the treatment effect was reported using partial eta squared. In addition, N-gain was calculated as a supplementary descriptive analysis to describe the magnitude of improvement in students' digital literacy scores. Thus, ANCOVA served as the primary inferential analysis, whereas N-gain was used to provide additional descriptive information about score improvement. All statistical procedures were performed with SPSS, applying a 0.05 significance threshold.

RESULTS AND DISCUSSION

Assumption test result

Assumption test findings indicated that learners' digital literacy pretest and posttest scores in the treatment and comparison groups followed a normal distribution and showed homogeneous variance. These findings indicate that the data fulfilled the basic statistical requirements needed for further inferential analysis. Thus, ANCOVA became a suitable method for assessing how the instructional treatment influenced learners' digital literacy, with their initial digital literacy scores controlled statistically.

Table 3. Results of data distribution and variance homogeneity tests

Shapiro-Wilk Normality Test			Levene's Homogenity Test		
Group	**p-value**	**Data Distribution**	**Levene's Statistic**	**p-value**	**Data Variance**
Experimental pretest	0.274	Normal	1.296	0.259	Homogeneous
Control pretest	0.076				
Experimental posttest	0.084	Normal	2.375	0.128	Homogeneous
Control posttest	0.729				

Descriptive results of students' digital literacy

Descriptively, students' digital literacy scores increased within both the treatment and comparison groups, but the increase was more pronounced in the experimental group. The mean score for the treatment group showed an improvement, rising from 64.06 at the pretest stage to 84.31 at the posttest stage, representing a gain of 20.25 points. Meanwhile, the mean score for the comparison group showed an increase from 57.97 to 69.27, representing a gain of 11.30 points. These descriptive findings suggest that the RICOSRE model supported by a Google Sites-based digital module contributed to a greater improvement in students' digital literacy than RICOSRE instruction without digital module support.

Table 4. Students' digital literacy score and percebtage improvement

Digital Literacy Indicator	Control Group			Experimental Group		
	Mean Score		Improvement (%)	Mean Score		Improvement (%)
	Pretest	Posttest		Pretest	Posttest	
Finds	60.74	68.33	19.34	66.27	83.92	52.33
Uses Multiple Sources	56.76	69.54	29.55	58.14	84.22	62.30
Selects	58.78	70.44	28.30	65.29	84.35	54.92
Evaluates	57.22	69.31	28.25	64.71	87.06	63.33
Considers Source, Message Effect	55.44	69.11	30.67	64.94	84.24	55.03
Uses to produce original work	58.89	68.89	24.32	65.00	82.06	48.74
Average	57.97	69.27	26.74	64.06	84.31	56.11

Based on the digital literacy indicators, all aspects showed improvement within the treatment and comparison classes. In the experimental group, the highest increases were observed in the "Evaluates" indicator at 63.33% and the "Uses Multiple Sources" indicator at 62.30%, whereas the lowest increase was found in the "Uses Information to Produce Original Work" indicator at 48.74%. In the control group, the highest increase was observed in the "Considers Source and Message Effect" indicator at 30.67%, while the lowest increase was found in the "Finds" indicator at 19.34%. These descriptive findings suggest that the Google Sites-based digital module integrated with the RICOSRE model contributed more strongly to improving students' ability to evaluate digital information and use multiple digital sources than to developing their ability to produce original digital works.

Students' posttest digital literacy scores across indicators are shown in Figure 1. The graph shows that learners in the treatment group outperformed those in the comparison group across all digital literacy indicators. This pattern supports the descriptive evidence that the integration of the Google Sites-based digital module with the RICOSRE model provided greater support for students' digital literacy development than RICOSRE instruction without digital module support.

