

Optimizing science learning through differentiated models to improve science literacy in the digital era



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Abstract Differentiated models in science learning in elementary schools are essential to improve science literacy in line with the provisions of the Independent Curriculum. The application of this model allows teachers to adjust teaching methods that are more responsive to the individual learning needs of students, thereby maximizing their learning potential in understanding complex and relevant scientific concepts. This study aimed to investigate how using a differentiated approach to make science learning more effective can help students learn more about science. The research used a quantitative approach and a quasiexperimental nonequivalent control group design. The study was split into two groups: the experimental group and the control group, which consisted of a total of 274 elementary school students in Jakarta who were used as the population. Cluster random sampling was used for the sampling process, and interviews, observations, and instruments in the form of science literacy tests in the form of surveys were used to collect the data. An independent t test and an N-gain score test was used to look at the data. The results showed that using a differentiated model to improve students' science literacy had a big impact. This was supported by an independent t test with a significance value of $0.000 < 0.05$ and an N-gain score test that met the medium criteria. The differentiated learning model has a positive impact on the development of students' scientific literacy, with a substantive increase in their ability to apply scientific concepts in various situations.

Keywords: differentiated, science literacy, curriculum, elementary school, learning innovation, digital-based education

1. Introduction

In the era of globalization, which is full of technological advances, scientific literacy has become a fundamental need for students (Fadli & Kissiya, 2024). Scientific literacy allows students not only to understand scientific concepts but also to apply them in everyday life and develop critical thinking and problem-solving skills (Aiman et al., 2020). To create an adaptive and innovative generation, the independent curriculum introduced by the Indonesian government provides a more flexible and integrative framework for science learning (Bahtiar et al., 2022).

Scientific literacy is an important ability that involves the use of science in everyday life to understand, interact with scientific issues, and solve problems in ways that can improve overall quality of life (Lestari & Rahmawati, 2020). Indonesian students still need to learn more about science. The results of the Program for International Student Assessment (PISA) test show this. Indonesia received an average score of 403, which is much lower than the average score for the OECD, which was 493. As a result, Indonesia is ranked 62nd out of 72 participating countries (Rosana et al., 2020). This low score indicates significant challenges in the science education system in Indonesia, which require attention and improvement to strengthen science literacy skills among students (Wijaya et al., 2024).

The problem of low science literacy skills in Indonesia is very clear from the results of the PISA science literacy assessment. From 2000–2018, the achievement of science literacy among students in Indonesia has increased, with significant progress. According to PISA 2018 data, Indonesia is ranked 69th out of 77 participating countries (Sholikah & Pertiwi, 2021). This situation indicates significant challenges in the science education system in Indonesia. The latest data from the PISA 2022 show a decline in the science literacy skills of students in Indonesia compared with those in 2018 (Ismawati et al., 2023). This decline underscores the existence of deep-seated problems that require serious attention. The lack of improvement or even decline in science literacy outcomes reflects the need for more fundamental reforms in the approach and strategy of science education in Indonesia (Zahroh et al., 2022). Efforts to address these challenges must involve improvements in teaching methods, curricula, and available resources to ensure that students can develop strong and relevant science literacy skills.



Elementary schools play a vital role as early milestones in improving science literacy. Students in elementary schools are introduced to the basics of science, which forms the foundation for their understanding of science in the future (Ke et al., 2021). Elementary school science classes are meant to do more than teach scientific ideas. They are also meant to spark students' interest, help them think critically, and help them learn how to solve problems from a young age (Asrial et al., 2024). Elementary schools are the first stage of education and provide science learning experiences; elementary schools serve as a strong foundation for the further development of science literacy (Chen et al., 2021; Haryanto et al., 2022).

In today's digital era, the challenges and opportunities in science learning are increasing. This transformation requires educators to adapt and optimize their teaching methods to be more effective and relevant to the needs of diverse students (Amanda et al., 2022). One promising approach to address this diversity is the application of a differentiated learning model. Differentiated learning is an educational strategy designed to accommodate diversity in the learning readiness, interests, and learning profiles of each student (Songer et al., 2020). This approach gives students the freedom to develop and enhance their potential to the fullest by adjusting the teaching approach to their individual needs (Yusnidar et al., 2024). This model is designed to adapt the learning process to the different speeds, interests, and learning abilities of each student so that everyone can optimize their learning potential in understanding science concepts (Hasanah et al., 2022).

