

The Effect of Interactive Digital Diorama Media on Fifth-Grade Students' Learning Outcomes in Marine Ecosystem Topics

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ABSTRACT

Background: This investigation evaluated the instructional impact of interactive digital dioramas on fifth-grade elementary students' academic achievement in marine ecosystem concepts. **Methodology:** Employing a quantitative approach within a quasi-experimental pretest-posttest control group design, the study involved 62 fifth-grade pupils partitioned equally into experimental and control cohorts. Empirical data gathered via pretest and posttest instruments were evaluated through descriptive metrics, diagnostic tests for distributional normality and variance homogeneity, and inferential testing using an Independent-Samples *t*-test. **Findings:** Inferential results confirmed a statistically significant divergence in academic attainment between the two conditions, with the experimental cohort attaining a substantially higher post-intervention mean score than the control group. Hypothesis testing yielded a significance value of $p = 0.000$ ($p < 0.05$), substantiating that digital diorama integration exerts a significant positive effect on student learning outcomes. Furthermore, effect size calculations demonstrated a profound practical impact, evidenced by a Cohen's *d* coefficient of 2.391 and an Eta-Squared (η^2) value of 0.596. Normalized Gain (*N-Gain*) indices similarly reflected superior learning progression in the experimental class relative to the control group. These empirical insights indicate that digital diorama technology aids conceptual acquisition by translating abstract scientific phenomena into concrete, interactive, and contextual visual representations. **Contribution:** Consequently, interactive digital dioramas represent an effective pedagogical innovation for enhancing primary science instruction.

Keywords: Digital diorama media; Interactive visual media; Learning outcomes; Marine ecosystem; Science learning



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INTRODUCTION

Elevating the caliber of primary-level science education remains a fundamental imperative for cultivating future generations capable of critical inquiry, analytical reasoning, and evidence-driven decision-making. This objective directly aligns with the framework of the Merdeka Curriculum, which positions learners as active agents who construct knowledge through contextual educational experiences. Consequently, the instruction of Natural and Social Sciences (IPAS) must transcend mere rote memorization, shifting its primary focus toward fostering scientific reasoning, problem-solving proficiencies, and the capacity to link abstract principles with real-world phenomena. Student learning outcomes which serve as critical metrics of instructional success reflect the fulfillment of these competencies. To realize these goals, educators are increasingly required to adopt student-centered, contextualized pedagogical strategies and instructional tools tailored to the cognitive developmental profiles of primary school pupils (Nurmia et al., 2025; Siregar, 2024).

Among the various domain-specific topics within the IPAS framework, the study of marine ecosystems poses unique pedagogical challenges. Mastering this topic necessitates a comprehensive grasp of the intricate, reciprocal dynamics between biotic and abiotic variables, along with the symbiotic interactions that sustain ecological equilibrium (Febrian et al., 2025). The inherent complexity of this subject stems largely from the non-observable nature of marine phenomena within a standard classroom setting. When instruction relies predominantly on traditional verbal explanations or static two-dimensional visual representations, learners frequently struggle to form accurate mental models. Indeed, deficiencies in student comprehension regarding marine environments are closely linked to the underutilization of instructional tools capable of presenting concrete, realistic representations of natural phenomena (Agustira & Rahmi, 2022). This pedagogical bottleneck was similarly observed during preliminary field investigations at SDN Jagakarsa 03 Pagi. Instruction remained heavily dependent on conventional textbooks and static presentation tools, forcing pupils to memorize abstract concepts passively without grasping the underlying functional relationships within the ecosystem, ultimately yielding suboptimal academic performance.

Addressing this instructional gap demands the integration of innovative educational technology capable of translating complex phenomena into concrete, tangible, and contextualized learning experiences (Nurhidayati, 2024). Interactive digital dioramas offer a promising solution by providing three-dimensional representations of marine habitats. This medium allows learners to examine ecological features in detail, thereby facilitating a more intuitive grasp of inter-component ecosystem dynamics through lifelike visual immersion (Muchtar et al., 2023). By rendering abstract scientific concepts into concrete visual forms, diorama-based instruction substantially aids cognitive processing (Syahid et al., 2022). The theoretical foundation for this approach is grounded in Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2024), which posits that learning efficiency is optimized when information is presented simultaneously through complementary visual and auditory/verbal channels. This dual-channel processing enables pupils to construct

more organized, coherent mental representations, providing a robust theoretical rationale for employing digital dioramas in visual-heavy IPAS curricula.

