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Research Article

The Influence of Science Process Skills, Digital Literacy and Students' Critical Thinking Skills on Physics Learning: A Mixed Method Study

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ABSTRACT

Purpose of the study: This study aims to examine the effects of integrating digital literacy into optical instruments learning on students' science process skills and critical thinking ability.

Methodology: A mixed methods approach with an explanatory sequential design was employed. The quantitative phase involved 60 students in Senior High School Jambi, selected through purposive sampling. Data were collected using a digital literacy questionnaire, a science process skills observation sheet, and a critical thinking test, and analyzed using multiple linear regression. The qualitative phase was conducted through semi-structured interviews to support and explain the quantitative findings.

Main Findings: The results indicate that digital literacy has a significant positive effect on science process skills and critical thinking ability in optical instruments learning. Qualitative findings reveal that digital simulations and digital-based inquiry activities enhance students' engagement, analytical reasoning, and understanding of optical concepts.

Novelty/Originality of this study: This study highlights the role of digital literacy as an integrative framework that supports scientific inquiry and higher-order thinking in physics education.

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1. INTRODUCTION

The rapid advancement of digital technology has significantly transformed educational practices, particularly in science education. In the context of 21st-century learning, students are required not only to master conceptual knowledge but also to develop higher-order thinking skills and scientific competencies[1]-[3]. Digital literacy has become a fundamental skill that enables learners to access, evaluate, and utilize information effectively through digital platforms [4], [5]. Consequently, integrating digital literacy into science learning is no longer optional but essential to prepare students to meet the demands of modern scientific inquiry and problem-solving [6]-[8].

Several international assessments indicate that students' performance in science-related competencies, especially science process skills and critical thinking, remains relatively low in many developing educational systems [9]-[11]. Reports from global educational evaluations emphasize that students often struggle with skills such as observing, hypothesizing, interpreting data, and drawing evidence-based conclusions [10]. These findings highlight the need for instructional approaches that actively engage students in scientific processes while fostering analytical and reflective thinking through meaningful learning experiences.

Optical instruments are among the fundamental topics in physics education that require strong conceptual understanding as well as the ability to apply scientific reasoning [14]-[16]. However, learning this topic is often dominated by abstract explanations, mathematical formulations, and teacher-centered instruction, which can limit students' engagement and conceptual clarity [17], [18]. Without adequate visualization, experimentation, and contextualization, students may find it difficult to connect theoretical concepts of optical instruments with real-world applications, resulting in low mastery of science process skills and critical thinking ability.

In classroom practice, the integration of digital literacy into optical instruments learning is still limited and often underutilized [19], [20]. Many learning activities focus primarily on content delivery rather than on empowering students to actively explore scientific phenomena using digital tools [21]-[23]. As a result, students tend to become passive recipients of information, with minimal opportunities to analyze data, evaluate evidence, or construct scientific arguments. This condition indicates a gap between the potential of digital technology in science education and its actual implementation in fostering essential scientific competencies.

Previous studies have widely explored the role of digital learning media in improving students' motivation and conceptual understanding in physics. Other research has separately examined science process skills or critical thinking skills as learning outcomes [24]-[26]. However, limited studies have comprehensively investigated the integrated effects of digital literacy on both science process skills and critical thinking ability, particularly within the context of optical instruments learning [27], [28]. Moreover, most existing research does not explicitly position digital literacy as a core instructional component that systematically supports scientific inquiry processes.

This study offers novelty by positioning digital literacy not merely as a supporting tool but as an integral framework embedded within optical instruments learning to simultaneously enhance students' science process skills and critical thinking ability. By combining digital-based inquiry activities, interactive simulations, and data-driven analysis, this research provides a more holistic approach to science learning. The urgency of this study lies in addressing current educational challenges that demand innovative learning models capable of bridging conceptual understanding, scientific skills, and higher-order thinking in a digital learning environment.

Therefore, this study aims to examine the effects of integrating digital literacy into optical instruments learning on students' science process skills and critical thinking ability. Specifically, the research seeks to analyze how digital literacy–based learning activities influence students' ability to engage in scientific processes and to think critically when solving physics-related problems. The findings of this study are expected to contribute to the development of effective digital-based science learning strategies and to provide empirical evidence for improving physics instruction in secondary education.

