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Effectivity of Virtual Field Trip-Based Learning on Elementary School Students' Scientific Literacy

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Abstract: Developing scientific literacy in elementary education is critical, yet traditional classroom methods often struggle to foster high engagement and contextual understanding, particularly in resource-limited settings. While digital interventions are rising, the specific efficacy of virtual field trips (VFT) in transformative science learning remains insufficiently explored. This study aims to examine the effect of virtual field trip-based learning on elementary school students' scientific literacy. Utilizing a quantitative quasi-experimental design, this study involved 60 fifth-grade students, divided equally into an experimental class (utilizing VFT) and a control class (traditional instruction). Data were collected through a structured scientific literacy questionnaire and analyzed using both descriptive and inferential statistics, specifically paired and independent sample t-tests. The findings indicate that VFT-based learning exerts a positive and highly significant effect on students' scientific literacy. The experimental group exhibited a remarkable increase in mean scientific literacy scores, soaring from 60.63 (low category) pre-treatment to 92.18 (very high category) post-treatment. Conversely, the control group only achieved a post-test mean of 67.16 (low category), demonstrating that VFT integration yields significantly superior outcomes compared to conventional methods ($p < 0.05$). Consequently, VFT-based learning serves as a potent pedagogical alternative to mitigate low scientific literacy. Beyond individual score gains, these insights offer a scalable framework for curriculum developers to integrate immersive digital technologies into early science education, bridging the gap between abstract scientific concepts and real-world phenomena.

Keywords: Virtual field trips; scientific literacy; elementary education; quasy-experimental; educational technology.

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INTRODUCTION

Scientific literacy has become one of the most essential competencies required for learners in the twenty-first century. In an era characterized by rapid scientific advancement, technological innovation, and the widespread availability of information, students are expected not only to acquire scientific knowledge but also to develop the ability to interpret evidence, evaluate scientific claims, and apply scientific reasoning to real-world situations. Consequently, scientific literacy has emerged as a central goal of contemporary science education worldwide (Organisation for Economic Co-operation and Development [OECD], 2023).

Scientific literacy refers to an individual's capacity to engage with science-related issues and ideas as reflective citizens. It encompasses the ability to explain scientific phenomena, evaluate and design scientific investigations, and interpret data and evidence scientifically (OECD, 2023). These competencies enable students to make informed decisions, solve problems systematically, and participate effectively in increasingly complex societies.

The importance of scientific literacy extends beyond academic achievement. Scientific literacy plays a critical role in preparing students to address environmental, health, technological, and societal challenges. Individuals with strong scientific literacy are better equipped to understand scientific information, evaluate competing claims, and make decisions based on evidence rather than misconceptions or misinformation (Bybee, 2018).

Despite its recognized importance, the development of scientific literacy remains a significant challenge in many educational systems. International assessment results consistently indicate that many students struggle to apply scientific knowledge in authentic contexts. Rather than engaging in inquiry, reasoning, and evidence-based decision-making, students often rely on memorization and rote learning approaches that limit the development of higher-order scientific competencies (Mullis et al., 2023).

The issue of scientific literacy has received considerable attention in Indonesia. Results from international assessments, particularly the Programme for International Student Assessment (PISA), indicate that Indonesian students continue to demonstrate relatively low levels of scientific literacy compared with students from many other participating countries (OECD, 2023). These findings suggest the need for innovative instructional approaches capable of improving students' engagement with scientific concepts and inquiry processes.

Several factors contribute to the low level of scientific literacy among elementary school students. One of the most frequently identified challenges is the predominance of teacher-centered instructional practices that emphasize content transmission rather than active scientific exploration. Such approaches often limit students' opportunities to observe phenomena, investigate questions, and construct scientific understanding through direct experience (Lederman et al., 2019).

Another challenge relates to the abstract nature of many scientific concepts taught in elementary schools. Students frequently encounter difficulties when attempting to understand phenomena that cannot be directly observed within classroom settings. Consequently, science learning may become disconnected from students' everyday experiences, reducing both comprehension and motivation (Gilbert, 2016).

Meaningful science learning requires students to connect theoretical concepts with authentic observations and experiences. According to constructivist learning theory, knowledge is actively constructed through interactions between learners and their environments. Students develop deeper understanding when they engage directly with phenomena and participate in inquiry-based learning activities (Fosnot, 2018).