Prior empirical literature consistently demonstrates that interactive visual technologies yield substantial benefits for both classroom engagement and academic attainment (Destyaningrum & Arini, 2023). Interactive visual formats significantly enhance conceptual retention by rendering complex subject matter accessible and visually stimulating (Fitriyani, 2024). Furthermore, diorama-based learning tools have been shown to improve academic outcomes directly (Qurrotaini et al., 2024) while simultaneously bolstering student motivation and active participation (Puspita et al., 2025). Nevertheless, existing scholarship has predominantly focused on physical, non-digital dioramas or general media development frameworks. Empirical inquiries that rigorously quantify the specific instructional efficacy of interactive digital dioramas for marine ecosystem topics through rigorous experimental designs remain scarce (Nugraha et al., 2025).

To bridge this empirical gap, the present study evaluates the pedagogical impact of interactive digital dioramas in primary-level IPAS marine ecosystem instruction using a pretest-posttest control group design (Purwanti et al., 2025). Distinct from prior works centered on physical artifacts or product design pipelines, this research employs a quasi-experimental methodology to evaluate the direct effect of digital diorama intervention on student academic outcomes. Here, the proposition that digital dioramas enhance learning quality represents the central hypothesis under empirical testing, whereas the general educational benefits of digital media proposed by (Gagasi et al., 2026) serve as the overarching conceptual framework rather than a research finding. Accordingly, this investigation aims to determine the effect of interactive digital diorama media on the learning outcomes of fifth-grade elementary students studying marine ecosystems. The empirical insights generated from this research are intended to advance the literature on digital technology integration in primary science education, while offering practitioners an empirically validated tool for student-centered learning.

METHOD

To evaluate the pedagogical impact of interactive digital dioramas on student achievement regarding marine ecosystem concepts, this research adopted a quantitative paradigm using a quasi-experimental methodology. The selection of this experimental framework directly serves the investigation's core aim: quantifying the causal relationship between the independent variable the integration of interactive digital dioramas (X) and the dependent variable student learning outcomes (Y). This methodological stance aligns with the principles outlined by (Sugiyono, 2022), who defines experimental research as a rigorous scientific mechanism for evaluating the precise magnitude of effect exerted by a specific treatment upon a target variable under controlled conditions.

The operational structure of this study implemented a Non-equivalent Pretest-Posttest Control Group Design, incorporating two distinct cohorts: an experimental group and a control group. Prior to the instructional intervention, both groups were subjected to a baseline assessment (O_1 and O_3) to establish pre-existing conceptual

competence. Following the completion of the instructional unit, a post-intervention assessment (O_2 and O_4) was administered to both cohorts. While the experimental group received instruction augmented by interactive digital dioramas (X), the control group underwent conventional instruction void of diorama integration. Comparative statistical analysis of the score gains between the baseline and post-intervention evaluations across both groups was conducted to gauge the magnitude of academic progression and determine the instructional efficacy of the digital diorama intervention.

Table 1. Pre-test, Post-test, Control Group Experimental Framework

Group	Pre-test	Treatment	Post-test
Experimental	O_1	X	O_2
Control	O_3	–	O_4

Notes: X = Instructional implementation utilizing interactive digital dioramas.

O_1 = Pre-test learning outcome score of the experimental cohort.

O_2 = Post-test learning outcome score of the experimental cohort.

O_3 = Pre-test learning outcome score of the control cohort.

O_4 = Post-test learning outcome score of the control cohort.

Population, Sample, and Research Location

This empirical investigation was executed at SDN Jagakarsa 03 Pagi, situated in South Jakarta. The target population encompassed the entire fifth-grade student body, which was organized into two parallel academic cohorts: Class V-A and Class V-B. Prior assessment confirmed that these two groups exhibited comparable educational baselines regarding curriculum delivery, thematic depth, and prevailing instructional routines within the institution.