Optimizing science learning through a differentiated model not only improves individual conceptual understanding but also significantly improves science literacy among students (Sulistianingrum et al., 2023). Science literacy, which is the ability to understand, evaluate, and analyze scientific information, is a crucial skill that every student must develop to succeed in a society that is increasingly dependent on technology and information (Hidayah et al., 2023). According to a study by Aguanda et al. (2023), using differentiated learning to its fullest has helped students become more science literate. This finding is in line with the independent curriculum principles that were put in place in Indonesia. These principles stress the importance of having an open approach to teaching and learning that is tailored to each student's needs and characteristics. Witraguna & Jaya (2024) further emphasized that the application of differentiated methods in science learning at the elementary school level is highly relevant and beneficial. This model not only helps students understand scientific concepts more deeply but also improves their ability to apply that knowledge in real life.

Optimizing differentiated learning in science is an effective strategy for improving science literacy because it supports the principles promoted by the independent curriculum, which prioritizes adaptive and personalized learning experiences. Differentiated learning not only helps students understand science ideas better but also helps them learn important skills such as how to solve problems and think critically. These skills are important for children because they help them do well in and out of school and prepare them to handle challenges better in the future. This study aims to investigate how well using a tailored model to improve science literacy in the digital age helps students learn science. Furthermore, please determine how using learning methods that are tailored to each student's speed, hobbies, and learning style can help them understand scientific ideas better and improve their ability to think critically and solve problems. This research will also look at how technology can help diverse learning and how it can help people learn more about science.

2. Materials and Methods

2.1. Design research

This research used a quantitative approach and a quasiexperimental design with a control class. However, the class did not fully control outside factors that could have changed how the experiment was carried out (Balnaves & Caputi, 2018; Johnson & Christensen, 2022). A nonequivalent control group design with two class groups—an experimental class and a control class—was used for the study (Teo, 2014). The purpose of this study is to investigate the differences and benefits of using a differentiated model to help students learn science better. A full description of the study design and methods is provided in the Table 1 below.

Table 1 Quantitative research design

Pretest	Treatment	Posttest
O1	X	O2

This study began by providing both groups, the experimental group and the control group, with a pretest (O1). After the pretest, both groups underwent a posttest (O2) to measure the final learning results. The experimental group received treatment (X) in the form of applying a differentiated model in science learning, whereas the control group followed a conventional learning model without such treatment.

2.2. Research participants

The elementary schools included in this study were State Elementary School Wijaya Kusuma 02 Pagi, State Elementary School Tanjung Duren Selatan 01 Pagi, State Elementary School Tamansari 03 Pagi, State Elementary School Mangga Besar 15 Pagi, and State Elementary School Jatipulo 05 Pagi in Jakarta, Indonesia. Two groups, one receiving treatment and the

other following conventional learning without treatment, were formed from 274 elementary school students who participated in the research. Each group will take a short quiz to gauge their starting point of knowledge before receiving treatment. To measure the efficacy of the learning model and to observe any changes that may have occurred, both groups will be administered a posttest following therapy. The sampling technique used in this study was cluster random sampling, where the sample is divided into several separate groups (clusters). This technique allows random group selection to ensure sample representation.

2.3. Measuring tools and data collection techniques

The data collection techniques used in this study include observations, interviews, and questionnaire tests (pretest and posttest) designed to analyze improvements in students' scientific literacy. The data were collected via a questionnaire with a five-point Likert scale adapted from previous studies. The development of this questionnaire was based on a literature review covering differentiated learning models and scientific literacy in elementary schools (Atta et al., 2020; Syofyan et al., 2024). The instrument consists of 14 statements written in a language that is easy for elementary school students to understand. Each statement is carefully designed to enable students to provide precise and accurate responses. The questionnaire was distributed online via Google Forms, facilitating a streamlined completion process. Additionally, students were accompanied by facilitators or peers who were familiar with the questionnaire content to ensure the results were accurate and representative. A summary of the responses to the survey questions is presented in Table 2 below.