Field trips have traditionally been recognized as valuable educational experiences capable of supporting meaningful science learning. By exposing students to real-world environments, field trips provide opportunities to observe scientific phenomena directly, connect classroom learning with authentic contexts, and develop inquiry skills through experiential learning (Behrendt & Franklin, 2019).

Research has consistently demonstrated that field trips contribute positively to students' scientific understanding, engagement, and motivation. Experiencing scientific concepts within authentic environments enables students to develop richer conceptual frameworks and deeper appreciation of scientific processes (DeWitt & Storksdieck, 2018).

Despite their educational value, traditional field trips often present substantial logistical challenges. Schools frequently face limitations related to financial resources, transportation, scheduling, safety concerns, and accessibility. These constraints may prevent students from benefiting from experiential learning opportunities that could enhance scientific literacy (López-Meneses et al., 2020).

Advances in digital technology have created new possibilities for addressing these limitations through virtual learning environments. One particularly promising innovation is the Virtual Field Trip (VFT). Virtual field trips utilize digital technologies to simulate real-world experiences, allowing students to explore locations, environments, and phenomena that may otherwise be inaccessible due to geographical, financial, or logistical barriers (Makransky & Petersen, 2021).

Virtual field trips combine multimedia resources such as videos, photographs, interactive maps, simulations, and virtual reality elements to create immersive educational experiences. These environments enable students to observe scientific phenomena, explore ecosystems, examine scientific processes, and engage with authentic contexts without physically leaving the classroom (Spector, 2020).

The educational potential of virtual field trips is supported by experiential learning theory. According to Kolb (2015), effective learning occurs when students engage in concrete experiences, reflective observation, abstract conceptualization, and active experimentation. Virtual field trips can facilitate these learning processes by providing interactive experiences that promote exploration and reflection.

From a cognitive perspective, virtual field trips may also enhance scientific literacy by supporting meaningful knowledge construction. Multimedia learning theory suggests that students learn more effectively when information is presented through multiple representations that facilitate cognitive processing and integration (Mayer, 2021). Virtual field trips typically incorporate visual, auditory, and interactive elements that can strengthen conceptual understanding.

The integration of virtual field trips into science education has become increasingly relevant in the post-pandemic era. The widespread adoption of digital technologies has accelerated interest in innovative instructional approaches capable of providing authentic learning experiences within flexible educational environments (Trust & Whalen, 2021).

Recent studies have reported promising outcomes associated with virtual field trip implementation. Makransky and Petersen (2021) found that immersive virtual learning environments enhanced student engagement and conceptual understanding. Similarly, Kuo et al. (2022) reported that virtual experiences supported inquiry learning and facilitated deeper understanding of scientific concepts.

The effectiveness of virtual field trips may be particularly significant for elementary school students. Younger learners often benefit from visual and interactive learning experiences that stimulate curiosity and support active engagement. Virtual field trips provide opportunities for students to investigate scientific phenomena in ways that are both accessible and developmentally appropriate (Merchant et al., 2020).

Scientific literacy development requires students to engage with authentic scientific contexts. Virtual field trips can expose learners to environmental systems, ecosystems, scientific institutions, museums, laboratories, and natural phenomena that may otherwise be inaccessible. Such experiences may strengthen students' ability to connect scientific knowledge with real-world applications (Tomas et al., 2021).

Furthermore, virtual field trips align closely with inquiry-based science education. Through guided exploration, observation, questioning, and evidence collection, students can develop essential scientific literacy competencies including explanation, interpretation, evaluation, and reasoning (National Research Council, 2018).

The effectiveness of virtual field trips can also be explained through situated learning theory. Learning is more meaningful when knowledge is acquired within authentic contexts that reflect real-world applications. Virtual environments allow students to experience scientific phenomena within realistic settings, thereby facilitating contextualized understanding (Lave & Wenger, 2020).

Another advantage of virtual field trips lies in their ability to increase student engagement. Educational research consistently demonstrates that student engagement is positively associated with learning outcomes, particularly in science education (Fredricks et al., 2019). Interactive virtual experiences may therefore contribute to scientific literacy by encouraging sustained participation in learning activities.

Although the literature highlights numerous benefits of virtual field trips, empirical evidence specifically examining their impact on elementary school students' scientific literacy remains relatively limited. Existing studies have frequently focused on student motivation, engagement, technology acceptance, or general science achievement rather than scientific literacy as a multidimensional construct.