To determine the study sample, a total sampling technique was deployed, thereby incorporating all 62 students across the target population. This census-based sampling approach was deemed optimal given the manageable size of the population and the uniform alignment of all participants with the pre-established inclusion criteria. In primary education research involving constrained participant pools, the utilization of total sampling within quasi-experimental frameworks is widely established and methodologically advocated (Farikhatin et al., 2024; Sukma & Handayani, 2022). The specific breakdown of the research population and cohort assignments is detailed in Table 2.

Table 2. Distribution of Research Population and Experimental Sample

Class	Role in the Study	Amount of Students	Instructional Intervention
V-A	Experimental Group	31	Digital Diorama Media
V-B	Control Group	31	Conventional Media
Total		62	

As outlined in Table 2, the final sample consisted of 62 participants distributed symmetrically into two equal cohorts: 31 students assigned to the experimental condition and 31 students designated as the control group. While the experimental class underwent instruction supported by interactive digital dioramas, the control class

received conventional instruction utilizing static slide presentations (PowerPoint). To maintain alignment with institutional operations, instruction in each class was delivered by its regular teacher in accordance with the school's official schedule. Notably, both cohorts were subjected to identical curricular contents, learning objectives, and instructional duration. This controlled division was structured to enable an objective, unconfounded comparison of post-intervention learning outcomes, thereby isolating and precisely measuring the pedagogical impact of the digital diorama treatment.

Diorama Media

The core intervention evaluated in this investigation comprises a digital diorama specifically engineered to model marine environmental systems within a three-dimensional visual environment. Developed and deployed via the Assemblr EDU platform accessible through both web browsers and mobile application interfaces (Android/iOS) this digital diorama enables learners to manipulate and interact directly with 3D spatial representations. The virtual environment meticulously depicts both biotic and abiotic marine elements, including coral reef systems, various fish species, sharks, cetaceans, benthic flora, and submarine topography. By rendering these elements in detail, the medium facilitates a more concrete observation of interspecies dynamics and ecological relationships (Syahid et al., 2022).

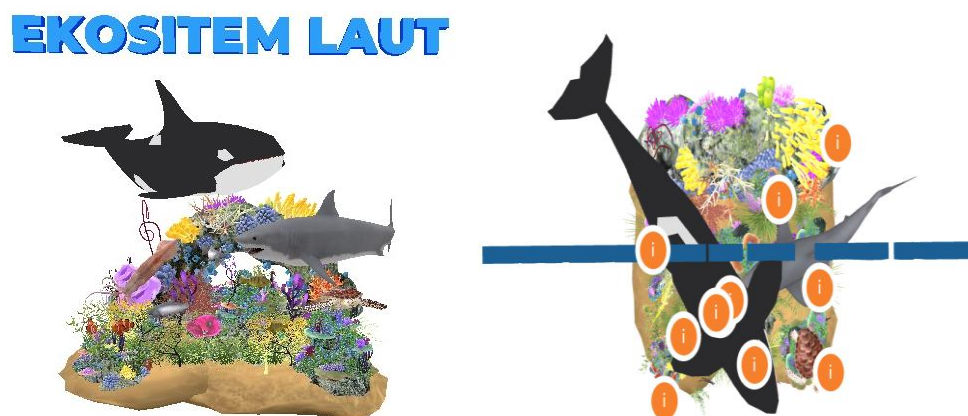


Figure 1. Digital Diorama Representation of the Marine Ecosystem

The selection of a digital diorama platform was driven by its capacity to translate intricate, highly abstract scientific concepts into intuitive, lifelike visual representations. Such interactive visual architectures have consistently been demonstrated to heighten sustained attentiveness, provoke scientific inquiry, and foster active student immersion across instructional sessions (Nurkamaliah et al., 2018).

During the classroom intervention, pupils engaged in inquiry-driven learning tasks that required them to navigate the digital diorama, catalog the biodiversity within the marine habitat, and analyze food web structures as well as symbiotic associations. The instructional deployment spanned two dedicated sessions, each with a duration of 35 minutes. Within these learning modules, students systematically analyzed the 3D models within the virtual diorama, collaborated in peer groups to address structured

inquiry prompts, and articulated their synthesis during plenary class presentations. This instructional framework was intentionally designed to promote learner autonomy, positioning the classroom instructor as a learning facilitator who guided exploratory activities and consolidated key conceptual takeaways (Winangsih & Harahap, 2023).

