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Integrating Digital Literacy into Biology Learning to Improve High School Students' Critical Thinking Skills

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ABSTRACT

This study aims to analyze the effectiveness of integrating digital literacy into Biology learning to enhance senior high school students' critical thinking skills. Digital literacy, as a 21st-century competence, encompasses the ability to access, evaluate, and process information through technology in an ethical manner. In Biology learning, the integration of digital literacy is expected to foster students' critical thinking through the exploration of interactive resources, data analysis, and the formulation of scientific arguments. The method used in this research was a quasi-experimental design with a Non-Equivalent Control Group. The research subjects consisted of two grade XI science classes selected purposively: the experimental group received Biology instruction based on digital literacy (interactive simulations, online journal analysis, infographic creation), while the control group was taught using conventional methods (lectures, discussions, manual experiments). Data were collected through critical thinking skill tests administered during the pre-test and post-test stages. The results showed that the average pre-test scores of both groups were nearly the same (62.5 and 63.1). After the treatment, the experimental group's average score significantly increased to 82.7 (gain score 20.2), while the control group reached only 70.3 (gain score 7.2). The t-test revealed a significant difference between the two groups (t=6.45; p=0.000). In conclusion, the integration of digital literacy in Biology learning proved to be more effective than conventional methods in improving students' critical thinking skills. This study highlights the importance of teachers systematically integrating digital literacy with adequate digital infrastructure support in schools.

Keywords: *Digital literacy, Biology, Critical thinking, Senior high school.*

INTRODUCTION

The development of digital technology has had a significant impact on the world of education, including Biology learning in Senior High Schools (SMA). Digital literacy, which includes skills in accessing, understanding, evaluating, and producing information through technology, has become one of the important 21st-century competencies that students must have (Trilling, 2023). Digital literacy is not only related to the use of hardware and software, but also involves higher-order thinking skills in sorting credible information from false information, managing data, and presenting analysis results ethically and responsibly. In the context of Biology learning, digital literacy enables students to explore interactive learning resources, access scientific journals,

analyze experimental data through software, and develop a deeper conceptual understanding of complex natural phenomena, such as ecosystem dynamics, human physiological systems, and modern biotechnology. Thus, digital literacy in biology learning is not just an additional tool, but a prerequisite for students to participate in a meaningful and contextual learning process. However, digital literacy that is only used technically without critical thinking skills has the potential to trap students in disinformation, especially in an era of information overload where scientific content is mixed with unvalidated opinions (Ariyanti, 2022). Therefore, the integration of digital literacy in biology learning should not stop at technological skills, but should be directed at strengthening students' critical thinking skills as preparation for facing the challenges of 21st-century life.

This research is highly relevant to the demands of 21st-century learning, which emphasizes mastery of the 4C skills (*critical thinking, creativity, collaboration*, and *communication*) as key competencies for students to be able to adapt to global changes (Kemendikbudristek, 2022). Of these four competencies, critical thinking skills occupy a central position in biology learning because this field is full of empirical data that requires logical and analytical interpretation. Biology not only teaches students to remember scientific facts, but also trains them to ask questions, formulate hypotheses, analyze experimental data, and make evidence-based decisions (Saido, 2018). Without critical thinking skills, students tend to be passive, merely accepting information, and less able to connect the knowledge they have acquired with real-life situations. In fact, the challenges of the 21st century require students to be able to identify complex environmental, health, and biotechnology problems, while offering creative solutions that are scientifically accountable.

A number of recent studies support the relevance of digital literacy integration for improving critical thinking skills. Wulandari (2023) shows that digital literacy contributes significantly to student learning outcomes and critical thinking skills in science learning, where students with high digital literacy are better able to evaluate information and relate it to the scientific knowledge they have mastered. Similarly, Nurfadilah's (2022) research proves that the use of science literacy-based digital teaching materials is effective in improving critical thinking skills on ecological topics, particularly energy flow and biogeochemical cycles. Furthermore, international studies show that the integration of digital technology accompanied by the right pedagogical approach plays an important role in fostering critical thinking and complex problem-solving skills in science learning (Hennessy, 2022). In fact, a recent meta-analysis found that *game-based learning* digital interventions have a significant positive effect on cognitive learning outcomes ($g = 0.67$) and student learning motivation, although their impact on metacognitive aspects is still limited (Barz, 2024). These findings confirm that digital innovation, if properly integrated, can strengthen the learning experience while fostering critical thinking skills.