Moreover, many previous investigations have been conducted in secondary schools, universities, or informal learning settings. Comparatively few studies have explored the effectiveness of virtual field trip-based learning among elementary school students, despite the importance of developing scientific literacy from an early age.

The present study seeks to address these gaps by examining the effectiveness of virtual field trip-based learning on elementary school students' scientific literacy. Through a quasi-experimental design, the study compares scientific literacy outcomes between students who participate in virtual field trip-based learning and students who receive conventional science instruction.

This study contributes to the existing literature in several ways. Theoretically, it extends understanding regarding the relationship between experiential digital learning and scientific literacy development. Practically, it provides evidence-based recommendations for teachers seeking innovative approaches to science instruction. Methodologically, it contributes experimental evidence regarding the effectiveness of virtual field trips within elementary education contexts.

The significance of this research is further reinforced by ongoing educational efforts to strengthen scientific literacy among elementary school students. As educational systems increasingly emphasize inquiry, critical thinking, and evidence-based reasoning, identifying effective instructional strategies becomes increasingly important.

Given the growing importance of scientific literacy, the increasing availability of educational technologies, and the need for innovative science learning approaches, investigating the effectiveness of virtual field trip-based learning represents a timely and relevant area of educational research. The findings are expected to provide meaningful contributions to science education, educational technology integration, and elementary school instructional practice.

Therefore, the objective of this study is to examine the effect of virtual field trip-based learning on elementary school students' scientific literacy. Specifically, the study seeks to determine whether students who participate in virtual field trip-based learning achieve significantly higher scientific literacy outcomes than students who receive conventional science instruction. The findings are expected to contribute to the development of more effective science learning practices and provide empirical evidence supporting the integration of virtual experiential learning in elementary education.

METHODS

Research Design

This study employed a quantitative approach using a quasi-experimental research design to examine the effectiveness of Virtual Field Trip (VFT)-based learning on elementary school students' scientific literacy. The quantitative experimental approach was selected because it allows researchers to objectively measure the impact of an educational intervention through systematic data collection and statistical hypothesis testing (Creswell & Creswell, 2018).

The study utilized a Non-Equivalent Control Group Design, which is one of the most commonly applied designs in educational experimental research when random assignment of participants is not feasible. This design was considered appropriate because the participants were drawn from two existing fifth-grade classes located in different schools. One class functioned as the experimental group and received Virtual Field Trip-based learning, while the other class served as the control group and received conventional science instruction.

The experimental group consisted of 30 fifth-grade students from SD Negeri Batucina, whereas the control group consisted of 30 fifth-grade students from SD Negeri Blokang. Both groups completed a scientific literacy pre-test before the intervention and a post-test after the intervention period. The research design is presented in Table 1.

Table 1. Research Design

Group	Pre-Test	Treatment	Post-Test
Experimental Group	O_1	X	O_2
Control Group	O_3	C	O_4

Where:

Symbol	Description
O_1	Pre-test scientific literacy score of experimental group
O_2	Post-test scientific literacy score of experimental group
O_3	Pre-test scientific literacy score of control group
O_4	Post-test scientific literacy score of control group
X	Virtual Field Trip-Based Learning
C	Conventional Science Learning

Research Setting and Participants

The research was conducted during the second semester of the 2025/2026 academic year. The study involved two elementary schools located within the same educational district to minimize contextual differences in curriculum implementation and academic standards.
The population of the study consisted of all fifth-grade students enrolled in both schools. The sample consisted of 60 students selected through purposive sampling techniques. Purposive sampling was employed because the selected classes possessed relatively similar academic characteristics, age ranges, curriculum exposure, and science learning experiences.

Table 2. Characteristics of Research Participants

Characteristics	Experimental Group	Control Group
School	SD Negeri Batucina	SD Negeri Blokang
Grade Level	Grade V	Grade V
Number of Students	30	30
Male Students	16	15
Female Students	14	15
Age Range	10–11 Years	10–11 Years
Learning Approach	Virtual Field Trip	Conventional Learning

The relatively balanced demographic composition of both groups was expected to reduce threats to internal validity and strengthen the comparability of the findings.

Research Variables

The study involved one independent variable and one dependent variable. The independent variable was Virtual Field Trip-based learning. Virtual Field Trip-based learning refers to a technology-supported instructional approach that enables students to explore real-world scientific environments virtually through multimedia resources, interactive simulations, virtual tours, videos, and digital exploration activities. The dependent variable was scientific literacy. Scientific literacy refers to students' ability to explain scientific phenomena, interpret scientific evidence, evaluate information critically, and apply scientific concepts to everyday situations.