Research Instruments

The primary data collection tool deployed in this research comprised a 20-item objective multiple-choice assessment designed in alignment with the educational learning outcomes framework for marine ecosystems (Jannah et al., 2023). To go beyond mere factual recall and systematically evaluate higher-order cognitive capabilities, the test items were operationalized across the higher tiers of Bloom's Taxonomy, specifically spanning the Application (C3), Analysis (C4), and Evaluation (C5) domains. This structural design guaranteed that the instrument rigorously captured participants' scientific competencies and analytical problem-solving skills. The detailed mapping of test items across Bloom's cognitive taxonomy is presented in Table 3.

Table 3. Taxonomic Distribution of Cognitive Domains and Assessment Items

Cognitive Level	Competency Indicators & Material Scope	Valid Item Numbers	Total Items
Applying (C3)	Application of ecosystem balance principles, component interactions, and marine resource utilization.	1, 7, 8, 17, 18	5
Analyzing (C4)	Analysis of biotic/abiotic factors, food webs/chains, organismal ecological roles, and ecosystem dynamics.	4, 5, 6, 9, 10, 11, 12, 13, 14, 21, 25, 28	11
Evaluating (C5)	Assessment of anthropogenic impacts (e.g., overexploitation, pollution), conservation motives, and remediation strategies.	15, 16, 19, 20	4
Total			20

Prior to main data collection, the assessment tool underwent empirical pilot testing with a non-sample pilot cohort ($n= 31$) possessing demographic and educational attributes identical to the study sample. Performing pilot validation on an equivalent non-sample group represents an essential standard in empirical educational research to establish measurement validity and internal consistency (Supriyani et al., 2021).

Item validity was computed using Pearson's Product-Moment Correlation coefficient by benchmarking the calculated r -value (r_{count}) against the critical table value (r_{table}) at a $\alpha = 0.05$ significance threshold (Anitra et al., 2026). Assessment items demonstrating $r_{count} > r_{table}$ were classified as valid for deployment, whereas non-qualifying items were either structurally revised or excluded.

Subsequently, the overall internal consistency of the instrument was evaluated via Cronbach's Alpha coefficient using IBM SPSS software. The measurement tool was confirmed to possess high internal reliability as its Cronbach's Alpha statistic surpassed the standard acceptability threshold of 0.70, thereby ensuring temporal and conceptual consistency across repeated applications (Fitria & Suryanti, 2022).

Data Analysis Techniques

Quantitative evaluation of the empirical data was executed via IBM SPSS Statistics, encompassing both descriptive and inferential analytical frameworks. Descriptive metrics were initially computed to establish the data profiles, capturing baseline parameters such as arithmetic means, minimum and maximum ranges, and standard deviations. Subsequently, preliminary diagnostic checks were performed on both baseline (pre-test) and post-intervention (post-test) datasets, specifically utilizing the Shapiro-Wilk protocol for normality testing and Levene's test for variance homogeneity. The Shapiro-Wilk procedure was selected as the optimal normality test given that each study subgroup comprised fewer than 50 participants ($n < 50$). A significance threshold of $p > 0.05$ served as the criterion for confirming normal distribution, whereas homogeneity of variances across cohorts was established when Levene's test yielded $p > 0.05$. Satisfying both parametric assumptions confirmed the structural suitability of the dataset for downstream parametric inferential testing (Farikhatin et al., 2024).

Upon verifying that all parametric assumptions were satisfied, hypothesis testing was conducted via an Independent Samples t-test to contrast the academic achievements of the experimental and control cohorts. This inferential procedure was first applied to baseline pre-test scores to confirm initial cohort equivalence, and subsequently executed on post-test scores to identify significant post-intervention divergence. Statistical decisions were governed by a two-tailed significance criterion at $\alpha = 0.05$, wherein a significance value of $p < 0.05$ warranted the rejection of the null hypothesis and the acceptance of the alternative research hypothesis, indicating significant differences in student learning outcomes (Sukma & Handayani, 2022). Furthermore, to evaluate the specific instructional efficacy of the interactive digital diorama intervention, Normalized Gain (N-Gain) scores were calculated by gauging individual score gains from pre-test to post-test. The resulting N-Gain indices were subsequently mapped onto three standard interpretative tiers: high (reflecting optimal learning progression), moderate (indicating satisfactory improvement), and low (signifying constrained growth) (Ghozali, 2021).