However, the results of the main literature review show that the digital literacy of high school students in Indonesia is generally still in the moderate category. Ariani (2023) reports that students' ability to verify scientific information, assess the credibility of sources, and perform critical analysis is still limited. This is exacerbated by students' low exposure to quality digital learning resources, as most learning still focuses on textbooks or conventional materials. Correlational research by Rahayu (2024) in Padang City also found a significant relationship between digital literacy and the critical thinking skills of biology students, although neither is yet optimal. The results of this study indicate a gap between the potential of digital literacy as a driver of critical thinking skills and the reality of learning practices in the field, which have not fully utilized this potential.

This study found a lack of biology learning strategies that structurally integrate digital literacy as a means of developing critical thinking skills. Until now, the use of digital literacy in

biology learning has often been sporadic and dependent on teacher initiative, such as the use of educational videos or online simulations without follow-up reflective assignments that require critical analysis. This condition means that digital literacy functions only as a medium for conveying information, not as a profound pedagogical instrument. In fact, contextual and digital literacy-based biology learning can provide a more authentic, critical, and meaningful learning experience. For example, through digital literacy-based *project-based learning* activities, students not only access information from various sources, but also compare the validity of data, construct scientific arguments, and produce digital products that reflect their critical thinking.

Global research shows that the integration of digital literacy in science learning has been widely studied in developed countries, but is still relatively new in Indonesia. Several international studies show that digital literacy integrated with *inquiry-based learning* or *problem-based learning* approaches can improve students' critical thinking, problem-solving, and collaboration skills (Chai, 2021). Findings from studies on higher education curricula also show that digital literacy is a basic competency that needs to be prepared early on so that students are ready to face the digital world of work (Ossiannilsson, 2022). Similarly, recent research emphasizes that the integration of *design thinking* in curriculum development can strengthen prospective teachers' understanding of digital literacy in the context of 21st-century learning (McKillup, 2022). In other words, digital literacy is not only relevant for high school students but also important in preparing teachers to be able to design digital-based learning that encourages critical thinking skills.

Based on the above description, this study aims to analyze the model of digital literacy integration in Biology learning in high schools and to examine the extent to which this integration can improve students' critical thinking skills. This study not only attempts to describe the digital literacy conditions of students but also evaluates the effectiveness of learning strategies designed to systematically integrate digital literacy into Biology classes. Theoretically, this study is expected to enrich the literature on the relationship between digital literacy and critical thinking in Biology education, particularly in Indonesia. Practically, this study can be a reference for teachers in designing Biology learning strategies that are relevant to the needs of 21st-century students, while also supporting the implementation of the Merdeka Curriculum more effectively. Thus, the integration of digital literacy in Biology learning is not merely a technological innovation, but an urgent need to equip students with critical thinking skills that will determine their future success. This study attempts to address these challenges by providing empirical insights and strategic solutions that can be applied in educational practice.

METHODS

This study used a quantitative approach with a *quasi-experimental* design of the *Non-Equivalent Control Group Design*, involving two groups, namely the experimental group, which was given treatment in the form of digital literacy-based biology learning (interactive simulations, online journal data analysis, and digital infographic creation), and the control group, which received conventional learning in the form of lectures, discussions, and manual practicums (Hennessy et al., 2022). The research population consisted of all 11th grade science students at a high school, with two classes selected purposively because they had relatively similar characteristics in terms of the number of students, academic background, and curriculum used (Sugiyono, 2019). The independent variable in this study was the learning model, while the dependent variable was students' critical thinking skills, with the control variables being the curriculum, time allocation, and subject matter. Data were collected through pre-tests and post-tests compiled based on critical thinking indicators according to Ennis (2011). Data analysis was performed using normality tests (*Kolmogorov-Smirnov or Shapiro-Wilk)* and homogeneity tests (*Levene's Test)* as prerequisites, followed by a *paired sample t-test* to examine the difference between the pre-test and post-test within groups, and an *independent sample t-test* to examine the difference between groups. If the assumptions of normality of the are not met, then alternative non-

parametric tests are used, namely the Wilcoxon Signed Rank Test for paired data and *the Mann-Whitney U Test* for independent data (Field, 2018).