Table 2 Responses to the survey questions.

Choice of Answers	Weighted Score
Strongly agree	5
Agree	4
Doubtful	3
Do not agree	2
Strongly Disagree	1

2.4. Data analysis technique

In this study, statistical tests such as the independent sample t test and N-gain score were used to evaluate how differentiated learning models affect science literacy improvement. This was achieved by comparing the pretest and posttest scores. Before hypothesis testing, a preliminary examination was conducted to ensure that the data met the necessary assumptions. These initial tests included normality and homogeneity tests. The normality test was performed via the Kolmogorov–Smirnov method with a significance level of $p > 0.05$ to confirm the data's normal distribution. The homogeneity test was conducted through one-way ANOVA with Levene's test, with a significance level of $p > 0.05$, to ensure that the variances among the compared groups were similar.

Analysis of the data was performed via version 26 of SPSS software (Thrane, 2022). To evaluate significant differences between the experimental and control groups, an independent sample t test was applied, with a significance threshold set at $p < 0.05$. The N-gain score test was used to assess improvements in students' science literacy. The interpretation of the N-gain scores is as follows (Kim & Steiner, 2021): an N-gain value greater than 0.7 ($g > 0.7$) indicates a high level of improvement; values between 0.3 and 0.7 ($0.3 \leq g \leq 0.7$) suggest a moderate level of improvement; and values below 0.3 ($g < 0.3$) are considered low (May & Hittner, 2010). Table 3 shows these criteria for interpreting the N-gain score results.

Table 3 Allocation of N-Gain scores.

N-gain Value	Criteria
$g > 0.7$	High
$0.3 \leq g \leq 0.7$	Medium
$g < 0.3$	Low

3. Results

3.1. Statistical analysis review

The statistical analysis in this study aims to explain the data obtained from the research sample, which consists of 274 students. This sample is divided into two groups, namely, 198 students in the experimental class and 76 students in the control class. The data analyzed include the pretest and posttest scores from both groups. The results of the statistical analysis revealed that in the experimental class, the average pretest score was 68.12, with a significant increase in the posttest score, reaching an average of 79.90. In contrast, in the control class, the average pretest score was 59.21, and after treatment, the posttest score increased to 69.88. The range of scores in the experimental class for the pretest was between 53.00 and 87.00, with a standard deviation of 8.17, whereas that for the posttest was in the range of 58.00 to 96.00, with a standard deviation of 7.98.

In the control class, the pretest score ranged from 51.00 to 81.00, with a standard deviation of 8.12, and the posttest score ranged from 62.00 to 89.00, with a standard deviation of 9.57. Further details can be found in Table 4 below.

Table 4 Statistical data summary

	Descriptive Statistics				
	N	Minimum	Maximum	Mean	Std. Deviation
Experiment Pretest	198	62.00	87.00	72.1249	8.16781
Experiment Posttest	198	66.00	91.00	80.6183	7.97609
Control Pretest	76	63.00	71.00	63.1891	8.12328
Control Posttest	76	59.00	71.00	59.1986	9.56797
Valid N (listwise)	76				

Table 4 indicates a notable difference between the experimental and control classes. The experimental class improved the average pretest and posttest scores more than the control class did. The statistical analysis revealed that the intervention in the experimental class had a more significant effect on enhancing science literacy via the student-differentiated model than did the method used in the control class.

3.2. Prerequisite test

A preliminary test is performed to verify whether the data meet the necessary criteria for advancing to the hypothesis testing phase. This step is crucial because it ensures that the variance of the data satisfies two key conditions: a normal distribution across the population and homogeneity among the groups compared. This preliminary test encompasses analyses for data normality and homogeneity. The normality of the data was assessed via the Kolmogorov–Smirnov method, whereas homogeneity was evaluated via one-way ANOVA.

3.3. Normality test

Table 5 presents the results of the normality analysis via the Kolmogorov–Smirnov method. The significance values are 0.191 for the experimental group and 0.199 for the control group. Since both values are greater than 0.05 ($p > 0.05$), it can be concluded that the data for both groups are normally distributed. The detailed results of this analysis are shown in Table 5.

