International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(RESEARCH ARTICLE)

The contribution of digital literacy to elementary school students' science learning outcomes

Dei Hukunala [1], Marleny Leasa [1,*], Melvie Talakua [1], Johanes Pelamonia [1] and John Rafafy Batlolona [2]

[1] *Elementary School Teacher Education Study Program, Faculty of Teacher Training and Education, Pattimura University, Ambon, Indonesia.*
[2] *Physics Education Study Program, Faculty of Teacher Training and Education, Pattimura University, Ambon, Indonesia.*

International Journal of Science and Research Archive, 2026, 19(03), 975-984

Publication history: Received on 08 May 2026; revised on 21 June 2026; accepted on 23 June 2026

Article DOI: https://doi.org/10.30574/ijsra.2026.19.3.1311

Abstract

Science learning outcomes among elementary school students remain a significant concern, particularly in the context of rapid technological advancement and the increasing demand for 21st-century competencies. Many students continue to demonstrate limited achievement in science, which may be associated with insufficient digital literacy skills and low engagement in learning activities. This study aimed to examine the contribution of digital literacy to science learning outcomes among fourth-grade students at SD Negeri 2 Latihan SPG Ambon. A quantitative research design was employed using a simple random sampling technique. The population comprised all upper elementary school students (Grades IV, V, and VI). The research sample was determined through a lottery method, in which Grade IV was randomly selected from the three grade levels. The selected sample consisted of 42 fourth-grade students from two parallel classes. Data were collected using a digital literacy questionnaire and a science achievement test. The questionnaire data were transformed from an ordinal to an interval scale using the Method of Successive Intervals (MSI) before statistical analysis. The data were analyzed using simple linear regression to examine the effect and contribution of digital literacy to students' science learning outcomes. The findings revealed that students demonstrated a moderate-to-high level of digital literacy, with a mean score of 70.17, while the average science achievement score was 82.86. Regression analysis indicated that digital literacy had a positive and statistically significant effect on science learning outcomes ($p < 0.05$). Furthermore, digital literacy accounted for 39.7% of the variance in students' science learning outcomes, highlighting its substantial contribution to academic achievement. These findings suggest that strengthening students' digital literacy skills can improve science learning outcomes. Therefore, schools should integrate digital literacy into science instruction and provide continuous support for technology-enhanced learning environments to optimize students' academic achievement in the digital era.

Keywords: Digital Literacy; Science Learning Outcomes; Elementary School Students; Science Education; Academic Achievement.

1. Introduction

One of the primary roles of education is to equip future generations with the knowledge and competencies necessary to become a workforce and citizenry capable of addressing the challenges of their time. In the coming years, occupations requiring mastery of knowledge and intellectual abilities are expected to be among the most in-demand. Consequently, expectations of educational outcomes in the 21st century have increasingly emphasized higher-order thinking skills, including synthesis, analysis, and evaluation. However, science education in schools continues to be dominated by low-level cognitive demands (Osborne, 2013). The findings of Kain et al., (2024) indicate that students still demonstrate inadequate competency levels in several skill areas. For example, employers reported that many graduates have not yet mastered fundamental skills, particularly those related to knowledge and mathematical abilities, with 53.3% of students

* Corresponding author: Marleny Leasa

identified as lacking proficiency in these areas. Deficiencies were also observed in writing skills, affecting 72.0% of students. Furthermore, shortcomings were evident in applied skills such as communication (80.9%), critical thinking and problem-solving (69.6%), and professional work ethics (70.3%). These deficiencies can be attributed to classroom instruction that remains heavily focused on traditional, back-to-basics educational approaches. Only a limited number of teachers provide learning experiences that actively promote critical thinking, effective communication, collaboration, negotiation, and problem-solving skills. This lack of essential competencies is often associated with inadequate educational practices that fail to keep pace with rapid technological advancements. One way to respond to ongoing societal transformation is to develop educational systems that emphasize the cultivation of students' skills and the enhancement of learning experiences, enabling them to meet evolving challenges and achieve both professional and personal success. At the core of this approach is the belief that adapting to such transformations requires mastery of a wide range of skills and competencies necessary for effective participation in societal development. Survey results reveal that elementary school science teachers tend to focus more on the delivery of factual knowledge than on the development of skills. Science instruction often emphasizes the memorization of isolated facts, relies heavily on textbooks without adequately considering students' understanding, and provides limited opportunities for students to raise questions or contribute comments during classroom discussions. As a result, the development of critical thinking skills is hindered, reducing students' ability to connect scientific concepts with real-life experiences (Abualrob, 2019).