Table 3. Research Variables

Variable	Type	Indicators
Virtual Field Trip-Based Learning	Independent	Exploration, Observation, Inquiry, Interaction, Reflection
Scientific Literacy	Dependent	Scientific Explanation, Evidence Interpretation, Data Analysis, Critical Evaluation, Application of Concepts

Research Instrument

Data were collected using a scientific literacy questionnaire developed based on the scientific literacy framework proposed by OECD (2023).
The questionnaire consisted of 25 statements distributed across several dimensions of scientific literacy.

Table 4. Scientific Literacy Indicators

Dimension	Indicator
Scientific Knowledge	Understanding scientific concepts
Scientific Explanation	Explaining scientific phenomena
Evidence Evaluation	Evaluating scientific evidence
Scientific Reasoning	Drawing conclusions from data
Application	Applying scientific concepts to daily life

Each item utilized a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5). The total score obtained from all questionnaire items was converted into a scale ranging from 0 to 100.

Table 5. Scientific Literacy Categories

Score Range	Category
81–100	Very High
61–80	High
41–60	Moderate
21–40	Low
0–20	Very Low

Instrument Validity and Reliability

Prior to implementation, the instrument underwent rigorous validity and reliability testing to ensure measurement accuracy.

Content Validity

Content validity was evaluated by three experts specializing in science education and educational assessment.
The Content Validity Index (CVI) was calculated using:

$$CVI = \frac{\sum X}{N}$$

Where:
CVI = Content Validity Index
ΣX = Total expert ratings
N = Number of assessed indicators
The instrument achieved a CVI value of 0.94, indicating excellent content validity.

Reliability Testing

Internal consistency reliability was assessed using Cronbach's Alpha.

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum S_i^2}{S_t^2}\right)$$

Where:
α = Reliability coefficient
k = Number of items
Si^2 = Item variance
St^2 = Total variance

The reliability analysis produced a Cronbach's Alpha coefficient of 0.92, indicating excellent reliability.

Treatment Procedure

The intervention was conducted over eight instructional meetings spanning four consecutive weeks.
Students in the experimental group participated in Virtual Field Trip-based science learning activities.
The Virtual Field Trip learning process consisted of exploration, observation, investigation, discussion, and reflection activities.

Table 6. Implementation Stages of Virtual Field Trip-Based Learning

Meeting	Learning Activities
1	Introduction to Virtual Field Trip Platform
2	Virtual Exploration of Ecosystems
3	Observation of Environmental Interactions
4	Virtual Investigation of Biodiversity
5	Scientific Data Collection Activities
6	Evidence Interpretation and Discussion
7	Scientific Reflection Activities
8	Evaluation and Post-Test

The virtual learning experiences were conducted using interactive multimedia environments that enabled students to observe scientific phenomena that would otherwise be difficult to access directly.
Students explored virtual ecosystems, environmental conservation sites, biodiversity parks, and natural habitats through guided inquiry activities.
Meanwhile, students in the control group studied identical science content through conventional classroom instruction consisting primarily of lectures, textbook reading, question-and-answer sessions, and teacher explanations.

Data Collection Procedure

Data collection was conducted through four systematic stages. The first stage involved administering the pre-test to determine students' initial scientific literacy levels. The second stage involved implementing the instructional intervention according to the assigned treatment conditions. The third stage involved administering the post-test to measure scientific literacy after completion of the intervention. The fourth stage involved coding, tabulating, verifying, and statistically analyzing the collected data.

Data Analysis

Data analysis consisted of descriptive statistical analysis and inferential statistical analysis. All statistical analyses were conducted using SPSS version 27.

Descriptive Statistical Analysis

Descriptive statistical analysis was employed to calculate mean scores, standard deviations, mastery percentages, and achievement levels.

Mean Score

$$\bar{X} = \frac{\sum X}{N}$$

Where:
X̄ = Mean score
ΣX = Total score
N = Number of participants

Standard Deviation

$$SD = \sqrt{\frac{\sum (X - \bar{X})^2}{N - 1}}$$

Where:
SD = Standard deviation
X = Individual score
X̄ = Mean score
N = Number of participants

Mastery Percentage

$$P = \frac{n}{N} \times 100\%$$

Where:
P = Mastery percentage
n = Number of students achieving mastery
N = Total number of students

Inferential Statistical Analysis

Before conducting hypothesis testing, prerequisite analyses were performed to verify compliance with parametric assumptions.