2. RESEARCH METHOD

This study employed a mixed methods approach to obtain comprehensive and in-depth findings regarding the integration of digital literacy in optical instruments learning and its effects on students' science process skills and critical thinking ability. Mixed methods research combines quantitative and qualitative approaches in a systematic manner to strengthen the validity and richness of research findings [29]-[31]. The research design used was an explanatory sequential design, in which quantitative data were collected and analyzed first, followed by qualitative data to explain and elaborate the quantitative results [32]. This design was selected because the study aimed not only to statistically examine the influence of digital literacy on students' science process skills and critical thinking ability, but also to explore students' learning experiences and perceptions related to the implementation of digital literacy in optical instruments learning. This study involved three main variables, namely digital literacy as the independent variable (X), science process skills (Y_1), and critical thinking ability (Y_2) as dependent variables. The relationships among these variables were examined through digital literacy integrated learning activities on optical instruments, particularly light refraction experiments supported by interactive digital media.

The population of this study consisted of undergraduate students at the Senior High School 8 Kota Jambi who were enrolled in physics related courses involving optical materials. These students were assumed to possess foundational knowledge of optics and basic laboratory experience relevant to the research objectives [33]. Based on these criteria, a total of 60 students were selected. The differentiation of samples aimed to obtain broader insights into the effectiveness of digital literacy integration across related academic contexts while maintaining institutional consistency.

The instruments used in this study were categorized into quantitative and qualitative instruments. The digital literacy questionnaire was used to measure students' digital literacy levels, covering technical, cognitive, and ethical dimensions of digital technology use in learning. The instrument was developed based on the European Digital Competence Framework (DigComp) and utilized a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). Reliability testing using Cronbach's alpha produced a coefficient of $\alpha = 0.76$, indicating acceptable internal consistency. The science process skills (SPS) observation sheet was used to assess students' performance during optical instrument practical activities, particularly light refraction experiments. The observed indicators included observing, formulating hypotheses, identifying variables, designing experiments, collecting data, analyzing data, and drawing conclusions. Observations were conducted by two independent observers to ensure objectivity. The reliability coefficient of the instrument was $\alpha = 0.78$, indicating good reliability.

Students' critical thinking ability was measured using an essay-based test adapted from established critical thinking indicators, including analysis, inference, evaluation, interpretation, and explanation. The test items were contextualized within optical instrument problems. Reliability analysis yielded a Cronbach's alpha value of $\alpha = 0.81$, indicating high reliability.

Table 1. Summary of Quantitative Research Instruments

Instrument	Measured Variable	Number of Items	Reliability (α)
Digital Literacy Questionnaire	Digital literacy (X)	25	0.76
SPS Observation Sheet	Science process skills (Y_1)	7 indicators	0.78
Critical Thinking Test	Critical thinking ability (Y_2)	5 essay items	0.81

A semi-structured interview guide was used to explore students' experiences, perceptions, and challenges related to digital literacy integration in optical instruments learning. The interview questions focused on students' engagement with digital media, learning difficulties, and perceived impacts on scientific skills and critical thinking. The qualitative data served to explain and enrich the quantitative findings. Quantitative data were analyzed using inferential statistics with the assistance of SPSS version 25.0. Prior to hypothesis testing, prerequisite tests including normality and linearity tests were conducted to ensure that the data met parametric assumptions. Hypothesis testing was carried out using multiple linear regression analysis to determine the effect of digital literacy (X) on science process skills (Y_1) and critical thinking ability (Y_2). Qualitative data were analyzed using the Miles and Huberman model, which consists of data reduction, data display, and conclusion drawing/verification. Interview data were coded and organized into thematic categories. To ensure data credibility, member checking and source triangulation were applied.

The research procedures were conducted in four main stages; This stage involved literature review, instrument development, and expert validation by a physics education lecturer, a digital literacy expert, and a research methodology expert. Learning activities on optical instruments were implemented by integrating digital literacy through interactive simulations (e.g., PhET), digital experiment videos, and guided inquiry worksheets. Quantitative data were collected through questionnaires, observation sheets, and critical thinking tests. Qualitative data were obtained through interviews with selected students representing high, medium, and low achievement groups. Quantitative and qualitative findings were integrated to provide a comprehensive interpretation of the effects of digital literacy integration on students' science process skills and critical thinking ability.