New educational theories emerged during the transition from the nineteenth to the twentieth century and became known as reformist or progressive pedagogical approaches. Their fundamental principles include children's freedom, recognizing and supporting children as individuals, the coordinating and facilitative role of teachers, and the provision of a supportive pedagogical environment (Molnár et al., 2023). In the first quarter of the twenty-first century, societal and technological changes have become increasingly rapid. During this period, in line with student-centered, quality-oriented, and competency-based educational approaches, the concept of skill-oriented education has gained a prominent position within educational science (Karacaoğlu, 2025). Furthermore, teachers are expected to serve as facilitators who support students' learning processes while creating a conducive classroom environment that enables learners to develop the competencies required for the future. The quality of classroom instruction and its relationship to learning outcomes can play a significant role in driving educational transformation. Nevertheless, a deeper understanding of the dynamics that occur during classroom learning processes remains an important area for further investigation. One of the primary goals of education is to equip students with the knowledge, skills, and abilities necessary to navigate life successfully. In this context, collaboration has become an essential element throughout students' learning experiences (Parker et al., 2022). As implied by constructivist perspectives, student-centered education typically emphasizes active, inquiry-based teaching and learning methods through which students can effectively construct their understanding under appropriate instructional guidance. Student-centered education also requires educators and researchers to focus their efforts on learners' needs, not only by providing effective teaching and learning approaches but also by continuously aligning instructional practices with the educational demands of the contemporary era (Bao & Koenig, 2019).

Findings from international studies, such as those conducted in India, indicate that the quality of student learning remains relatively low. This is evidenced by the fact that only about 18% of students achieved scores above 60%. In addition, 23% of students were classified within the average category, while 38% performed below average on science achievement tests. The majority of students continue to demonstrate unsatisfactory learning outcomes in science, highlighting the need for greater attention from teachers, schools, and policymakers to improve the quality of science education (Raj & Gausiya, 2019). Teachers also continue to employ traditional science teaching methods, which have contributed to rote learning rather than genuine conceptual understanding, particularly at the elementary school level. The goal of science education is not to transform every student into a scientist but rather to cultivate positive attitudes toward science. For example, in Pakistan, education is largely based on the memorization of factual knowledge. Teachers rely heavily on lecture-based instruction at all levels of science education, especially in primary schools, which is particularly concerning. Lessons are predominantly teacher-centered, resulting in persistent uncertainty in students' understanding of scientific principles, phenomena, and hypotheses (Ali & Hashmi, 2022). Another noteworthy finding is that although female students demonstrated higher levels of achievement, the observed differences were not statistically significant. When viewed within the context of contemporary science education, these findings may serve as a basis for designing science learning strategies that are appropriate for students in Indonesia. Science learning in the modern era is a complex process because it involves not only the delivery of scientific concepts and content but also consideration of the unique characteristics and learning needs of each student as an individual learner (Park et al., 2020). The current state of science education requires special attention, as international assessment results indicate that students' science achievement remains lower than that of many other countries, particularly within Southeast Asia. Although various stakeholders have undertaken numerous initiatives to address this issue, the outcomes remain far from the intended goals. Therefore, all parties must collaborate to develop comprehensive plans and implement them consistently, particularly by maximizing the potential of local resources (Nugraha, 2023). This condition is believed to

be associated with differences in students' abilities to understand learning materials, varying levels of learning interest, and the limited utilization of digital literacy to support the learning process.

Digital literacy represents an appropriate solution as it has become an integral component of technology-based science education development. Digital literacy is not merely associated with browsing websites or sharing photos and comments on social media. Rather, it encompasses an understanding of technology, the ability to recognize its potential in achieving meaningful goals, and the competence to use it wisely in support of personal and professional development. Nevertheless, many young people still do not fully understand the concept of digital literacy or the level of digital literacy skills they possess (Ngoc & Chong, 2023). Today's students are growing up in environments heavily influenced by digital technology and are generally capable of accessing, creating, and distributing information in digital formats (Ting, 2015). However, digital literacy extends beyond the ability to locate and manage information; it also requires the skills to evaluate, analyze, and integrate information obtained from various digital sources. Although the current generation is often perceived as technologically proficient, many students still encounter difficulties in using digital information effectively and critically (Greene et al., 2014). Therefore, students need to develop the ability to plan, monitor, and regulate information-management processes, accompanied by strong critical-thinking skills. Consistent with this perspective, Tinmaz et al. (2022) argue that digital literacy is not merely the ability to search for information on the internet but also the capacity to understand, interpret, and organize information derived from a variety of sources, both print and digital. Consequently, digital literacy places greater emphasis on the mastery and meaningful interpretation of ideas than on the mere use of technology itself (Tang & Chaw, 2016).