To complement hypothesis testing and provide a nuanced interpretation of results, effect size metrics were computed to determine the practical magnitude of the intervention's impact on academic performance. Specifically, Cohen's d and Eta Squared (η^2) indices were calculated, ensuring the findings provided insights not merely regarding binary statistical significance, but also concerning the precise strength of the treatment effect. Cohen's d metrics were categorized into small, medium, and large effect sizes, whereas Eta Squared (η^2) quantified the proportional variance in learning outcome gains attributable to the digital diorama treatment (classified as small, medium, or large effect sizes). Integrating effect size metrics established a robust

empirical foundation for evaluating practical significance, thereby substantiating the intervention's value based on both statistical probability and tangible instructional impact.

Research Procedures

The execution of this investigation followed a systematic, three-phase operational workflow comprising preliminary preparation, classroom intervention, and post-experimental data analysis. In the initial preparation phase, activities concentrated on conducting preliminary field observations, formulating instructional modules, engineering the digital diorama software, and drafting the cognitive assessment instrument. This phase concluded with a pilot validation of the test items administered to a non-sample cohort of 31 participants.

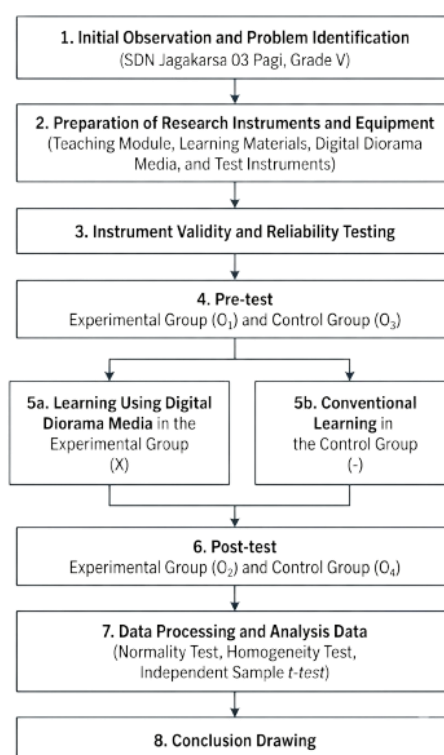


Figure 2. Methodological Flowchart of Research Procedures

The implementation stage commenced with the administration of baseline pre-tests to both the experimental and control cohorts to establish baseline conceptual performance. During the core intervention, the experimental group received instruction supported by interactive digital dioramas, whereas the control group was taught using standard static slide presentations (Padilaturrahmah et al., 2025). Following the completion of all instructional units, both groups underwent a post-intervention evaluation (post-test) to quantify final academic progress.

In the terminal phase of the study, the collected quantitative data were systematically tabulated and analyzed using IBM SPSS software. This analytical pipeline involved diagnostic checks for distributional normality and variance

homogeneity, followed by hypothesis testing via an Independent Samples t-test to derive empirical conclusions (Ghozali, 2021).

RESULTS AND DISCUSSION

Descriptive Statistics of the Data

Descriptive statistical evaluations were initially executed to map the distributional profile of student learning outcomes across both the experimental and control cohorts prior to and following instructional execution. Central tendency and dispersion parameters including arithmetic means, medians, modes, standard deviations, alongside minimum and maximum score boundaries were computed to establish baseline patterns and track performance progression across groups (Sugiyono, 2022). Table 4 synthesizes the complete descriptive statistical output for both experimental conditions.

