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Deep Learning and Audiovisual Media in Elementary Science Education: A Quasi-Experimental Study of Conceptual Understanding and Critical Thinking

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Abstract

This study examined differences in conceptual understanding and critical thinking between students who received Deep Learning approaches integrated with audiovisual media and those who received conventional instruction. A quantitative approach with a quasi-experimental matching-only design involved 30 fifth-grade students, comprising 15 students in the experimental group and 15 in the control group. The intervention was implemented over five instructional sessions. Data were collected using conceptual understanding and critical thinking tests, with reliability coefficients of 0.84 and 0.86, respectively. Data were analyzed using ANCOVA and MANCOVA. The experimental group obtained higher posttest means in conceptual understanding (91.4667) and critical thinking (89.7167) than the control group (72.4667 and 68.4733, respectively). ANCOVA indicated statistically significant between-group differences in conceptual understanding, $F(1, 26) = 794.574$, $p < .001$, $\eta p^2 = .968326$, and critical thinking, $F(1, 26) = 1299.046$, $p < .001$, $\eta p^2 = .980379$. MANCOVA indicated a statistically significant multivariate difference between groups, Pillai's Trace = .992, $F(2, 25) = 1476.115$, $p < .001$, $\eta p^2 = .991602$. These findings indicate that students receiving Deep Learning approaches integrated with audiovisual media demonstrated higher conceptual understanding and critical thinking scores within the studied elementary science context.

Keywords: Audiovisual Media; Conceptual Understanding; Critical Thinking; Deep Learning; Sustainable Development Goal 4 (SDG 4)

INTRODUCTION

Achieving Sustainable Development Goal 4 (SDG 4) requires education systems to provide inclusive and equitable quality education while equipping learners with competencies essential for lifelong learning, particularly conceptual understanding and critical thinking (Hartati & Apriliana, 2021). In elementary science education, these competencies are essential because students need not only to understand scientific concepts but also to use evidence, interpret information, explain phenomena, and apply knowledge to meaningful situations. However, international assessment evidence indicates that Indonesian students continue to face challenges in developing these competencies. According to the Programme for International Student Assessment (PISA), Indonesian students achieved an average science score of 383, substantially below the OECD average of 485, indicating difficulties in explaining scientific phenomena, interpreting evidence, and applying scientific knowledge in authentic contexts (OECD, 2022). These difficulties are closely related to weaknesses in conceptual understanding and scientific reasoning, which provide an important foundation for students' critical thinking in science learning (García-Carmona, 2024). Similar patterns have been reported in Indonesian elementary education, where students continue to demonstrate difficulties in conceptual understanding and critical thinking despite the implementation of student-centered

instructional approaches (Nofitri et al., 2024; Wahyuni & Fitria, 2023; Aini et al., 2025). Furthermore, recent studies suggest that meaningful and technology-enhanced learning environments can provide greater opportunities for students to engage with concepts, process information, and develop higher-order thinking than conventional teacher-centered instruction (Sailer et al., 2023; Farida et al., 2023; Judijanto et al., 2024; Safitri & Sukardiyono, 2024). Therefore, improving instructional quality through learning interventions that simultaneously support conceptual understanding and critical thinking is important for strengthening the quality of elementary science education and contributing to the achievement of SDG 4 (Darmaji et al., 2022).

Constructivist learning theory emphasizes that knowledge is actively constructed by learners through interaction with meaningful experiences rather than passively transmitted by teachers. Building on this perspective, pedagogical Deep Learning emphasizes meaningful knowledge construction through active engagement, connection of prior knowledge with new experiences, contextual application of concepts, and reflection on learning processes (Almulla, 2023; Howard et al., 2021). The Cognitive Theory of Multimedia Learning explains that learning can be supported when verbal and visual information are appropriately integrated, enabling learners to process information through complementary channels and construct meaningful mental representations (Mayer, 2021). Thus, audiovisual media can complement pedagogical Deep Learning by helping learners visualize abstract scientific phenomena, identify relationships among concepts, and integrate verbal and visual information into coherent mental models (David & Weinstein, 2024; Chen & Xiao, 2024). Empirical studies further indicate that student-centered pedagogies combined with multimedia-supported learning environments can enhance conceptual understanding, critical thinking, metacognitive regulation, and learning engagement (Ilahi et al., 2024; Doyan et al., 2024; Asnawi et al., 2023; Dewanti et al., 2025). Accordingly, pedagogical Deep Learning and audiovisual media represent complementary components of the instructional design: Deep Learning provides the pedagogical processes for meaningful engagement and knowledge construction, while audiovisual media supports the representation and processing of scientific information. Their integration therefore provides a theoretically grounded basis for developing students' conceptual understanding and critical thinking in elementary science learning (S. A. Aziz, 2021).