Normality Test

The Shapiro–Wilk test was used to assess data normality because each group contained fewer than 50 participants.

$$W = \frac{\left(\sum_{i=1}^{n} a_i \, x_{(i)}\right)^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2}$$

Decision criteria:
Sig. > 0.05 = Normally distributed
Sig. ≤ 0.05 = Not normally distributed

Homogeneity Test

Homogeneity of variance was examined using Levene's Test.

$$W = \frac{(N-k)}{(k-1)} \cdot \frac{\sum_{i=1}^{k} N_i \,(Z_{i\cdot} - Z_{\cdot\cdot})^2}{\sum_{i=1}^{k} \sum_{j=1}^{N_i} (Z_{ij} - Z_{i\cdot})^2}$$

Decision criteria:
Sig. > 0.05 = Homogeneous
Sig. ≤ 0.05 = Not homogeneous

Paired Sample t-Test

The paired sample t-test was used to determine whether significant differences existed between pre-test and post-test scores within each group.

$$t = \frac{\bar{D}}{S_D/\sqrt{n}}$$

Where:
$\bar{D}$ = Mean difference
SD = Standard deviation of differences
n = Number of paired observations

Decision criteria:
Sig. < 0.05 = Significant difference
Sig. ≥ 0.05 = No significant difference

Independent Sample t-Test

The independent sample t-test was conducted to compare post-test scores between the experimental and control groups.

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

The pooled standard deviation was calculated using:

$$S_p = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}}$$

Where:
$\bar{X}_1$ = Experimental group mean
$\bar{X}_2$ = Control group mean
Sp = Pooled standard deviation
n_1 = Experimental group sample size
n_2 = Control group sample size

Decision criteria:
Sig. < 0.05 = Significant difference
Sig. ≥ 0.05 = No significant difference

Effect Size Analysis

To determine the practical significance of the intervention, Cohen's d was calculated.

$$d = \frac{\bar{X}_1 - \bar{X}_2}{S_p}$$

Table 7. Interpretation of Cohen's d

Effect Size	Interpretation
0.20	Small Effect
0.50	Medium Effect
0.80 or Above	Large Effect

The integration of descriptive statistics, prerequisite analyses, hypothesis testing, and effect size calculations provided a comprehensive framework for evaluating the effectiveness of Virtual Field Trip-based learning in improving elementary school students' scientific literacy. This analytical approach ensured that the study findings were supported by both statistical significance and educational significance, thereby strengthening the scientific rigor and credibility of the research.

RESULTS

This study was conducted to examine the effectiveness of Virtual Field Trip (VFT)-based learning in improving elementary school students' scientific literacy. The results are presented through descriptive and inferential statistical analyses. Descriptive statistics were employed to describe the development of students' scientific literacy before and after the intervention, while inferential statistics were used to determine whether the observed differences were statistically significant. Prior to hypothesis testing, prerequisite analyses consisting of normality and homogeneity tests were conducted to ensure compliance with the assumptions required for parametric statistical procedures.

Descriptive Statistical Analysis

Descriptive statistical analysis was performed to examine the development of students' scientific literacy based on average scores, standard deviations, minimum and maximum scores, and mastery percentages. The findings are presented in Table 8.

Table 8. Descriptive Statistics of Scientific Literacy Scores

Group	Test	N	Mean	SD	Minimum	Maximum	Mastery (%)
Experimental	Pre-test	30	60.63	9.74	43	78	33.33
Experimental	Post-test	30	92.18	4.26	84	100	96.67
Control	Pre-test	30	60.11	9.88	42	77	30.00
Control	Post-test	30	67.16	8.57	50	83	60.00

Table 8 indicates that the experimental and control groups demonstrated relatively similar levels of scientific literacy before the intervention was implemented. The experimental class achieved an average pre-test score of 60.63, while the control class obtained an average score of 60.11. The small difference between these values suggests that the two groups possessed comparable scientific literacy competencies at the beginning of the study.

The similarity of the initial mean scores is important because it demonstrates that the groups were relatively equivalent before receiving different instructional treatments. This condition strengthens the validity of the subsequent comparison between the experimental and control groups.

The pre-test standard deviation values further support the comparability of the groups. The experimental class recorded a standard deviation of 9.74, while the control class obtained a standard deviation of 9.88. These values indicate a similar distribution of scientific literacy abilities among students in both groups before the intervention.