Table 4. Descriptive Statistics for Baseline (Pre-test) and Post-Intervention (Post-test) Measures

Statistics	Control Class Pre-test	Control Class Post-test	Experimental Class Pre-test	Experimental Class Post-test
<i>Mean</i>	56.13	61.13	60.65	84.03
<i>Median</i>	55	60	60	85
<i>Modus</i>	55	60	70	90
<i>Standar Deviation</i>	9.37	8.93	12.30	9.78
<i>Minimum</i>	35	40	30	65
<i>Maximum</i>	70	75	80	100

As detailed in Table 4, the experimental group recorded a mean pre-test score of 60.65, whereas the control group yielded a baseline average of 56.13. These initial figures confirm that both participant cohorts possessed broadly equivalent baseline competencies prior to the treatment intervention. Following the instructional period, the mean post-test score for the experimental cohort surged to 84.03, whereas the control cohort reached a mean of 61.13. Consequently, the experimental class achieved a mean gain of 23.38 points, substantially surpassing the modest 5.00-point gain observed in the control group. Concurrent upwards shifts were also observed in the median and modal values across both cohorts, with the experimental class displaying a far more pronounced trajectory. These baseline shifts provide preliminary descriptive evidence suggesting that digital diorama integration correlates with enhanced academic performance relative to conventional instructional media (Sugiyono, 2022).

Regarding score variance within the dataset, the standard deviation of the experimental cohort contracted from 12.30 at baseline to 9.78 post-test, demonstrating increased score homogeneity around the mean following the treatment. Furthermore, the minimum score within the experimental group rose markedly from 30 to 65, while its maximum attainment advanced from 80 to 100. Conversely, the control group exhibited a slight shift in minimum scores from 35 to 40 and maximum scores from 70 to 75. Descriptively, these distributional changes indicate that academic performance gains in the digital diorama group were not confined to high-performing students, but

rather spanned across the entire achievement spectrum, benefiting lower-performing pupils as well (Widyasari et al., 2024). To verify whether these observed descriptive disparities reflect genuine treatment effects rather than random variance, inferential statistical analyses were subsequently conducted (Ghozali, 2021).

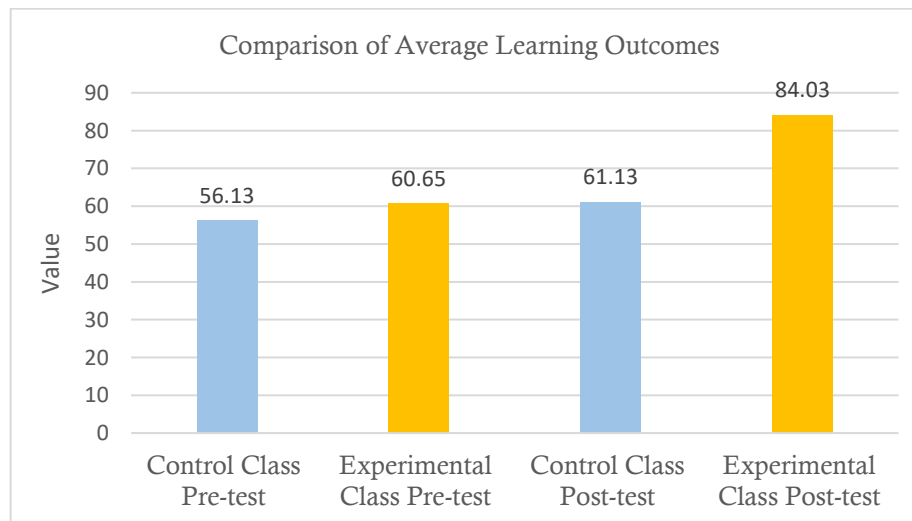


Figure 3. Comparative Mean Learning Outcomes Across Pre-test and Post-test Assessments

As illustrated in Figure 3, both instructional conditions demonstrated positive score gains following classroom instruction. Nevertheless, the magnitude of growth recorded in the experimental group was noticeably superior to that of the control group. The marked disparity in bar height between baseline and post-treatment measures within the experimental condition highlights the heightened instructional efficacy of interactive digital dioramas over conventional pedagogical tools.

The Normality Test

To verify whether the learning outcome data across both the experimental and control cohorts adhered to a normal distribution a fundamental assumption for deploying parametric inferential statistics a formal normality test was conducted. Because the sample size for each subgroup comprised fewer than 50 participants ($n < 50$), the Shapiro-Wilk protocol was executed via IBM SPSS Statistics. Under this diagnostic framework, distributional normality is established when the empirical significance value (p -value) exceeds the $\alpha = 0.05$ threshold (Ghozali, 2021). The statistical outputs of the Shapiro-Wilk test are summarized in Table 5.