Digital literacy plays a crucial role in improving students' learning outcomes because it enables them to access and effectively utilize a wide range of digital learning resources. The ability to use technology, understand digital information, and engage with interactive learning media can make the learning process more engaging and meaningful (Wei, 2024; Yuan et al., 2025) Students with strong digital literacy skills tend to be more confident, active, and interested in participating in learning activities. Conversely, low levels of digital literacy may hinder students' interest in learning, as difficulties in using digital devices and understanding digital information can lead to boredom and reduced motivation. Therefore, digital literacy is closely related to students' learning interest, particularly in creating enjoyable learning experiences and encouraging active engagement in the learning process (Momani et al., 2023). Digital learning in science education offers numerous benefits, including increased student engagement and motivation, expanded access to learning opportunities, support for personalized learning, facilitation of collaboration, and the integration of gamification elements into the learning process (Jovanovic & Milosavljevic, 2022). Various digital tools and platforms enable the creation of interactive and immersive learning experiences, helping students develop a deeper understanding of scientific concepts and apply them in real-world contexts. Nevertheless, the implementation of digital learning also presents several challenges, including limited financial resources and access to technology, technical difficulties, reduced face-to-face social interaction, potential distractions from digital media, and the possibility of diminishing attention to conventional instructional methods that remain relevant and valuable (Yang & Baldwin, 2020). Digital learning has emerged as a viable solution, enabling students to engage with scientific issues in innovative and meaningful ways (Bidarra & Rusman, 2017; Rapanta et al., 2021). Similarly, educators often perceive their own level of digital literacy as insufficient and believe that their digital competencies require further development. It is therefore essential to equip both educators and students with adequate digital literacy skills so that they can effectively utilize digital technologies to support teaching and learning processes (Sánchez-Cruzado et al., 2021; Chang et al., 2023). Accordingly, this study aims to examine the contribution of digital literacy to students' science learning outcomes.

2. Method

This study employed a quantitative research design to investigate the contribution of digital literacy to science learning outcomes among elementary school students. A quantitative approach was considered appropriate because the study aimed to examine the relationship between variables objectively through numerical data and statistical procedures. The research focused on determining the extent to which students' digital literacy skills contribute to their achievement in science learning. In the context of 21st-century education, digital literacy has become an essential competency that enables students to access, evaluate, manage, and utilize information effectively through digital technologies. Therefore, understanding its influence on academic achievement is important for improving the quality of science education. By applying a quantitative methodology, the study was able to generate empirical evidence regarding the relationship between digital literacy and science learning outcomes and to measure the magnitude of its contribution using statistical analysis. This approach also ensured that the findings were based on systematic data collection and objective interpretation, providing a reliable basis for educational decision-making and future research.

The study was conducted at SD Negeri 2 Latihan SPG Ambon. The target population consisted of all upper elementary school students (Grades IV, V, and VI) enrolled during the academic year of the study. To ensure that every student in

the population had an equal opportunity to be selected, the study employed a simple random sampling technique. In this probability sampling method, the sample was determined through a lottery procedure, in which the names of the three upper-grade levels (Grades IV, V, and VI) were randomly drawn. The lottery resulted in Grade IV being selected as the research sample. Grade IV consisted of two parallel classes, namely Class IV-A with 20 students and Class IV-B with 22 students, resulting in a total sample of 42 students. All students in the selected grade participated in the study. The use of simple random sampling minimized selection bias and enhanced the representativeness of the sample by providing each upper-grade level with an equal probability of being selected. This approach strengthened the validity of the study by ensuring that the sample was selected objectively and was representative of the target population.