Table 5 Normality test results.

Class	Kolmogorov–Smirnov			Description
	Statistic	df	Sig.	
Experiment	.182	198	.191	Normal
Control	.176	76	.199	Normal

3.4. Homogeneity test

Table 6 displays the results of the homogeneity test conducted between the experimental and control classes, where a significance value of 0.148 was obtained. Since this value exceeds 0.05 ($p > 0.05$), the variances of the two class groups are homogeneous. This result suggests that the variability across both groups is statistically similar, thereby justifying valid comparisons in subsequent analyses. More detailed information regarding the results of this homogeneity test is provided in Table 6.

Table 6 Homogeneity test results.

Class	Test of Homogeneity of Variances				Description
	Levene Statistic	df1	df2	Sig.	
Experiment and Control	4.126	1	274	.148	Homogen

3.5. Hypothesis testing via independent t tests and n-gain scores

The hypothesis testing in this study employed the independent samples t test, yielding a Sig. (2-tailed) value of 0.006. A value of less than 0.05 ($p < 0.05$) indicates a statistically significant difference. The findings demonstrate that students exposed to differentiated learning models in science achieved higher average science literacy scores than those who experienced conventional learning models did. This significant difference highlights the beneficial effect of differentiated learning models on students' science literacy. A summary of the detailed results from this t test is provided in Table 7 below.

The findings in Table 7 indicate a distinct difference between the experimental and control classes in terms of science learning, as evidenced by the independent samples t test. This difference demonstrates that the differentiated learning model used in the experimental class yields significantly better results than the conventional approach used in the control class does.

The results of the independent samples t test in this study are strengthened by the analysis using the N-gain score, which aims to measure the effectiveness of improving student learning outcomes from the pretest to the posttest (Coletta, 2023). The N-gain score analysis provides an overview of how much improvement was achieved by students after the application of the learning model, allowing for a more comprehensive assessment of the impact of the intervention applied in the experimental class than in the control class. The results of a more detailed recapitulation can be seen in Table 8 below.

Table 7 Independent sample t test results.

Result scientific literacy with differentiation	Independent samples test								
	Levene's Test for Equality of Variances		t test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	1.122	.426	4.188	198	.006	8.03321	2.00257	3.93332	8.66522
Equal variances not assumed			5.119	70.129	.000	6.12406	1.98695	3.76108	7.12908

Table 8 N-gain score analysis results.

Class	N-gain Score	Criteria
Experiment 1	0.6	Medium
Experiment 2	0.4	Medium
Experiment 3	0.4	Medium
Control	0.2	Low

Table 8 highlights a significant difference in the N-gain values between the experimental and control classes. The experimental classes—1, 2, and 3—achieved N-gain values ranging from 0.4--0.6, which falls into the moderate improvement category ($0.3 \leq g \leq 0.7$). This suggests a meaningful, though mild, enhancement in student learning outcomes due to the differentiated learning model. Conversely, the control class recorded an N-gain value of 0.2, categorizing it as low ($g < 0.3$), indicating only minimal improvement in learning outcomes.

The N-gain score analysis supports the conclusion that the differentiated learning model implemented in the experimental classes enhances students' scientific literacy more effectively than the conventional learning approach used in the control class does. This is corroborated by the average pretest and posttest scores: Experimental Class 1 improved from 71.11--82.12, Experimental Class 2 improved from 73.33--80.02, and Experimental Class 3 improved from 69.96--79.89. In contrast, the control class's average score increased from 58.62 to 71.49. The recap of the effectiveness results of differentiated learning compared to conventional learning can be seen in Figure 1 below.