Table 1: Quasi-Experimental Research Design

Group	Treatment	Learning Method
Experimental	Biology learning with digital literacy integration	Interactive simulation, online journal data analysis, digital infographic creation
Control	Biology Learning with conventional methods	Lectures, group discussions, manual practical work

RESULTS AND DISCUSSION

Results

1. Description of Pre-Test and Post-Test Data

This study designed two groups, namely the experimental group (applying digital literacy integration in Biology learning) and the control group (using conventional learning methods). Critical thinking skills were measured through pre-tests before treatment and post-tests after treatment.

Table 2: Average Pre-Test, Post-Test, and Gain Score Values

Group	N	Pre-Test	Post-Test	Gain Score (Post – Pre)
Experiment	32	62.5	82.7	20.2
Control	32	63.1	70.3	7.2
Initial Difference*	0.6 (average pre-test difference between the two groups)			

From the table above, it can be seen that before the treatment, the critical thinking skills of students in both groups were at almost the same level. However, after the treatment, there was a much greater increase in the experimental group (up 20.2 points) compared to the control group (up 7.2 points). This shows the great potential effect of digital literacy integration.

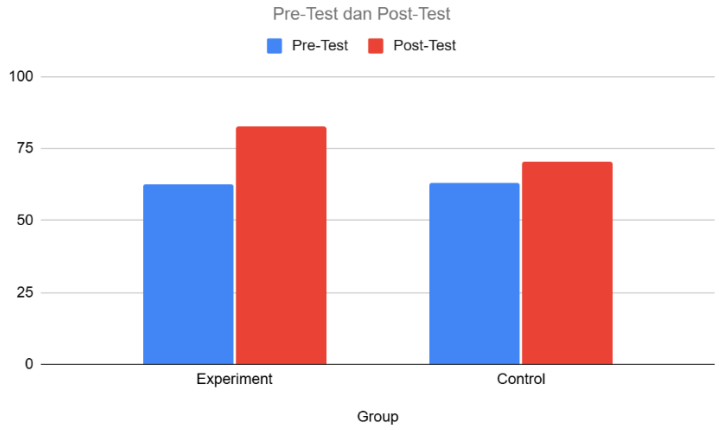

Figure 1. Pre-Test and Post-Test Scores

2. Statistical Test Results

Normality tests were conducted to ensure that the pre-test and post-test data in each group were normally distributed, as shown in Table 3, so that they could be analyzed using parametric tests. Furthermore, homogeneity tests were conducted to test the similarity of variances between groups so that comparisons between groups could be made objectively, as shown in Table 4.

Table 3. Normality Test Results

Group	Pre-test (p)	Post-test (p)	Description
Experimental	0.200	0.112	Normal
Control	0.134	0.085	Normal

Table 3 shows that the results of the normality test for both the pre-test and post-test groups are normally distributed ($p > 0.05$). Therefore, the analysis can be continued with a parametric test.

Table 4. Homogeneity Test Results

Variable	Levene Statistic (p)	Description
Pre-test & Post-test	0.287	Homogeneous

Based on the table above, the homogeneity test results show that the variance between groups is homogeneous ($p > 0.05$), so the homogeneity assumption is fulfilled for the t-test.

Table 5. Paired t-test Results

Group	t	Sig. (p)	Description
Experimental	12.45	0.000	Significant
Control	7.82	0.000	Significant

Based on Table 5 above, it shows that both groups experienced a significant increase in critical thinking skills between the pre-test and post-test ($p < 0.05$), but the increase in the experimental group was greater.

Table 6. Results of the Unpaired t-Test

Variable	t	Sig. (p)	Description
Post-test Experiment vs. Control	4.38	0.000	Significant

Based on Table 6 above, the unpaired t-test results show a significant difference between the post-test results of the experimental and control groups ($p < 0.05$), indicating that digital literacy-based learning is more effective than conventional learning in improving students' critical thinking skills.