The study involved two main variables: digital literacy as the independent variable (X) and science learning outcomes as the dependent variable (Y). Digital literacy refers to students' ability to access, understand, evaluate, and utilize digital information and technology effectively for learning purposes. Science learning outcomes refer to students' academic achievement in science subjects as measured through a standardized achievement test. Data were collected using two instruments. First, a digital literacy questionnaire was administered to measure students' digital literacy levels. The questionnaire consisted of indicators related to the use of digital technologies, information management, and critical evaluation of digital content. Second, a written science achievement test was used to assess students' understanding of science concepts and determine their learning outcomes. The instruments were administered directly to the participants under the supervision of the researcher and classroom teachers.

The instruments used in this study were questionnaires and a written test. A Likert scale was employed to assess students' digital literacy and learning interest. The questionnaires, designed to measure these constructs, consisted of a series of statements with four response options, each assigned a specific score. The questionnaire was administered in the form of a checklist, in which students placed a check mark (√) next to the response they considered most appropriate. Further indicators of digital literacy included functional skills, creativity, communication and teamwork, information searching and selection, critical thinking and evaluation, sociocultural understanding, and cybersecurity (Igonina et al., 2022). Meanwhile, students' enjoyment, interest, focus, and engagement in learning served as indicators of learning interest.

Table 1 Scoring of Positive and Negative Items Using the Likert Scale for Digital Literacy and Students' Learning Interest

Response Option	**Questionnaire Item Scores**	
	Positive Items (+)	Negative Items (-)
Always	4	1
Often	3	2
Sometimes	2	3
Never	1	4

As an initial step in the data analysis, the digital literacy scores obtained from the questionnaire were transformed from an ordinal scale to an interval scale using the Method of Successive Intervals (MSI). This transformation was necessary because the questionnaire employed a Likert-type scale, which yields ordinal data, whereas parametric statistical techniques, including simple linear regression, require interval-level measurements. The MSI procedure converted the ordinal responses into interval scores while preserving the relative ordering of the observations, thereby ensuring that the assumptions underlying the subsequent parametric analyses were satisfied.

The transformed data were subsequently analyzed using descriptive and inferential statistics. Descriptive statistics, including the mean, minimum score, maximum score, and standard error, were used to summarize students' digital literacy and science achievement levels. Inferential statistical analysis was performed using simple linear regression in SPSS version 29.0 to examine the effect of digital literacy on science learning outcomes. Furthermore, t-tests, analysis of variance (ANOVA), and the coefficient of determination (R^2) were employed to evaluate the regression model and quantify the proportion of variance in science achievement explained by digital literacy. Statistical significance was established at the 0.05 level, with *p*-values less than 0.05 indicating a statistically significant relationship between the variables. This analytical procedure enabled the study to provide robust empirical evidence regarding the contribution of digital literacy to elementary students' science learning achievement and its implications for improving educational quality in the digital era.

The collected data were analyzed using descriptive and inferential statistics. Descriptive statistics, including mean, minimum score, maximum score, and standard error, were used to provide an overview of students' digital literacy and science achievement levels. Inferential statistical analysis was conducted through simple linear regression analysis using SPSS version 29.0 to determine the significance and magnitude of the effect of digital literacy on science learning outcomes. Additionally, t-tests, ANOVA tests, and the coefficient of determination (R^2) were employed to evaluate the regression model and measure the proportion of variance in science achievement explained by digital literacy. Statistical significance was determined at the 0.05 level, with p-values below 0.05 indicating a significant relationship between the variables. Through this methodological approach, the study was able to provide empirical evidence regarding the role of digital literacy in supporting elementary students' science learning achievement and its potential contribution to improving educational quality in the digital era.

3. Results and Discussion

Data description constitutes the initial stage of the research analysis and aims to provide a general overview of the data collected from the field. At this stage, the data are presented systematically to facilitate an understanding of the characteristics of the respondents and the variables under investigation. The descriptive statistics for students' digital literacy are presented in Table 2.

Table 2 Descriptive Statistics of Digital Literacy

Statistic	**Value**
Number of Respondents (N)	42
Mean	70.17
Median	69.44
Standard Error of the Mean	1.42
Minimum	47.22
Maximum	91.67

Based on Table 2, the mean score for the digital literacy variable was 70.17. The minimum score obtained by students was 47.22, while the maximum score was 91.67. The descriptive statistics for students' learning outcomes are presented in Table 3.

Table 3 Descriptive Statistics of Students' Learning Outcomes

Statistic	**Value**
Number of Respondents (*N*)	42
Missing Data	0
Mean	82.86
Standard Error	2.00
Minimum	53.33
Maximum	100.00

Based on Table 3, the mean learning outcome score was 82.86, with a minimum score of 53.33 and a maximum score of 100.00.