Table 5. Shapiro-Wilk Normality Diagnostic Test Results

Variable	Sig.	Distribution Status
Experimental Class Pre-test	0.104	Normal
Experimental Class Post-test	0.225	Normal
Control Class Pre-test	0.103	Normal
Control Class Post-test	0.103	Normal

As detailed in Table 5, the derived p -values for both baseline (pre-test) and post-intervention (post-test) measures across both experimental conditions consistently exceeded the critical significance threshold of 0.05. Consequently, the achievement datasets for both cohorts satisfied the parametric assumption of normality, confirming their eligibility for downstream parametric hypothesis testing (Ghozali, 2021).

Homogeneity Test

Prior to conducting inferential hypothesis testing, Levene's Test of Equality of Variances was executed via IBM SPSS Statistics to determine whether variance homogeneity was preserved across the experimental and control cohorts. Evaluated at a standard significance threshold of $\alpha = 0.05$, group variances were deemed homogeneous if the computed significance value (p -value) exceeded 0.05 (Ghozali, 2021). Table 6 details the empirical outcome of the homogeneity diagnostic test.

Table 6. Results of Levene's Test for Homogeneity

Research Data	Sig.	Variance Status
Learning Outcomes	0.379	Homogen

As presented in Table 6, Levene's test yielded a significance statistic of $p = 0.379$, comfortably surpassing the predetermined $\alpha = 0.05$ critical value. This result confirms that the variance in academic performance between the experimental and control conditions is statistically equal. The verification of variance homogeneity coupled with the previously established distributional normality substantiates that the dataset satisfies all parametric prerequisites for downstream hypothesis testing via an Independent Samples t-test (Ghozali, 2021).

The Hypothesis Test (Independent-Samples t-Test)

Inferential hypothesis testing was conducted to determine whether a statistically significant divergence in academic attainment exists between pupils instructed via interactive digital dioramas and those exposed to conventional PowerPoint presentations.

Table 7. Independent-Samples t-Test Inferential Results

Variable	Mean Difference	t-value	Df	Sig. (2-tailed)
Learning Outcomes	22,903	9,412	60	0,000

As detailed in Table 7, the Independent-Samples t-test yielded a 2-tailed significance value of $p = 0.000$ ($p < 0.05$). This statistical outcome warrants the definitive rejection of the null hypothesis (H_0) and the acceptance of the alternative hypothesis (H_1). These inferential findings confirm a highly significant divergence in learning outcomes between the experimental and control cohorts. Given the demonstrably superior post-treatment average achieved by the experimental group, integrating digital dioramas exerts a significant positive influence on enhancing primary students' mastery of marine ecosystem concepts.

Table 8. Quantification of Instructional Treatment Effect Size

Statistics	Value
Cohen's d	2.391
Interpretation	Very High Effect

To quantify the practical magnitude of the digital diorama intervention, supplementary effect size analyses were conducted using Cohen's d and Eta-Squared (η^2) parameters. As shown in Table 8, the analysis revealed a Cohen's d index of 2.391, placing the treatment effect well within the "very large effect" threshold. Concurrently, an Eta-Squared value of $\eta^2 = 0.596$ indicates that approximately 59.6% of the variance in student post-intervention learning outcomes is directly attributable to the digital diorama treatment (Ghozali, 2021).

These parameters demonstrate that the pedagogical contribution of the digital diorama extends beyond mere binary statistical significance, exerting a profound practical impact on conceptual acquisition (Ghozali, 2021). These inferential insights are further corroborated by Normalized Gain (N-Gain) metrics. The experimental class achieved a mean N-Gain score of 59.43%, substantially surpassing the control group's modest efficiency score of 11.40%. This pronounced discrepancy in N-Gain indices confirms that academic performance in the experimental cohort progressed far more substantially following the digital diorama intervention compared to the control cohort, which underwent unidirectional, traditional instruction (Sugiyono, 2022).