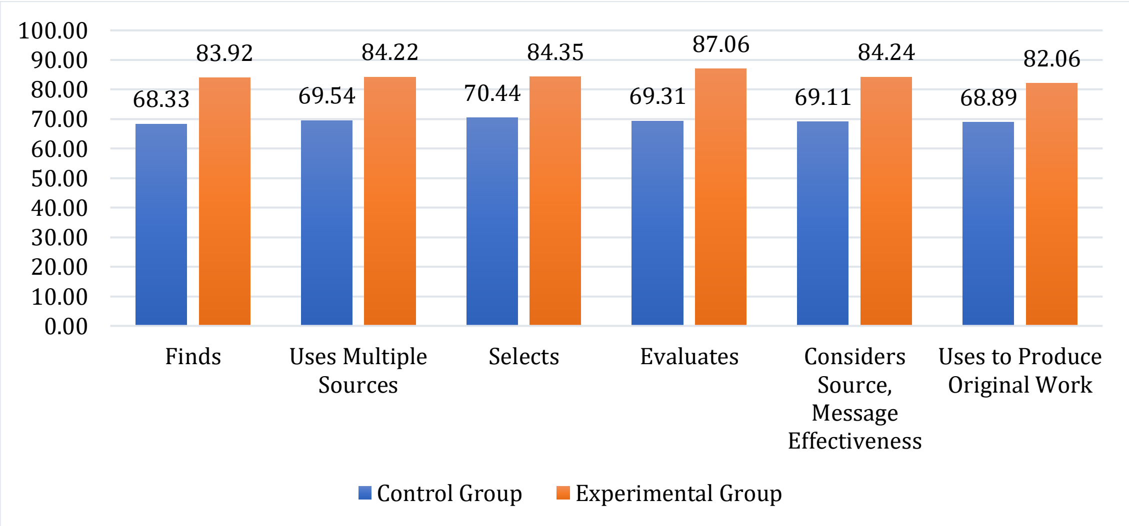

Fig. 1. Digital literacy posttest scores by indicator

ANCOVA results

The ANCOVA findings indicated a statistically significant difference in learners' posttest digital literacy outcomes across the treatment and comparison groups, with pretest scores statistically adjusted, $F = 128.008$, $p < 0.001$. This finding suggests that learners' digital literacy was significantly influenced by the instructional treatment. The partial eta squared value of 0.656 indicates a large effect size, suggesting that the Google Sites-based digital module integrated with the RICOSRE model made a substantial contribution to strengthening learners' digital literacy.

The ANCOVA results (Table 5) also showed that pretest scores did not significantly affect posttest scores, $p = 0.998$. This suggests that students' initial digital literacy did not significantly contribute to the variation in posttest scores. Therefore, the posttest digital literacy gap across the treatment and comparison groups remained evident after controlling for students' initial abilities.

Table 5. Statistical results of ANCOVA for digital literacy scores

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta squarred
Corrected Model	3929.145	2	1964.572	68.504	0.000	0.672
Intercept	13051.992	1	13051.992	455.119	0.000	0.872
XLD	0.000	1	0.000	0.000	0.998	0.000
Class Group	3671.036	1	3671.036	128.008	0.000	0.656
Error	1921.441	67	28.678			
Total	416733.000	70				
Corrected Total	5850.586	69				

N-gain results

The improvement in students' digital literacy was further examined using N-gain as a supplementary descriptive analysis. The results showed that the treatment group obtained a moderate N-gain value of 0.57, whereas the comparison group recorded a low N-gain value of 0.28. These findings indicate that learners in the treatment group showed stronger development in digital literacy compared with learners in the comparison group. This result supports the ANCOVA findings, suggesting that the Google Sites-based digital module integrated with the RICOSRE model provided stronger support for students' digital literacy development than RICOSRE instruction without digital module support.

Table 6. Digital literacy n-gain comparison

N-gain	Score	Effectiveness
Experimental Group	0.57	Moderate effectiveness
Control Group	0.28	Low effectiveness

These results reinforce the ANCOVA findings, showing that the implementation of a digital module developed through Google Sites in combination with the RICOSRE model contributed to greater improvement in students' digital literacy than RICOSRE instruction without digital module support. However, N-gain was used only as a supplementary descriptive analysis, whereas the primary evidence of the treatment's effectiveness was based on the ANCOVA results.