Tabel 4 Digital Regression Coefficients for Digital Literacy

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	12.450	10.020		1.220	0.230
	Digital Literacy	3.050	0.600	0.341	5.130	0.000
a. Dependent Variable: Learning Outcomes						

Based on the t-test results presented in Table 4, the significance value (Sig.) for digital literacy was 0.000. According to the decision criterion, where 0.000 < 0.05, the alternative hypothesis (H_1) is accepted and the null hypothesis (H_0) is rejected. Therefore, it can be concluded that digital literacy has a significant effect on the science learning outcomes of fourth-grade students at the SD Negeri 2 Latihan SPG Ambon.

Tabel 5 ANOVA Results

ANOVA[a]						
Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	2050.12	1	2050.12	2.630	0.000
	Residual	3117.45	40	77.49		
	Total	5167.57	41			
a. Dependent Variable: Learning Outcomes						
b. Predictors: (Constant), Digital Literacy						

Based on the ANOVA results shown in Table 5, the F-value was 2.630 with a significance value of 0.000, which is lower than 0.05. This indicates that the regression model is statistically significant. Accordingly, it can be concluded that digital literacy has a significant simultaneous effect on students' learning outcomes. In other words, digital literacy is able to explain a meaningful proportion of the variation in learning outcomes.

Tabel 6 Coefficient of Determination

Model Summary				
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	0.630[a]	0.397	0.382	8.850
a. Predictors: (Constant), Digital Literacy				

Based on the Model Summary output, the R Square value was 0.397. Therefore, it can be concluded that digital literacy contributes 39.7% to the science learning outcomes of fourth-grade students at the SD Latihan Ambon School Complex. The remaining 60.3% of the variance in learning outcomes is explained by other factors that were not examined in the present study.

4. Discussion

Hasil The findings of this study indicate that digital literacy has a positive and significant effect on elementary school students' science learning outcomes, contributing 39.7% to the variance in achievement. This result suggests that digital literacy is not merely a complementary skill but has become an essential competency that directly influences students' ability to understand scientific concepts and engage effectively in the learning process. Students with higher levels of digital literacy tend to be more capable of accessing, evaluating, and integrating information from various digital sources, enabling them to construct scientific understanding in a more independent and meaningful manner. The

positive relationship between digital literacy and science learning outcomes can be explained through the lens of constructivist theory, which emphasizes that knowledge is actively constructed through individuals' interactions with their environment and learning resources. Within digital learning environments, students with strong digital literacy skills are better equipped to navigate vast amounts of information, distinguish credible information from unreliable sources, and apply information effectively to solve problems. These findings are consistent with the study by Laar et al. (2020) which identified digital literacy as a fundamental twenty-first-century skill that enables learners to develop critical thinking, problem-solving, and decision-making abilities in technology-rich environments. Consequently, students with high levels of digital literacy are more likely to achieve deeper and more meaningful learning than those who rely solely on conventional learning resources.

The contribution of digital literacy identified in this study further reinforces the view that academic success in science is increasingly influenced by students' ability to utilize technology for knowledge acquisition rather than by the mere availability of technology itself. This finding is particularly important because many educational initiatives focus primarily on providing technological devices without simultaneously developing students' capacity to use them effectively. Bueno-Baquero et al. (2026) demonstrated that students' digital competence exerts a stronger influence on academic achievement than simple access to technology. In other words, the educational benefits of technology can only be fully realized when students possess the cognitive and metacognitive skills necessary to manage digital information effectively. Furthermore, digital literacy contributes to the development of self-regulated learning. Science education requires students to engage in inquiry, analyze data, and construct explanations based on scientific evidence. Students with strong digital literacy skills are generally better able to plan their learning activities, monitor their understanding, evaluate the quality of the information they obtain, and adjust their learning strategies when encountering difficulties. Hatlevik & Guðmundsdóttir (2015) explained that digital competence is closely associated with self-regulated learning, as students with well-developed digital skills tend to demonstrate higher levels of autonomy and confidence in managing their learning tasks. This relationship may help explain why students with higher levels of digital literacy in the present study achieved better science learning outcomes.