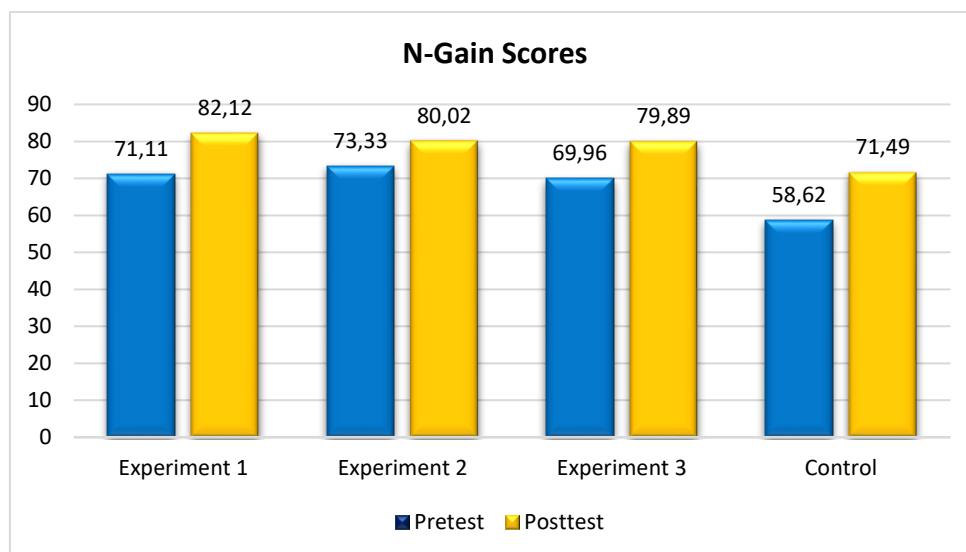


Figure 1 Differences in scores between the experimental and control groups.

The N-gain score results obtained in this study provide strong evidence that optimizing the use of differentiated learning models in science learning can significantly improve students' science literacy skills in elementary schools. On the basis of the data analysis, an increase in science literacy skills is clearly observed in students who learn via differentiated learning models



compared with those who use conventional learning models. Optimizing differentiated models in science education that address students' individual needs enhances comprehension and engagement and increases motivation (Smets et al., 2022; Strogilos et al., 2023). These models allow students to learn at their own pace, style, and interests, improving learning effectiveness and academic outcomes.

4. Discussion

Science learning in elementary schools plays a vital role in forming the foundation of scientific literacy for students (Hastuti et al., 2020). This aspect is essential because scientific literacy involves not only understanding scientific concepts but also analyzing information, thinking critically, and applying knowledge in real situations (Aristeidou & Herodotou, 2020). Scientific literacy helps students understand the world around them better, make decisions on the basis of scientific evidence, and contribute as informed citizens in dealing with global issues (Bennett, 2010; Zulyusri et al., 2023). Students in elementary schools are expected to begin to recognize various scientific principles through observations, experiments, and inquiry-based activities (Syofyan & Rachmadtullah, 2019). Students learn about the universe, the earth, life, and physical phenomena, all of which build curiosity and problem-solving skills (Russell & Martin, 2023; Suendarti & Virgana, 2022).

Integrating technology in science education is crucial for enhancing the learning experience by providing access to the latest scientific information and enabling participation in digital simulations (Putra et al., 2021; Rachmadtullah et al., 2020). This approach deepens students' understanding of scientific concepts and equips them with an increasingly digital world (Fadli et al., 2022; Wulandari et al., 2023). Technology transforms how students engage with the subject matter, making the learning process more interactive and stimulating and offering tools for independent and creative exploration of scientific concepts (Saïdo et al., 2015; Taupik & Fitria, 2023).

Science learning in elementary schools, which optimizes active and inclusive learning models, is a crucial step to ensure that all students get the most out of the subject matter (Atmojo et al., 2021; Ifdaniyah & Sukmawati, 2024; Lo et al., 2021). The differentiated learning model, described by Tomlinson (2017), supports the introduction and teaching that is tailored to the talents and learning styles that vary among students. This model enables teachers to tailor the teaching and learning process to fit each student's unique needs, acknowledging that individuals have different learning styles and paces (Tomlinson & Imbeau, 2023). According to Scarparolo and MacKinnon (2024), differentiated learning does not equate to individualized instruction. However, it involves a teaching approach that aligns with students' strengths and learning needs through more independent learning strategies (Scott et al., 2021).