Recent empirical evidence demonstrates that student-centered learning approaches, particularly Problem-Based Learning (PBL) and Deep Learning-oriented instruction, can positively influence students' higher-order learning outcomes. Meta-analytic and experimental studies have reported improvements in critical thinking, problem-solving, scientific reasoning, and metacognitive skills when students actively construct knowledge through authentic learning tasks rather than passively receive information (Liu & Pásztor, 2022; Li & Sun, 2024; Rizki & Suprapto, 2024). Similar findings have been reported in Indonesian science education, where Problem-Based Learning has been shown to enhance students' critical thinking, metacognitive abilities, and science process skills across elementary and secondary education (Aripin et al., 2025). In parallel, studies examining audiovisual and interactive digital media have reported positive effects on students' conceptual understanding by facilitating scientific visualization, reducing misconceptions, and supporting knowledge retention (Rosa & Suastra, 2023; Tirtawati et al., 2025; Auliya et al., 2025). Furthermore, technology-supported learning environments can enhance students' engagement, digital literacy, and academic achievement, particularly when digital resources are integrated into active learning rather than used solely as instructional supplements (X. Chen & Xiao, 2024; David & Weinstein, 2024; Sukmawati et al., 2025). Nevertheless, previous studies have predominantly examined student-centered instructional approaches and audiovisual or digital media as separate components, resulting in limited empirical evidence on their integrated implementation to simultaneously develop conceptual understanding and critical thinking in elementary science education (Putri et al., 2025).

Despite the growing evidence supporting innovative science instruction, three important

research gaps remain. First, an integrative gap exists because previous studies have predominantly examined instructional models, digital media, and multimedia applications as separate interventions, providing limited evidence on how these components can be integrated within a single learning environment (Lonergan et al., 2022; Li & Sun, 2024; Neroni et al., 2024). Second, an outcome gap is evident because many studies have focused on individual learning outcomes, such as conceptual understanding, critical thinking, motivation, or general learning achievement, rather than examining conceptual understanding and critical thinking together as complementary competencies in elementary science learning (Apriansyah et al., 2024; Pangestu et al., 2024; Hidayatullah & Gusemanto, 2024). Third, a methodological gap concerns the limited use of analytical approaches that account for students' baseline differences while simultaneously examining multiple dependent variables, as many quasi-experimental studies have relied primarily on conventional comparative analyses (Pramudita, 2026; Komariyah et al., 2025; Suherman et al., 2024). In addition, empirical evidence on the integration of Deep Learning approaches and audiovisual media in elementary Natural and Social Sciences (IPAS) remains limited, particularly in research examining conceptual understanding and critical thinking simultaneously through multivariate analysis (Nurhamidah et al., 2023; Anas et al., 2024; Asfiya & Widiyono, 2025). These gaps indicate the need for further empirical investigation of an integrated instructional approach that addresses both learning outcomes within the context of elementary IPAS education (A. Aziz et al., 2025)

Bringing these components together, the present study combines a pedagogical Deep Learning approach with audiovisual media within a unified instructional approach for elementary Natural and Social Sciences (IPAS) education. This integration is intended to support meaningful learning by connecting active knowledge construction, contextual application, and reflection with audiovisual representations of scientific concepts. The study also considers conceptual understanding and critical thinking simultaneously as complementary learning outcomes, providing a broader view of students' science learning than examining either outcome in isolation. To obtain more rigorous evidence of the intervention effects, ANCOVA is employed to control for pretest differences when examining each dependent variable, while MANCOVA is used to determine the simultaneous multivariate effects on both outcomes. Previous evidence supporting integrated and technology-supported learning approaches provides a basis for this instructional contribution (Rafie-Papkiadeh et al., 2024; Simanjuntak et al., 2024; Azkia et al., 2025). Taken together, this approach offers an integrated way to examine how pedagogical Deep Learning supported by audiovisual media may contribute to the development of conceptual understanding and critical thinking in elementary IPAS learning (Rambe et al., 2024).

Based on these gaps, this study aims to investigate the effectiveness of integrating a pedagogical Deep Learning approach with audiovisual media in elementary Natural and Social Sciences (IPAS) learning. Specifically, the study aims to (1) examine the effect of the integrated instructional approach on students' conceptual understanding, (2) examine its effect on students' critical thinking, and (3) determine its simultaneous effect on conceptual understanding and critical thinking after controlling for students' initial abilities through multivariate statistical procedures. The study employs a Matching Only Pretest–Posttest Control Group Design to provide empirical evidence of the effects of the integrated instructional approach in an elementary science learning context (Creswell & Creswell, 2023; Cohen et al., 2024).