Discussion

The marked escalation in academic performance observed within the experimental cohort underscores the superior instructional efficacy of digital dioramas relative to traditional media choices (Latifah et al., 2025). By projecting marine ecosystem elements through three-dimensional graphical models, the digital diorama offers pupils an immersive exploratory space to interact tangibly with inter-component relationships. Consequently, scientific principles that are inherently abstract and difficult to visualize are translated into concrete, accessible representations. This empirical pattern directly reinforces the foundational tenets of *Mayer's Cognitive Theory of Multimedia Learning* (Mayer, 2024), which asserts that dual-channel processing achieved through the concurrent presentation of synchronized visual and verbal stimuli effectively mitigates cognitive overload, stimulates memory consolidation, and deepens conceptual mastery. Such cognitive facilitation proves vital for enabling primary students to grasp complex ecological mechanisms, including marine trophic webs, symbiotic interactions, and biotic-abiotic interdependencies. This trajectory is further supported by Widyasari et al., (2024), who established that contextualized instructional technologies substantially heighten learner attentiveness while optimizing achievement metrics.

Moreover, the pedagogical impact recorded in the experimental class extended beyond a mere shift in arithmetic means, manifesting as a broader, more equitable distribution of conceptual comprehension across participants (Aulia & Alyani, 2024). The contraction of the standard deviation statistic from 12.30 to 9.78, paired with the substantial elevation of the minimum score threshold from 30 to 65, confirms that

academic growth was not restricted to high-performing pupils, but rather encompassed learners who initially exhibited foundational cognitive hurdles. This evidence highlights the capacity of digital dioramas to function as an inclusive, equitable pedagogical tool. This interpretation accords with the framework formulated by (Uno, 2023), which posits that deploying adaptive instructional tools tailored to the developmental cognitive profiles of primary-grade pupils naturally fosters intrinsic motivation while streamlining the acquisition of complex scientific concepts.

Furthermore, these experimental findings substantiate and extend prior scholarship. Fitriyani (2024) documented that interactive visual interventions successfully elevate conceptual retention by presenting instructional content in engaging, visually intuitive formats. In a similar vein, (Qurrotaini et al., 2024) demonstrated that diorama-based learning architectures exert a favorable effect on overall student outcomes. The present study reinforces these earlier observations by demonstrating that extending digital diorama technology specifically to marine ecosystem content generates a profound practical effect size, evidenced by a Cohen's d coefficient of 2.391 and an Eta-Squared (η^2) index of 0.596 (Dewi & Rahmiati, 2026).

Synthetically, these empirical outcomes confirm that digital dioramas constitute a highly effective instructional alternative for delivering primary-level IPAS curricula, particularly when mastering concepts that demand concrete visualization of non-observable real-world phenomena. By serving as an instructional bridge between abstract theoretical constructs and tangible visual models, this medium affords learners significantly more meaningful educational experiences (Ghozali, 2021; Nisa & Haroky, 2025). In light of these contributions, integrating interactive digital dioramas represents a compelling pedagogical innovation for elevating both instructional quality and academic attainment within marine ecosystem studies.

CONCLUSION

The integration of interactive digital dioramas significantly enhances fifth-grade elementary students' learning outcomes in marine ecosystem topics. Inferential testing via an Independent-Samples t -test confirmed a statistically significant divergence in academic attainment between the experimental and control cohorts ($p = 0.000$, $p < 0.05$). The pedagogical efficacy of this digital intervention is further corroborated by an experimental N-Gain index of 59.43% (categorized as moderately effective), alongside robust effect size metrics specifically a Cohen's d coefficient of 2.391 and an Eta-Squared (η^2) value of 0.596 demonstrating a substantial practical impact on student achievement. These empirical outcomes align with Mayer's Cognitive Theory of Multimedia Learning, which posits that dual-channel information processing via complementary visual and verbal streams optimizes conceptual mental representations. Pragmatically, digital dioramas represent a viable instructional innovation for IPAS curricula, particularly when delivering abstract scientific topics that require concrete visualization of non-observable phenomena.

Notwithstanding these positive insights, the scope of this study is constrained by certain methodological boundaries, notably its restriction to a single institutional site with a limited sample size, alongside an exclusive analytical focus on cognitive learning metrics. Consequently, the generalizability of these findings across broader

educational settings remains limited. To address these parameters, subsequent empirical inquiries should expand the sampling framework to include multiple diverse elementary institutions, explore digital diorama applications across broader IPAS subfields, and incorporate non-cognitive outcome variables such as affective development, critical thinking competencies, creative capabilities, learning motivation, and collaborative skills. Such expanded research avenues will yield a more holistic evaluation of digital diorama technology in primary education.

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