The findings of this study are also highly relevant to inquiry-based science learning approaches, which have become a major focus of twenty-first-century education. Modern science curricula no longer emphasize the memorization of concepts; instead, they prioritize the development of scientific thinking, evidence-based argumentation, and problem-solving skills. Digital technologies provide a wide range of learning resources, including virtual simulations, digital laboratories, interactive videos, and concept visualizations, all of which can help students understand complex scientific phenomena. Davor et al. (2026) found that students with higher levels of digital literacy consistently perform better on tasks requiring analytical skills, information evaluation, and critical reasoning. These competencies are closely aligned with the objectives of contemporary science education, thereby providing further support for the findings of the present study. Nevertheless, the coefficient of determination ($R^2 = 0.397$) indicates that digital literacy accounts for only 39.7% of the variance in students' science learning outcomes. This means that the remaining 60.3% of the variance is influenced by other factors that were not examined in this study. This finding suggests that learning outcomes are multidimensional phenomena shaped by a combination of internal and external factors. Previous studies have identified learning motivation, parental support, teaching quality, learning environment conditions, socioeconomic status, and students' self-efficacy as important contributors to academic success. Furthermore, Song et al. (2025) reported that learning engagement and self-efficacy often serve as significant mediating variables in the relationship between digital competence and academic achievement. Therefore, digital literacy should not be viewed as the sole determinant of learning success; rather, it should be understood as one component of an interconnected educational system in which multiple factors interact to influence student achievement.

The findings of this study also have important practical implications for the field of education. The development of digital literacy in elementary schools should not be limited to technical proficiency in using digital devices; it should also encompass critical thinking, information evaluation, digital communication, and the ethical use of technology. Ng et al. (2021) emphasized that effective digital literacy education must integrate technological, cognitive, and socio-emotional dimensions to enable learners to adapt to the complexities of modern digital environments. Therefore, science teachers need to design learning experiences that encourage students to engage in technology-supported investigations, critically analyze digital information, and collaborate through various digital platforms. Overall, the findings of this study reinforce the international consensus that digital literacy is one of the key competencies that significantly contributes to science learning achievement. Amid the rapid advancement of technology and the ongoing digital transformation of education, strengthening digital literacy has become an essential necessity rather than an optional component of learning. Digital literacy not only contributes to improved science learning outcomes but also equips students with critical-thinking skills, lifelong learning abilities, and the readiness to face the challenges of a knowledge-based society in the twenty-first century. Consequently, the integration of digital literacy into science

instruction at the elementary school level should be prioritized as a strategic effort to enhance educational quality and strengthen the competitiveness of future generations.

5. Conclusion

The findings of this study confirm that digital literacy plays a significant role in improving science learning outcomes among fourth-grade students at the SD Latihan Ambon Elementary School Complex. The statistical analysis revealed a positive and significant relationship between digital literacy and students' science achievement, indicating that students with stronger digital literacy skills tend to obtain higher academic results. In the context of contemporary education, digital literacy extends beyond the ability to operate technological devices; it also encompasses the capacity to access, evaluate, manage, and apply digital information critically and effectively. These competencies enable students to engage more actively in learning activities, explore diverse learning resources, and develop a deeper understanding of scientific concepts. The study also found that digital literacy contributed 39.7% to the variance in science learning outcomes, suggesting that it is an important predictor of academic success. This contribution highlights the growing importance of integrating digital competencies into elementary education, particularly in science learning, where access to interactive and technology-based resources can enhance students' understanding and motivation. However, since 60.3% of the variance in learning outcomes is influenced by other factors, it can be inferred that student achievement is a multidimensional phenomenon affected by additional variables such as learning motivation, teaching quality, family support, learning environment, and individual characteristics. Overall, the results emphasize that strengthening digital literacy among elementary school students is essential for improving science achievement and preparing learners to thrive in an increasingly digital and knowledge-driven society. Therefore, digital literacy should be considered a fundamental component of educational development and classroom practice in the twenty-first century.