Discussion

The results showed that before the treatment, the average pre-test scores for critical thinking skills among students in the experimental group (62.5) and the control group (63.1) were relatively balanced, with a difference of only 0.6 points. This condition indicated that the initial abilities of the two groups were at almost the same level, making them suitable for further comparison. After the treatment, the experimental group experienced a significant increase of 20.2 points, from 62.5 to 82.7. Meanwhile, the control group only experienced an increase of 7.2 points, from 63.1 to 70.3. These findings indicate that digital literacy-based learning has a stronger influence on improving students' critical thinking skills than conventional learning methods. This finding is in line with the results of research by Hennessy et al. (2022), which confirms that the use of digital literacy, such as interactive simulations, data analysis, , and visual representations, can stimulate high-level cognitive activity in students, thereby strengthening their critical thinking skills.

Before testing the main hypothesis, classical assumption tests consisting of normality and homogeneity tests were conducted. The results of the normality test showed that the pre-test and post-test data in both groups were normally distributed ($p > 0.05$). In addition, the results of the homogeneity test also showed that the variance between groups was homogeneous ($p > 0.05$). Thus, the two main requirements for parametric analysis were met, so that the use of the t-test was considered appropriate and the results were scientifically accountable. This is in line with Field's (2018) statement emphasizing the importance of normal distribution and variance equality to ensure the validity of parametric statistical analysis results.

The next analysis used a *paired sample t-test* to identify significant differences between the pre-test and post-test in each group. The test results showed that both the experimental and control groups experienced a significant increase in critical thinking skills ($p < 0.05$). However, the t-value for the experimental group (12.45) was much higher than that for the control group (7.82), which means that the improvement in the experimental group was greater. This proves that the integration of digital literacy in learning can improve students' critical thinking skills more effectively. This improvement can be explained through Vygotsky's constructivism theory, which emphasizes the importance of learning

media as a tool for student cognitive interaction. Digital media allows students to be actively involved in exploring information, organizing knowledge, and communicating ideas, thereby training higher-order thinking skills (Saido et al., 2018).

In addition, the *independent sample t-test* showed a significant difference between the post-test results of the experimental and control groups with a t-value of 4.38 ($p < 0.05$). These results confirm that digital literacy-based learning is more effective than conventional learning in improving students' critical thinking skills. This effectiveness occurs because digital literacy requires students to access information from various sources, analyze data, and present information in the form of digital products such as infographics or visual reports. This process is in line with the critical thinking indicators according to Ennis (2011), which include the ability to analyze, evaluate, and draw logical conclusions. These findings are also supported by research by Zainuddin et al. (2020) and Chen et al. (2021), which shows that the integration of digital technology in science learning can improve students' critical thinking, problem-solving, and information literacy skills.

Based on the research findings, several important implications can be drawn. First, digital literacy-based learning has proven to be effective as an alternative strategy for improving students' critical thinking skills, especially in Biology. Second, this learning model is in line with the demands of 21st-century competencies that emphasize critical thinking, communication, collaboration, and creativity skills. Third, teachers can use the results of this study as a basis for optimizing the use of digital media not only as a source of information, but also as a means of developing higher-order thinking skills in students. Thus, the application of digital literacy in learning is expected to equip students with the relevant competencies to face global challenges in the digital age.

CONCLUSION

Based on the results of the research and discussion described above, it can be concluded that the critical thinking skills of students in the experimental group and the control group were relatively balanced at the beginning, with pre-test average scores of 62.5 and 63.1, respectively. This shows that both groups had almost the same initial abilities, making them suitable for comparison. After the treatment was administered, there was a significant increase in the experimental group that participated in digital literacy-based learning, with an increase of 20.2 points, while the control group that used conventional learning only experienced an increase of 7.2 points. This difference in improvement shows that digital literacy contributes more to the development of students' critical thinking skills. The results of *the paired sample t-test* also confirmed that both the experimental and control groups experienced a significant increase in critical thinking skills between the pre-test and post-test ($p < 0.05$), although the increase in the experimental group was higher than that in the control group. Furthermore, the results of *the independent sample t-test* showed a significant difference in the post-test results between the two groups ($p < 0.05$), with the average post-test score of the experimental group (82.7) higher than that of the control group (70.3). This confirms that digital literacy-based learning is more effective in improving students' critical thinking skills than conventional learning. Overall, these findings prove that the integration of digital literacy in biology learning can improve students' critical thinking skills more optimally and reinforce the importance of applying digital media in science learning as a strategy to meet the demands of 21st-century competencies.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper. All authors have contributed equally to the conception, design, analysis, and writing of this manuscript, and there are no financial or personal relationships that could inappropriately influence the work reported herein.

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