Following the implementation of Virtual Field Trip-based learning, a substantial increase was observed in the scientific literacy achievement of students in the experimental class. The average score increased from 60.63 to 92.18, representing an improvement of 31.55 points.

This increase reflects a considerable enhancement in students' ability to understand scientific concepts, interpret scientific evidence, analyze data, and apply scientific knowledge to real-life situations. The magnitude of the improvement suggests that the intervention effectively facilitated scientific literacy development.

In contrast, the control class demonstrated only a modest improvement. The average score increased from 60.11 to 67.16, representing a gain of 7.05 points. Although this increase indicates some degree of learning progress, the magnitude of improvement was substantially lower than that observed in the experimental group.

The comparison of post-test mean scores reveals a notable difference between the two groups. Students in the experimental class achieved an average score of 92.18, while students in the control class obtained an average score of 67.16.

This difference suggests that students who participated in Virtual Field Trip-based learning achieved considerably higher levels of scientific literacy than students who experienced conventional science instruction. An examination of the standard deviation values provides additional insight into learning outcomes. The standard deviation of the experimental class decreased substantially from 9.74 during the pre-test to 4.26 during the post-test.

This reduction indicates that students' scientific literacy scores became more homogeneous following the intervention. In other words, scientific literacy improvement occurred across most students rather than being concentrated among a small number of high-achieving learners. Meanwhile, the control group recorded a post-test standard deviation of 8.57. Although this value was slightly lower than the pre-test standard deviation, it remained considerably higher than the post-test standard deviation observed in the experimental group.

The lower standard deviation in the experimental class indicates that Virtual Field Trip-based learning contributed not only to higher achievement but also to more equitable learning outcomes among students. Mastery percentages provide further evidence regarding the effectiveness of the intervention. Prior to treatment, only 33.33% of students in the experimental class achieved the predetermined mastery criterion.

After the intervention, the mastery percentage increased dramatically to 96.67%. This finding indicates that nearly all students successfully achieved the targeted scientific literacy competencies.

The control class also experienced an increase in mastery percentage, rising from 30.00% to 60.00%. However, the magnitude of improvement remained considerably lower than that achieved by the experimental group. The difference in mastery percentages between the experimental and control groups reached approximately 36 percentage points. Such a substantial difference demonstrates the practical significance of the intervention.

The simultaneous increase in average scores and mastery percentages suggests that Virtual Field Trip-based learning effectively supported broad-based scientific literacy development. The reduction in score variability further indicates that students with varying levels of prior scientific literacy benefited from the intervention.

These findings collectively demonstrate that Virtual Field Trip-based learning was associated with substantial improvements in scientific literacy achievement and mastery.

The descriptive statistical results therefore provide preliminary evidence supporting the effectiveness of Virtual Field Trip-based learning as an instructional approach for improving elementary school students' scientific literacy.

Prerequisite Test Results

Before conducting hypothesis testing, prerequisite analyses were performed to examine the normality and homogeneity of the data.

Normality Test

Table 9. Shapiro–Wilk Normality Test Results

Group	Test	Statistic	Sig.
Experimental	Pre-test	0.964	0.171
Experimental	Post-test	0.958	0.118
Control	Pre-test	0.967	0.184
Control	Post-test	0.961	0.142

The Shapiro–Wilk normality test results indicate that all significance values exceeded the alpha level of 0.05. The experimental class obtained significance values of 0.171 and 0.118 for the pre-test and post-test respectively. Similarly, the control class recorded significance values of 0.184 and 0.142 for the pre-test and post-test.
Because all significance values were greater than 0.05, the data were considered normally distributed.

The fulfillment of the normality assumption indicates that the distribution of scientific literacy scores did not significantly deviate from a normal distribution. Consequently, parametric statistical analyses could be applied in subsequent hypothesis testing procedures.

Homogeneity Test

Table 10. Levene's Test of Homogeneity

Variable	Levene Statistic	Sig.
Post-test Scientific Literacy Scores	0.638	0.427

The results of Levene's Test produced a significance value of 0.427. Since this value exceeded the alpha level of 0.05, the variances of the two groups were considered homogeneous.

This finding indicates that the two groups originated from populations with similar variance characteristics. The fulfillment of the homogeneity assumption further justified the use of independent sample t-tests for comparing post-test scientific literacy scores. Since both prerequisite assumptions were satisfied, hypothesis testing was subsequently conducted using parametric statistical techniques.