Based on the findings of this study, several recommendations can be proposed to enhance science learning outcomes through the development of digital literacy. First, teachers are encouraged to integrate digital literacy skills into science instruction by utilizing interactive digital media, educational applications, online learning platforms, and inquiry-based learning activities. Such approaches can help students become more engaged in the learning process while improving their ability to access, analyze, and apply scientific information from digital sources. Second, schools should provide adequate technological infrastructure, including reliable internet access, digital devices, and appropriate learning resources, to create a supportive environment for technology-enhanced learning. Schools should also organize training programs and workshops to strengthen teachers' competencies in using digital technologies effectively in classroom instruction. Furthermore, students should be encouraged to develop responsible and productive digital habits by using technology not only for entertainment purposes but also as a tool for learning, problem-solving, and knowledge acquisition. Developing critical thinking skills when evaluating digital information is equally important to ensure that students can distinguish reliable information from inaccurate or misleading content. At the policy level, educational authorities should support the integration of digital literacy into the elementary school curriculum and provide continuous professional development opportunities for teachers to adapt to the demands of digital-age education. Finally, future researchers are encouraged to investigate other factors that may influence science learning outcomes, such as learning motivation, self-regulated learning, parental support, learning environment, and technology readiness. Since digital literacy accounts for 39.7% of the variance in science achievement, exploring additional variables may provide a more comprehensive understanding of the factors that contribute to students' academic success and help develop more effective educational interventions.

Compliance with ethical standards

Disclosure of conflict of interest

The author declares that there are no conflicts of interest regarding the publication of this paper.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

References

[1] Abualrob, M. M. (2019). The role of science teachers in developing the 21st century skills for the elementary school students. *Interdisciplinary Journal of Environmental and Science Education*, *15*(1), 1–8.

[2] Ali, R., & Hashmi, M. A. (2022). Impact of activities on performance among science students at elementary level. *Global Educational Studies Review*, *7*(1), 130–138. https://doi.org/10.31703/gesr.2022(VII-I).14

[3] Bao, L., & Koenig, K. (2019). Physics education research for 21st century learning. *Disciplinary and Interdisciplinary Science Education Research*, *1*(1), 1–12. https://doi.org/10.1186/s43031-019-0007-8

[4] Bidarra, J., & Rusman, E. (2017). Towards a pedagogical model for science education : bridging educational contexts through a blended learning approach. *Open Learning: The Journal of Open, Distance and e-Learning*, *32*(1), 6–20. https://doi.org/10.1080/02680513.2016.1265442

[5] Bueno-Baquero, A., González-Calero, J. A., Olmo-Muñoz, J. Del, & Pérez, M. del C. S. (2026). Bridging digital transitions : Teacher digital competence across primary and secondary education. *Education and Information Technologies*, 1–28.

[6] Chang, C., Kuo, H., & Du, Z. (2023). The role of digital literacy in augmented , virtual , and mixed reality in popular science education : a review study and an educational framework development. *Virtual Reality*, *27*(3), 2461–2479. https://doi.org/10.1007/s10055-023-00817-9

[7] Davor, I., Boateng, F. O., Osei-Tutu, P., Osei-Bosompem, A., Patience, A. S., & Adusei, L. A. (2026). Examining the mediating roles of digital literacy and critical thinking in the relationship between ChatGPT use and university students' mathematical problem-solving efficacy. *Journal of Mathematics Science and Technology Education*, *3*(1), 1–15.

[8] Greene, J. A., Yu, S. B., & Copeland, D. Z. (2014). Measuring critical components of digital literacy and their relationships with learning. *Computers & Education*, *76*, 55–69. https://doi.org/10.1016/j.compedu.2014.03.008

[9] Hatlevik, O. E., & Guðmundsdóttir, G. B. (2015). Examining factors predicting students ' digital competence. *Journal of Information Technology Education: Research*, *14*, 123–137.

[10] Igonina, E. V., Povalyaeva, O. N., & Kotlyarova, O. A. (2022). Digital competence of Russian teachers (results of an empirical study on the example of the Lipetsk region). *Perspectives of Science and Education*, *60*(6), 625–643. https://doi.org/10.32744/pse.2022.6.38

[11] Jovanovic, A., & Milosavljevic, A. (2022). VoRtex Metaverse Platform for Gamified. *Electronics*, *11*, 1–20.

[12] Kain, C., Koschmieder, C., Matischek-jauk, M., & Bergner, S. (2024). Mapping the landscape : A scoping review of 21st century skills literature in secondary education. *Teaching and Teacher Education*, *151*, 1–27. https://doi.org/10.1016/j.tate.2024.104739

[13] Karacaoğlu, Ö. C. (2025). Basic Skills of 21st Century Teachers. *Australian Journal of Teacher Education*, *50*(1), 75–91.