The findings indicate that RICOSRE instruction supported by a Google Sites-based digital module was more effective in improving students' digital literacy than RICOSRE instruction without digital module support. This effectiveness was reflected in the more substantial improvement observed in the treatment group, the significant ANCOVA result after controlling for pretest scores, the strong magnitude of the treatment effect, and the better N-gain outcome recorded by the treatment group. These findings suggest that improvement in students' digital literacy was influenced not only by their initial abilities, but also by the quality of the digital learning design, which provided a structured and purposeful learning pathway. In this study, the Google Sites-based digital module served not merely as a medium for presenting biology content, but also as a digital learning space that guided students in navigating information, following task sequences, and maintaining focus on the problem-solving process. Therefore, the function of the digital module extended beyond content delivery and contributed to shaping students' digital literacy practices in a more systematic manner. This finding aligns with theoretical and empirical perspectives indicating that well-designed digital learning environments can strengthen digital learning behaviors and support improved learning outcomes. In addition, digital literacy programs can be considered effective when the learning process facilitates digital fluency, information verification, and the critical, ethical, and responsible use of technology (Buchan et al., 2024; Ernest & Putra M, 2023; Yuan et al., 2025).

The greatest improvements in the "Evaluates" and "Uses Multiple Sources" indicators point to the intervention's strong role in strengthening learners' capacity to compare, verify, and assess the quality of digital information. Theoretically, the finding aligns with a principle of digital literacy development: learners strengthen this competence when they are trained to evaluate sources, integrate evidence, and engage in information-based reasoning using more than one source (Barzilai et al., 2020). In the experimental group, students did not merely stop at finding information; they were guided to explore multiple sources, compare information across sources, and determine which information is most appropriate and trustworthy to support problem-solving. Thus, the learning process involved not only passive information reception but also deeper cognitive processing in selecting and evaluating information. This pattern aligns with previous studies, which emphasize that learners develop stronger understanding when they are trained to systematically integrate and synthesize evidence from various sources (Barzilai et al., 2020; List & Alexander, 2017). These findings are also supported by previous studies indicating that many learners still tend to engage in superficial information evaluation; therefore, instruction must explicitly train students in reflective and evidence-based evaluation strategies (McGrew, 2020; Nagel & Zlatkin-Troitschanskaia, 2025; Trixa & Kaspar, 2024). Therefore, the ability to evaluate credible digital information needs to be developed through task designs that explicitly train students to search for, select, verify, and account for the information used in problem-solving.

The "Uses Information to Produce Original Work" indicator showed improvement, although its achievement was still lower than the other indicators. This finding implies that not all dimensions of digital literacy develop at the same rate, and that the creation dimension requires more complex cognitive processes than the evaluation dimension (Fraillon, 2025; Vuorikari et al., 2022). This finding requires careful interpretation, as the low increase in this indicator does not necessarily mean that the intervention was ineffective; rather, it indicates that the ability to produce original work is a more complex dimension of digital literacy. From a cognitive taxonomy perspective, creative activities are at a higher cognitive level than evaluative activities because they require students to generate new representations based on previously analyzed information (Anderson & Krathwohl, 2001). This process involves a higher cognitive load, a longer practice period, and more intensive feedback to ensure the quality of the resulting products (Deschênes, 2024; Fiorella, 2023; Vandermeulen et al., 2024). In accordance with this interpretation, Findings from recent studies indicate that digital literacy is associated with students' ability to engage in knowledge production and digital creation; however, this ability tends to develop more effectively when students are supported by an adequate digital learning environment and are given repeated opportunities to create, revise, and communicate digital products (Zhao et al., 2025; Zhou et al., 2025). Therefore, the lower achievement in the "Uses Information to Produce Original Work" indicator suggests that media support and a structured learning framework can provide an initial foundation for digital literacy, but strengthening the creation dimension requires more intensive, sustained, and feedback-oriented pedagogical intervention.