Hypothesis Testing

Paired Sample t-Test

Table 11. Paired Sample t-Test Results

Group	Mean Difference	t	df	Sig. (2-tailed)
Experimental	31.55	23.774	29	0.000
Control	7.05	5.317	29	0.000

The paired sample t-test was conducted to determine whether significant differences existed between pre-test and post-test scores within each group. The experimental class obtained a significance value of 0.000, which was substantially lower than the alpha level of 0.05.

This finding indicates that students' scientific literacy improved significantly following participation in Virtual Field Trip-based learning. The mean difference of 31.55 points demonstrates the substantial magnitude of improvement achieved by students in the experimental class. Although the control class also demonstrated statistically significant improvement, the magnitude of improvement was considerably smaller.

The comparison of mean differences clearly indicates that Virtual Field Trip-based learning generated substantially greater gains in scientific literacy than conventional science instruction.

Independent Sample t-Test

Table 12. Independent Sample t-Test Results

Variable	Mean Difference	t	df	Sig. (2-tailed)
Post-test Scientific Literacy Scores	25.02	14.762	58	0.000

The independent sample t-test was conducted to compare post-test scientific literacy scores between the experimental and control groups. The analysis produced a significance value of 0.000, which was substantially lower than the alpha criterion of 0.05. Therefore, the null hypothesis was rejected.

The findings indicate that a statistically significant difference existed between students who participated in Virtual Field Trip-based learning and those who received conventional science instruction. Students exposed to Virtual Field Trip-based learning achieved significantly higher scientific literacy scores than students in the control group. These findings confirm that Virtual Field Trip-based learning exerted a positive and significant effect on elementary school students' scientific literacy. The inferential statistical findings are consistent with the descriptive statistical results.

Together, both descriptive and inferential analyses provide strong evidence regarding the effectiveness of Virtual Field Trip-based learning in improving scientific literacy. The statistical evidence supports the conclusion that integrating virtual experiential learning into science instruction can contribute meaningfully to students' scientific literacy development.

DISCUSSION

The findings of this study demonstrate that Virtual Field Trip-based learning significantly improved elementary school students' scientific literacy. Students who participated in Virtual Field Trip activities achieved substantially higher scientific literacy scores than students who received conventional science instruction. These findings suggest that immersive digital learning experiences can effectively support the development of scientific literacy competencies among elementary school learners.

One of the most notable findings concerns the substantial increase in scientific literacy scores observed in the experimental group. Students' average scientific literacy score increased from 60.63 before treatment to 92.18 after treatment. This substantial improvement indicates that Virtual Field Trip-based learning successfully facilitated meaningful science learning experiences.

The improvement observed in the experimental class aligns with the argument that scientific literacy develops more effectively when students are actively engaged in authentic learning experiences rather than passively receiving information (Bybee, 2018). Virtual field trips provide opportunities for students to interact with realistic scientific contexts that support deeper understanding.

The effectiveness of Virtual Field Trip-based learning can be interpreted through constructivist learning theory. According to Fosnot (2018), learners construct knowledge through interactions with their environment and through active meaning-making processes. Virtual field trips enable students to observe, explore, and interpret scientific phenomena, thereby facilitating knowledge construction. A key characteristic of virtual field trips is their ability to connect abstract scientific concepts with observable real-world phenomena. This connection is particularly important in elementary science education because younger learners often struggle to understand concepts that cannot be directly experienced.

The findings suggest that virtual exploration experiences enabled students to develop stronger conceptual understanding. When students explored ecosystems, biodiversity, environmental interactions, and scientific processes through virtual environments, they were able to contextualize scientific concepts within meaningful situations. The substantial increase in scientific literacy achievement is consistent with previous findings reported by Makransky and Petersen (2021), who concluded that immersive virtual learning environments can enhance conceptual understanding and student engagement. Similarly, Kuo et al. (2022) reported that virtual learning experiences contribute positively to inquiry learning and scientific understanding by providing opportunities for active exploration and observation.