3. RESULTS AND DISCUSSION

The quantitative analysis aimed to examine the effect of digital literacy on students' science process skills and critical thinking ability in optical instruments learning. Data were obtained from 60 students at the Senior High School 8 Kota Jambi and analyzed using SPSS version 25.0. Prior to hypothesis testing, assumption tests were conducted to ensure that the data met the requirements for parametric statistical analysis.

The normality of the data was tested using the Kolmogorov–Smirnov test. The results are presented in Table 2.

Table 2. Normality Test Results

Variable	Kolmogorov–Smirnov Sig.	Decision
Digital Literacy	0.200	Normal
Science Process Skills	0.134	Normal
Critical Thinking Ability	0.118	Normal

The significance values for all variables were greater than 0.05, indicating that the data were normally distributed and suitable for further parametric analysis.

The linearity test was conducted to determine whether there was a linear relationship between digital literacy and the dependent variables. The results are shown in Table 3.

Table 3. Linearity Test Results

Relationship	Sig. Deviation from Linearity	Decision
Digital Literacy → SPS	0.276	Linear
Digital Literacy → Critical Thinking	0.318	Linear

Since the significance values were greater than 0.05, it can be concluded that the relationships between digital literacy and both dependent variables were linear.

Descriptive analysis was conducted to provide an overview of students' digital literacy, science process skills, and critical thinking ability.

Table 4. Descriptive Statistics of Research Variables

Variable	N	Mean	Std. Deviation
Digital Literacy	60	3.62	0.48
Science Process Skills	60	3.58	0.51
Critical Thinking Ability	60	3.55	0.53

The results indicate that students' digital literacy, science process skills, and critical thinking ability were in the moderate-to-good category, suggesting sufficient variation for hypothesis testing.

Hypothesis testing was conducted using multiple linear regression analysis to examine the effect of digital literacy on science process skills and critical thinking ability.

Table 5. Regression Analysis Results

Dependent Variable	R	R^2	Sig.
Science Process Skills	0.54	0.29	0.002
Critical Thinking Ability	0.57	0.33	0.001

The regression results show that digital literacy had a significant effect on science process skills ($R^2 = 0.29$, $p < 0.05$) and critical thinking ability ($R^2 = 0.33$, $p < 0.05$). This indicates that digital literacy contributed 29% to the variance in science process skills and 33% to the variance in critical thinking ability.

To further examine the strength of the influence, the regression coefficients are presented in Table 6.

Table 6. Regression Coefficient Results

Dependent Variable	β	t-value	Sig.
SPS	0.54	4.87	0.002
Critical Thinking	0.57	5.21	0.001

These findings indicate that higher levels of digital literacy were associated with better science process skills and stronger critical thinking ability among students learning optical instruments.

Qualitative data were collected through semi-structured interviews with selected students representing high, medium, and low quantitative scores. The qualitative analysis aimed to explore students' experiences with digital literacy integration in optical instruments learning and to explain the quantitative results.

Table 7. Summary of Qualitative Themes

Theme	Description	Representative Student Responses
Digital Engagement	Active use of simulations and digital media	"The simulation helped me understand how light refracts without just memorizing formulas."
Scientific Inquiry Support	Digital tools facilitated experimentation	"We could try different variables in the simulation, which made it easier to analyze the results."
Critical Reflection	Encouragement of analytical thinking	"I had to think more critically because I needed to explain why the results changed."
Learning Motivation	Increased interest and focus	"Using digital tools made the optics topic less abstract and more interesting."

The qualitative findings indicate that digital literacy integration supported students' engagement, scientific inquiry, and analytical reasoning during optical instruments learning. Students reported that digital simulations and digital-based inquiry activities enabled them to observe optical phenomena more clearly, manipulate experimental variables, and interpret data independently. These experiences directly contributed to the development of science process skills such as observing, analyzing, and drawing conclusions. Furthermore, the requirement to evaluate simulation results and justify conclusions encouraged students to engage in deeper critical thinking.