The unequal outcomes recorded in the two groups indicates that the RICOSRE model provided a structured problem-solving framework, but its effect was stronger when supported by a Google Sites-based digital module. The improvement observed in the control group suggests that changes in learning outcomes were influenced not only by digital media implementation, but also by the contribution of the RICOSRE framework itself. However, without structured digital module support, students had fewer opportunities to explore multiple sources, verify source credibility, organize information, and document their learning process at each stage of RICOSRE. In this context, Google Sites functioned not only as a platform for presenting content, as an organized learning setting that enabled learners to interact with digital information. This finding is supported by previous research, which emphasizes that learners' interaction with digital technology should be positioned as an essential element of instructional design because it supports the teaching of digital literacy skills more effectively (Nkomo et al., 2021). It is also consistent with studies emphasizing that effective digital literacy learning requires digital support that helps students locate relevant information, assess its quality, choose appropriate sources, organize the information, and apply it to address authentic problems (Al Mamun & Lawrie, 2024; Li & Lau, 2025; Thomann & Deutscher, 2025)

Conceptually, the evidence from this study confirms the importance of digital literacy in biology education does not develop simply because students have access to technology. A more crucial factor is how technology is integrated into learning tasks that encourage critical reading, problem identification, evaluation of information quality, and current findings provide support for the idea that digital. In the current study, the strength of the intervention lies in the integration of the RICOSRE framework and the features of the digital module, which guided students' activities gradually and systematically. The theoretical implication of these findings is that digital literacy can be understood as the result of the interaction between pedagogical design, the quality of engagement with digital sources, and structured problem-solving processes. The practical implication is that teachers need to design digital tasks that require students not only to locate information, but also to critically assess, compare, and transform it into new products or solutions. However, the relatively lower achievement in the "Uses Information to Produce Original Work" indicator suggests that access to information and the ability to evaluate it do not automatically lead to the ability to produce original digital work. Therefore, future instructional development should place greater emphasis on tasks that promote knowledge transformation, argument construction, and the creation of information-based products, while maintaining rigorous source evaluation exercises (Mayer, 2024; Wineburg & McGrew, 2019).

This study has certain limitations due to the narrow sample scope, as it involved only two classes at a single grade level; therefore, generalizing the findings requires caution. In addition, the limited duration of the intervention may have affected the development of students' digital creativity, which generally requires longer practice and repeated feedback.

The findings may also have been influenced by teacher and school context factors. Therefore, future studies should involve more schools, longer intervention periods, and more diverse implementation designs.

CONCLUSION

This study demonstrates that a digital module developed through Google Sites in combination with the RICOSRE learning model significantly enhances learners' digital literacy in biology instruction compared to RICOSRE instruction without digital module support. The main findings of the study indicate that this intervention is more effective in enhancing students' ability to evaluate digital information and utilize various information sources, but remains less effective in developing their ability to produce original digital works. Further research should involve a broader sample, more diverse school contexts, and a longer intervention duration to test the sustainability of digital learning's impact on more complex dimensions of digital literacy, particularly the ability to produce original digital works.

REFERENCES

Al Mamun, M. A., & Lawrie, G. (2024). Cognitive presence in learner–content interaction process: The role of scaffolding in online self-regulated learning environments. *Journal of Computers in Education*, *11*(3), 791–821. https://doi.org/10.1007/s40692-023-00279-7

Anderson, L. W., & Krathwohl, D. R. (2001). *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives: Complete Edition* (Complete E). Longman.