Differentiated models in science learning recognize that students have different learning speeds, diverse interests, and unique strengths (Westbroek et al., 2020). This strategy facilitates more personalized and interactive learning by adjusting a) content where teachers provide various learning resources and different levels of difficulty according to students' abilities. b) The process whereby teaching methods are adjusted, such as the use of technology, group discussions, or project-based learning, to attract students' interest and deepen their understanding. c) Products where students are given the opportunity to demonstrate their understanding through various forms, such as presentations, papers, or multimedia projects, allowing them to use their strengths (Kaplan, 2023; Pozas et al., 2020; Moallemi, 2024).

Differentiated learning models play a significant role in improving elementary school students' science literacy (Puzio, et al., 2020; Iqbal et al., 2020). Optimizing science learning through differentiated models becomes more inclusive and exciting, which are factors that are very important for subjects that require deep conceptual and analytical understanding (Mertoğlu, 2020). Differentiated approaches enrich the learning experience by ensuring that learning activities are designed to meet the diverse learning needs of students (Rachmadtullah et al., 2020; Syofyan & Ratih, 2022). Optimizing differentiated models is achieved through adjusting content, processes, products, and learning environments according to individual needs (Krishan & Al-rsa'i, 2023; Mićanović et al., 2023).

Witraguna's et al. (2024) explained that the use of differentiated learning models in mathematics education has significant effectiveness in improving students' mathematical thinking skills, showing better adaptation to individual needs in understanding complex mathematical concepts. Kutlu's (2021) revealed that the application of differentiated learning models in natural sciences in junior high schools succeeded in improving students' critical thinking skills by providing more varied and in-depth learning strategies. Furthermore, Sandra et al. (2024) emphasized that the implementation of differentiated models in science learning is highly relevant to developing science analysis skills among elementary school students, integrating methods that are more responsive to the diversity of learning styles and speed of understanding (Ismajli & Morina, 2018). Previous research highlights that optimizing science learning through differentiated models not only supports improving science literacy in elementary schools but also underlines the importance of personalizing teaching approaches to accommodate diversity in the learning environment.

Optimizing differentiated learning models in science learning offers a dynamic and responsive approach that is very suitable for preparing elementary school students to have strong science literacy skills (Hidayah et al., 2024; Klepsch & Seufert, 2020). Teachers implement differentiated models to adjust teaching methods and materials according to the needs, interests, and different levels of understanding among students so that each child has the opportunity to develop according to their potential (Dalila et al., 2022; Lai et al., 2020). Through differentiated learning models, students are invited to actively explore

science concepts through various means, such as hands-on experiments, inquiry-based projects, and class discussions, all of which can increase their understanding of natural science more deeply (Demir, 2021; Mabsutsah et al., 2023).

Differentiated learning models not only strengthen scientific literacy but also sharpen critical and analytical skills that are essential for future success (Özdeniz et al., 2023; Variacion et al., 2021). By using this model, a strong foundation of scientific literacy is instilled early on, thus preparing elementary school students not only to face future academic challenges but also to develop as critical thinkers. In addition, they are prepared to become global citizens who can understand, adapt, and make an impact in a dynamic and ever-changing world.

5. Final Considerations

Optimizing science learning through differentiated models has been proven effective in improving elementary school students' science literacy in the digital era. This study demonstrates that a learning approach customized to each student's needs, learning styles, and pace enhances their grasp of scientific concepts and fosters critical and analytical skills. By integrating responsive technology and methodologies, this model offers an inclusive and engaging environment for students to explore and understand science deeply. The findings have significant implications for shaping educational policies and pedagogical practices. Highlighting the need to better support and develop learning models that adapt to the uniqueness of individual students, this study also highlights the importance of integrating technology in science education. This underscores that in today's digital era, more than traditional approaches may be needed to meet the demands of dynamic and diverse science learning. Therefore, optimizing science learning through differentiated models is not only a necessity but also a catalyst for producing a generation of young people who are scientifically literate, adaptive, and innovative.

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Ethical Considerations

Ethical considerations were followed throughout the research process, including obtaining consent from respondents to publish the information they provided while maintaining the confidentiality of their identities and institutions.

Conflict of Interest

The authors declare that there are no conflicts of interest that could affect the objectivity and integrity of this research.

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