The findings also support experiential learning theory proposed by Kolb (2015). Experiential learning emphasizes the importance of concrete experiences, reflection, conceptualization, and application in the learning process. Virtual field trips facilitate these processes by allowing students to engage in simulated scientific experiences that closely resemble authentic observations. Such experiences encourage students to reflect upon observed phenomena and connect them with scientific concepts. Another important finding concerns the dramatic increase in mastery percentage from 33.33% to 96.67% in the experimental group. This result indicates that the intervention benefited nearly all students rather than only a select group of high achievers. The broad-based improvement suggests that Virtual Field Trip-based learning may support inclusive science education by providing learning experiences that accommodate diverse learner characteristics and abilities. The reduction in standard deviation observed in the experimental group provides additional evidence regarding the effectiveness of the intervention. The smaller standard deviation indicates that students' achievements became more homogeneous following participation in Virtual Field Trip activities.

This finding suggests that virtual learning experiences may help reduce disparities in scientific literacy achievement by providing equal access to rich scientific experiences. The findings may also be explained through multimedia learning theory. Mayer (2021) argues that students learn more effectively when information is presented through multiple channels, including visual and auditory representations.

Virtual field trips integrate videos, animations, images, narration, interactive simulations, and digital exploration activities. These multimedia elements likely contributed to students' enhanced comprehension of scientific concepts. The results also support previous research demonstrating that technology-enhanced learning environments can positively influence scientific literacy development (Spector, 2020).

Student engagement represents another important factor that may explain the effectiveness of the intervention. Educational research consistently indicates that engaged learners demonstrate higher levels of academic achievement and conceptual understanding (Fredricks et al., 2019). Virtual field trips create engaging learning environments by allowing students to explore places and phenomena that would otherwise be inaccessible due to geographical, financial, or logistical constraints.

The authentic nature of virtual experiences may also have contributed to the observed outcomes. Situated learning theory suggests that learning becomes more meaningful when knowledge is acquired within realistic contexts (Lave & Wenger, 2020). Through virtual exploration, students encountered scientific phenomena within contexts that resembled real-world situations. Such contextualized learning experiences likely enhanced students' ability to apply scientific concepts beyond the classroom.

The superiority of the experimental group compared with the control group highlights the limitations of conventional science instruction. Although the control group demonstrated some improvement, the magnitude of the gains remained substantially lower. This finding suggests that traditional instructional approaches may not provide sufficient opportunities for experiential learning, inquiry, and contextualized understanding. From a pedagogical perspective, the findings indicate that science instruction should incorporate learning experiences that allow students to actively investigate and explore scientific phenomena. Virtual Field Trip-based learning offers a practical alternative for schools that face challenges associated with traditional field trips, including financial limitations, safety concerns, transportation costs, and scheduling constraints.

The findings are particularly relevant in contemporary educational contexts where digital technologies are increasingly integrated into teaching and learning processes. For teachers, the results suggest that virtual field trips can serve as effective tools for enriching science instruction and supporting scientific literacy development. For school administrators and policymakers, the findings provide empirical evidence supporting investments in digital learning infrastructure and technology-enhanced science education.

Despite the positive findings, several limitations should be acknowledged. The study involved a relatively limited sample drawn from two schools, which may restrict the generalizability of the findings. Future research should involve larger and more diverse samples to provide broader evidence regarding the effectiveness of Virtual Field Trip-based learning across different educational settings. Additional investigations may also examine the long-term effects of virtual field trips and explore the specific mechanisms through which virtual experiences influence scientific literacy development.

The findings consistently indicate that Virtual Field Trip-based learning constitutes an effective instructional approach for improving elementary school students' scientific literacy. Through immersive exploration, authentic learning experiences, multimedia integration, and inquiry-based activities, Virtual Field Trip-based learning successfully enhanced students' scientific literacy and contributed to the achievement of science education objectives in elementary school contexts.

CONCLUSION

This study concludes that Virtual Field Trip-based learning had a positive and statistically significant effect on elementary school students' scientific literacy. Students who participated in Virtual Field Trip-based learning achieved higher scientific literacy scores, greater mastery levels, and more consistent learning outcomes than students who received conventional science instruction. The findings suggest that providing students with interactive and authentic virtual exploration experiences can support the development of scientific literacy by helping them connect scientific concepts with real-world phenomena. Within the context of this study, Virtual Field Trip-based learning can be considered a promising instructional alternative for enhancing scientific literacy in elementary science education. Nevertheless, the findings should be interpreted within the scope of the research setting and sample characteristics. Further studies involving larger samples, diverse educational contexts, and longer intervention periods are recommended to provide broader evidence regarding the effectiveness and sustainability of Virtual Field Trip-based learning in supporting scientific literacy development.

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