Barzilai, S., Mor-Hagani, S., Zohar, A. R., Shlomi-Elooz, T., & Ben-Yishai, R. (2020). Making sources visible: Promoting multiple document literacy with digital epistemic scaffolds. *Computers & Education*, *157*, 103980. https://doi.org/https://doi.org/10.1016/j.compedu.2020.103980

Bedenlier, S., Bond, M., Buntins, K., Zawacki-Richter, O., & Kerres, M. (2020). Facilitating student engagement through educational technology in higher education: A systematic review in the field of arts and humanities. *Australasian Journal of Educational Technology*, *36*(4), 126–150. https://doi.org/10.14742/AJET.5477

Bermes, A. (2021). Information overload and fake news sharing: A transactional stress perspective exploring the mitigating role of consumers' resilience during COVID-19. *Journal of Retailing and Consumer Services*, *61*, 102555. https://doi.org/https://doi.org/10.1016/j.jretconser.2021.102555

Buchan, M. C., Bhawra, J., & Katapally, T. R. (2024). Navigating the digital world: development of an evidence-based digital literacy program and assessment tool for youth. *Smart Learning Environments*, *11*(1), 8. https://doi.org/10.1186/s40561-024-00293-x

Deschênes, A.-A. (2024). Digital literacy, the use of collaborative technologies, and perceived social proximity in a hybrid work environment: Technology as a social binder. *Computers in Human Behavior Reports*, *13*, 100351. https://doi.org/https://doi.org/10.1016/j.chbr.2023.100351

Ernest, I. Z., & Putra M, M. D. (2023). The Use of Google Sites-based Electronic Modules in

Science Learning Against Digital Literacy of Junior High School Students. *JPI (Jurnal Pendidikan Indonesia)*, *12*(2), 293–304. https://doi.org/10.23887/jpiundiksha.v12i2.56311

Fiorella, L. (2023). Making Sense of Generative Learning. *Educational Psychology Review*, *35* (2). https://doi.org/10.1007/s10648-023-09769-7

Fisher, D., Frey, N., Hattie, J., & Thayre, M. (2017). *Teaching Literacy in the Visible Learning Classroom, Grades 6-12*. Corwin. https://www.corwin.com/books/lessons-for-visible-grades-6-12-249341

Fraillon, J. (2025). *An International Perspective On Digital Literacy: Results from ICILS 2023*. Springer Cham. https://doi.org/10.1007/978-3-031-87722-3

Gafur, I. A., Yustina, Suryawati, E., & Hadriana. (2024). Exploring Challenges in Understanding Abstract Biological Concepts: A Visual Literacy Perspective. *Proceedings of the 2nd Annual International Conference on Mathematics, Science and Technology Education (AICMSTE 2023)*. 234–245. https://doi.org/10.2991/978-2-38476-216-3_25

Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. (2022). Understanding the role of digital technologies in education: A review. *Sustainable Operations and Computers*, *3*, 275–285. https://doi.org/https://doi.org/10.1016/j.susoc.2022.05.004

Hinostroza, J. E., Armstrong-Gallegos, S., & Villafaena, M. (2024). Roles of digital technologies in the implementation of inquiry-based learning (IBL): A systematic literature review. *Social Sciences & Humanities Open*, *9*, 100874. https://doi.org/https://doi.org/10.1016/j.ssaho.2024.100874

Jayanti, M. A. (2023). Developing an interactive e-module for digestive system materials to improve the analysis ability of high school students. *Jurnal Kependidikan: Penelitian Inovasi Pembelajaran*, *7*(1), 103–114. https://doi.org/10.21831/jk.v7i1.48412

Jenkins, H. (2009). Confronting the Challenges of Participatory Culture – Media Education for the 21st Century (Part Two). *Nordic Journal of Digital Literacy 2*(2). https://doi.org/10.18261/issn1891-943x-2007-02-04

Kirschner, P. A., & De Bruyckere, P. (2017). The myths of the digital native and the multitasker. *Teaching and Teacher Education*, *67*, 135–142. https://doi.org/https://doi.org/10.1016/j.tate.2017.06.001

Kominfo, B. (2023). *Peluncuran hasil pengukuran Indeks Masyarakat Digital Indonesia (IMDI) tahun 2023*. https://bpsdm.komdigi.go.id/berita-peluncuran-hasil-pengukuran-indeks-masyarakat-digital-indonesia-imdi-tahun--46-2092