[14] Laar, E. Van, Deursen, A. J. A. M. Van, Dijk, J. A. G. M. Van, & Haan, J. De. (2020). Determinants of 21st-Century Skills and 21st-Century Digital Skills for Workers : A Systematic Literature Review. *SAGE Open*, *10*(1), 1–14. https://doi.org/10.1177/2158244019900176

[15] Molnár, Z., Gyuris, Á., Radács, M., Nemes, P., & Bátori, I. (2023). Complex natural science and the challenges of its education in the 21st century. *Cogent Education*, *10*(2), 1–14. https://doi.org/10.1080/2331186X.2023.2240166

[16] Momani, M. A. K. Al, Alharahasheh, K. A., & Alqudah, M. (2023). Digital learning in Sciences education : A literature review. *Cogent Education*, *10*(2), 1–19. https://doi.org/10.1080/2331186X.2023.2277007

[17] Ng, D. T. K., Leung, J. K. L., Chu, S. K. W., & Qiao, M. S. (2021). Conceptualizing AI literacy : An exploratory review. *Computers and Education: Artificial Intelligence*, *2*, 1–11. https://doi.org/10.1016/j.caeai.2021.100041

[18] Ngoc, D. D. L., & Chong, S. L. (2023). Undergraduate students ' digital literacy skills in the digital world of sustainable development. *International Conference on Research in Education and Science*, *4*, 677–700.

[19] Nugraha, I. (2023). Unearthing the academic time capsule : delving into the evolution of science education among Indonesian students. *Journal of Science Learning*, *7*(3), 213–226. https://doi.org/10.17509/jsl.v6i4.60828

[20] Osborne, J. (2013). The 21st century challenge for science education : Assessing scientific reasoning. *Thinking Skills and Creativity*, *10*, 265–279. https://doi.org/10.1016/j.tsc.2013.07.006

[21] Park, W., Wu, J., & Erduran, S. (2020). The nature of STEM disciplines in the science education standards documents from the USA, Korea and Taiwan. *Science & Education*, *29*, 899–927.

[22] Parker, J., Asare, I., Badu, C., & Ossei-anto, T. A. (2022). Examining the use of 21 st -Century teaching skills in basic school science classrooms. *European Journal of Education and Pedagogy*, *3*(4), 28–31.

[23] Raj, H., & Gausiya, F. (2019). Learning outcomes in science among elementary level students. *Issues and Ideas in Education*, *7*(2), 65–70. https://doi.org/10.15415/iie.2019.72007

[24] Rapanta, C., Botturi, L., Goodyear, P., & Guàrdia, L. (2021). Balancing technology , pedagogy and the new normal : post - pandemic challenges for higher education. *Postdigital Science and Education*, *3*, 715–742. https://doi.org/10.1007/s42438-021-00249-1

[25] Sánchez-Cruzado, C., Campión, R. S., & Sánchez-Compaña, T. (2021). Teacher digital literacy: the indisputable challenge after COVID-19. *Sustainability*, *13*, 1–29.

[26] Song, Y., Lv, S., Wang, M., Wang, Z., & Dong, W. (2025). The impact of digital learning competence on the academic achievement of undergraduate students. *Behavioral Sciences*, *15*(7), 1–25.

[27] Tang, C. M., & Chaw, L. Y. (2016). Digital literacy : a prerequisite for effective learning in a blended learning environment ? *The Electronic Journal of E-Learning*, *14*(1), 54–65.

[28] Ting, Y. (2015). Internet and Higher Education Tapping into students ' digital literacy and designing negotiated learning to promote learner autonomy. *The Internet and Higher Education*, *26*, 25–32. https://doi.org/10.1016/j.iheduc.2015.04.004

[29] Tinmaz, H., Lee, Y. T., Fanea-Ivanovici, M., & Baber, H. (2022). A systematic review on digital literacy. *Smart Learning Environments*, *9*(1), 1–18. https://doi.org/10.1186/s40561-022-00204-y

[30] Wei, Z. (2024). Navigating digital learning landscapes: unveiling the interplay between learning behaviors, digital literacy, and educational outcomes. *Journal of the Knowledge Economy*, *15*, 10516–10546.

[31] Yang, D., & Baldwin, S. J. (2020). Using technology to support student learning in an integrated STEM learning environment. *International Journal of Technology in Education and Science*, *4*(1), 1–11.

[32] 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 Communication*, *10*, 1–11. https://doi.org/10.3389/feduc.2025.1641687