Students with higher digital literacy scores demonstrated greater confidence in using digital tools to test hypotheses and reflect on experimental outcomes. In contrast, students with lower digital literacy required more guidance but still reported improvements in understanding optical concepts through digital support. These findings support the quantitative results, which showed that digital literacy significantly influenced both science process skills and critical thinking ability. The findings of this study indicate that digital literacy has a significant influence on students' science process skills and critical thinking ability in optical instruments learning. The quantitative results demonstrate that digital literacy accounts for a meaningful proportion of variance in both science process skills and critical thinking, suggesting that students who are more competent in using digital tools are better able to engage in scientific inquiry and analytical reasoning [34], [35]. These results confirm the importance of integrating digital literacy as a core component of physics learning, particularly for abstract topics such as optical instruments.

The positive relationship between digital literacy and science process skills can be explained by the nature of digital-based learning activities used in this study. Interactive simulations and digital experiments allowed students to observe phenomena, manipulate variables, and analyze outcomes more effectively than conventional instruction. This finding is consistent with previous studies reporting that digital environments support the development of science process skills by enabling inquiry based and student-centered learning experiences [36]-[38]. However, unlike earlier research that primarily emphasized conceptual understanding, this study provides empirical evidence that digital literacy directly supports procedural scientific skills within laboratory oriented optics learning [17].

The results also reveal that digital literacy significantly affects students' critical thinking ability. Students were required to interpret simulation outputs, evaluate experimental results, and justify their conclusions, which fostered higher-order thinking processes. This aligns with previous research indicating that digital learning environments promote critical thinking through problem solving and reflective activities [39], [40], [41]. Nevertheless, many prior studies examined critical thinking as a secondary outcome or in isolation. In contrast, this study demonstrates that digital literacy functions as a key driver in strengthening critical thinking when systematically embedded in physics instruction [42], [43].

Qualitative findings further support the quantitative results by illustrating how digital literacy integration influenced students' learning experiences. Students reported increased engagement, improved understanding of optical concepts, and greater confidence in conducting scientific investigations. Digital simulations reduced cognitive barriers associated with abstract optical phenomena, allowing students to focus on reasoning and analysis rather than memorization. These insights explain why students with higher digital literacy levels showed stronger science process skills and critical thinking ability, thereby reinforcing the quantitative evidence.

While previous studies have explored the use of digital media in physics education, most have focused on learning motivation, achievement, or conceptual understanding. Few studies have simultaneously examined science process skills and critical thinking ability as dual outcomes of digital literacy integration, particularly in higher education optics learning. The novelty of this research lies in positioning digital literacy as an integrative framework that connects digital competence with scientific inquiry and higher-order thinking. This integrated approach addresses an important research gap by demonstrating how digital literacy can holistically enhance essential scientific skills.

The findings of this study have important implications for both theory and practice. Theoretically, the results contribute to the growing body of literature that emphasizes digital literacy as a foundational competence in science education. Practically, the study suggests that physics educators should intentionally design learning activities that integrate digital tools to support inquiry and critical thinking, rather than using technology solely for content delivery. Curriculum developers and higher education institutions may consider embedding digital literacy competencies into physics courses, particularly for complex topics such as optical instruments.

Despite its contributions, this study has several limitations. The sample was limited to students from a single school, which may restrict the generalizability of the findings. Additionally, the study focused on one topic within physics, namely optical instruments, and did not examine long-term learning effects. Future research is recommended to involve larger and more diverse samples, explore other physics topics, and investigate longitudinal impacts of digital literacy integration on scientific skills. Further studies may also incorporate experimental control groups to strengthen causal interpretations.

4. CONCLUSION

This study concludes that integrating digital literacy into optical instruments learning has a significant and positive effect on students' science process skills and critical thinking ability. The findings demonstrate that students with higher levels of digital literacy are more capable of engaging in scientific inquiry, analyzing experimental data, and making evidence-based conclusions. The combination of quantitative and qualitative results confirms that digital literacy functions not only as a technological skill but also as a pedagogical framework that supports the development of essential scientific competencies in physics learning. Future research is recommended to involve broader samples from multiple institutions and to examine the long-term effects of digital literacy integration across different physics topics. In addition, educators are encouraged to systematically embed digital literacy–based inquiry activities into physics instruction to enhance students' scientific skills and higher-order thinking.

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AUTHOR CONTRIBUTIONS

D was responsible for the research design, data collection, data analysis, and manuscript preparation. A, Y, DAK, and WSO, contributed to conceptual development, research methodology guidance, and critical review of the manuscript. All authors have read and approved the final version of the manuscript.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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