Li, N., & Lau, K.-L. (2025). A two-staged SEM-ANN approach to predict learning presence in online foreign language education: The role of teaching presence and online interaction. *The Internet and Higher Education*, *66*, 101012. https://doi.org/https://doi.org/10.1016/j.iheduc.2025.101012

List, A., & Alexander, P. A. (2017). Analyzing and Integrating Models of Multiple Text Comprehension. *Educational Psychologist*, *52*(3), 143–147. https://doi.org/10.1080/00461520.2017.1328309

Mahanal, S., Zubaidah, S., Sumiati, I. D., Sari, T. M., Ismirawati, N. (2019). RICOSRE : A Learning Model to Develop Critical Thinking Skills for Students with Different Academic Abilities. *International Journal of Instruction*, *12*(2), 417–434. https://doi.org/10.29333/iji.2019.12227a

Mahanal, S., Zubaidah, S., Setiawan, D., Maghfiroh, H., & Muhaimin, F. G. (2022). Empowering College Students' Problem-Solving Skills through RICOSRE. *Education Sciences 12(3)*. 196. https://doi.org/10.3390/educsci12030196

Mayer, R. E. (2024). The Past, Present, and Future of the Cognitive Theory of Multimedia Learning. *Educational Psychology Review*, *36*(1), 1–25. https://doi.org/10.1007/s10648-023-09842-1

McGrew, S. (2020). Learning to evaluate: An intervention in civic online reasoning. *Computers & Education*, *145*, 103711. https://doi.org/https://doi.org/10.1016/j.compedu.2019.103711

McGrew, S., & Breakstone, J. (2023). Civic Online Reasoning Across the Curriculum: Developing and Testing the Efficacy of Digital Literacy Lessons. *AERA Open*, *9*, 23328584231176452. https://doi.org/10.1177/23328584231176451

Nagel, M.-T., & Zlatkin-Troitschanskaia, O. (2025). The competence to deal critically with online information among economics education students and teacher trainees in economics: implications for teacher training. *Empirical Research in Vocational Education and Training*, *17*(1), 11. https://doi.org/10.1186/s40461-025-00186-4

Ng, W. (2012). Can we teach digital natives digital literacy? *Computers & Education*, *59*(3), 1065–1078. https://doi.org/https://doi.org/10.1016/j.compedu.2012.04.016

Nkomo, L. M., Daniel, B. K., & Butson, R. J. (2021). Synthesis of student engagement with digital technologies: a systematic review of the literature. *International Journal of Educational Technology in Higher Education*, *18*(1), 34. https://doi.org/10.1186/s41239-021-00270-1

OECD. (2019). Education at a glance 2019: CD Publishing. In *OECD indicators. Paris: OE*. OECD Publihing. https://doi.org/10.1787/f8d7880d-en.

OECD. (2021). Education at a glance: OECD indicators. In *Education at a glance: OECD indicators*. OECD Publishing. https://doi.org/10.1787/b35a14e5-en.

Petchamé, J., Iriondo, I., Korres, O., & Paños-Castro, J. (2023). Digital transformation in higher education: A qualitative evaluative study of a hybrid virtual format using a smart classroom system. *Heliyon*, *9*(6), e16675. https://doi.org/https://doi.org/10.1016/j.heliyon.2023.e16675

Polizzi, G. (2020). Digital literacy and the national curriculum for England: Learning from how the experts engage with and evaluate online content. *Computers & Education*, *152*, 103859. https://doi.org/https://doi.org/10.1016/j.compedu.2020.103859

Ramdani, D., Idaman, R. P., & Ali, M. (2025). Fostering 21-st century skills: The effectiveness of Ricosre and digital flipbooks in enhancing student collaboration in biology learning. *Biosfer: Jurnal Pendidikan Biologi*, *18*(2), 424–436. https://doi.org/10.21009/biosferjpb.59320

Schneeweiß, N., & Gropengießer, H. (2019). Organising levels of organisation for biology education: A systematic review of literature. *Education Sciences*, *9*(3). https://doi.org/10.3390/educsci9030207

Selwyn, N. (2009). The digital native - myth and reality . In *Aslib Proceedings, 61*(4). 364-379. https://doi.org/10.1108/00012530910973776

Thomann, H., & Deutscher, V. (2025). Scaffolding through prompts in digital learning: A systematic review and meta-analysis of effectiveness on learning achievement. *Educational Research Review*, *47*, 100686.

https://doi.org/https://doi.org/10.1016/j.edurev.2025.100686
Trixa, J., & Kaspar, K. (2024). Information literacy in the digital age: information sources, evaluation strategies, and perceived teaching competences of pre-service teachers. *Frontiers in Psychology*, *15*. 1–22. https://doi.org/10.3389/fpsyg.2024.1336436
UNESCO. (2018). *A global framework of reference on digital literacy skills for indicator 4.4.2*. UNESCO. https://unesdoc.unesco.org/notice?id=p::usmarcdef_0000265403
Vandermeulen, N., Van Steendam, E., De Maeyer, S., Lesterhuis, M., & Rijlaarsdam, G. (2024). Learning to write syntheses: the effect of process feedback and of observing models on performance and process behaviors. *Reading and Writing, 37*(6). https://doi.org/10.1007/s11145-023-10483-7
Verhoeff, R. P., Knippels, M.-C. P. J., Gilissen, M. G. R., & Boersma, K. T. (2018). The Theoretical Nature of Systems Thinking. Perspectives on Systems Thinking in Biology Education. *Frontiers in Education*, *3*. https://doi.org/10.3389/feduc.2018.00040
Vuorikari, R., Kluzer, S., & Punie, Y. (2022). *DigComp 2.2. The Digital Competence Framework for Citizens. With new examples of knowledge, skills and attitudes*. Publications Office of the European Union. https://doi.org/10.2760/115376
Wineburg, Sam, & McGrew, Sarah. (2019). Lateral Reading and the Nature of Expertise: Reading Less and Learning More When Evaluating Digital Information. *Teachers College Record*, *121*(11), 1–40. https://doi.org/10.1177/016146811912101102
Wulandari, D. R., Sholihat, N., Purwanto, H., & Jehloh, N. (2024). Development Of Google Site As An Interactive Learning Media Integrated With Islamic Values. *Biosfer: Jurnal Tadris Biologi*, *15*(1), 101. https://doi.org/10.24042/biosfer.v15i1.19424
Yuan, N., Yu, Q., & Liu, W. (2025). The impact of digital literacy on learning outcomes among college students: the mediating effect of digital atmosphere, self-efficacy for digital technology and digital learning. *Frontiers in Education*, *10*. https://doi.org/10.3389/feduc.2025.1641687
Yusha, C. M., & Risnani, L. Y. (2023). Pengembangan Modul Digital Berbasis Google Sites pada Materi Sistem Pertahanan Tubuh Kelas XI: (Developing Digital Module Based Google Sites for Material Immune System for 11th Grade of Senior High School). *BIODIK*, *9*(3), 23–36. https://doi.org/10.22437/biodik.v9i3.27678
Zhao, L., Liu, J., Karimov, A., & Saarela, M. (2025). Assessing and developing college students' digital learning power: an empirical study based on questionnaire survey in a Chinese university. *International Journal of Educational Technology in Higher Education*, *22*(1). https://doi.org/10.1186/s41239-025-00514-4
Zhou, X., Sun, K., Zhu, K., Feng, L., Sun, Q., & Zhong, D. (2025). The impact of digital literacy on university students' innovation capability: evidence from Ningbo, China. *Frontiers in Psychology*, *16*. https://doi.org/10.3389/fpsyg.2025.1548817