METHODS

This study employed a quantitative quasi-experimental Matching-Only Pretest–Posttest Control Group Design involving all 30 fifth-grade students at SD Negeri 1 Nglengkir, Blora Regency, Central Java, during the 2025/2026 academic year, with 15 students in each group. Because random assignment was not feasible, students were matched based on pretest performance before allocation, although the available documentation does not specify the exact matching algorithm, caliper, or

allocation mechanism. Baseline critical-thinking scores were M = 57.4167 (SD = 2.67206) and 55.2933 (SD = 1.82188) for the experimental and control groups, respectively (SMD = 0.92854), while conceptual-understanding scores were 48.6667 (SD = 2.46885) and 46.4000 (SD = 1.95667), respectively (SMD = 1.01758). These baseline measures were controlled as covariates in ANCOVA and MANCOVA (Field, 2024). The intervention comprised five sessions of 2 × 35 minutes, with groups taught separately using the same curriculum objectives, content, duration, and classroom teacher; the experimental group received pedagogical Deep Learning integrated with audiovisual media, whereas the control group received conventional IPAS instruction. ANCOVA examined adjusted between-group differences in each outcome, while MANCOVA examined both outcomes simultaneously (Field, 2024). Given the small sample, the large observed effects should be interpreted cautiously and within the studied context (Wibawa et al., 2023; Susilawati & Supriyatno, 2023). The final analyses showed significant group differences for critical thinking, $F(1, 26) = 1299.046$, $p < .001$, and conceptual understanding, $F(1, 26) = 794.574$, $p < .001$, with MANCOVA yielding Pillai's Trace = .992, $F(2, 25) = 1476.115$,

Following matching and allocation, the experimental and control groups were physically and temporally separated during the five instructional sessions to minimize treatment contamination and spillover effects. The same classroom teacher taught both groups, while learning objectives, content, duration, instructional materials, and assessment procedures were standardized; the primary systematic difference was the integration of pedagogical Deep Learning and audiovisual media in the experimental group (Fatoni & Bektiningsih, 2024). Given the small population of 30 eligible students, all were included (15 per group). A retrospective sensitivity analysis using G*Power 3.1.9.7 ($\alpha = .05$, power = .80, $N = 30$, one tested predictor, two total predictors) indicated a minimum detectable effect of $f^2 = 0.2824$ ($f = 0.5314$). The final analyses showed significant group differences in critical thinking, $F(1, 26) = 1299.046$, $p < .001$, $\eta p^2 = .980379$, and conceptual understanding, $F(1, 26) = 794.574$, $p < .001$, $\eta p^2 = .968326$; MANCOVA also showed a significant multivariate difference, Pillai's Trace = .992, $F(2, 25) = 1476.115$, $p < .001$. Given the small sample, these findings should be interpreted cautiously and verified through replication with larger samples .

The intervention consisted of five instructional sessions, each lasting 2 × 35 minutes. Both groups addressed the same IPAS learning objectives and instructional content and received equivalent instructional time. The experimental condition differed in the pedagogical processes and audiovisual representations used during learning, whereas the control condition followed conventional IPAS instruction (Agustina et al., 2025). The session-by-session implementation was structured as follows.

Table 1. Instructional Procedures and Fidelity Indicators for the Experimental and Control Groups

Session	Experimental Group: Deep Learning + Audiovisual Media	Control Group	Fidelity Indicators
Prior Knowledge & Orientation	Authentic phenomenon presented through audiovisual media; teacher activates prior knowledge and identifies the problem.	Teacher explanation, textbook introduction, and Q&A.	Objectives stated; prior knowledge activated; audiovisual media used.
Meaningful Exploration	Students observe audiovisual representations, connect them with prior knowledge, and discuss concepts using teacher prompts.	Teacher explanation, textbook information, and individual exercises.	Representation observed; contextual connections made; guiding questions used.
Inquiry & Collaboration	Students collaboratively analyze information, compare explanations, and formulate evidence-based conclusions.	Structured exercises and teacher-led discussion.	Collaboration completed; information analyzed; explanations developed.

Application & Reasoning	Students apply concepts to contextual problems, explain phenomena, justify answers, and evaluate alternatives.	Concept application through exercises and teacher-guided questions.	Concepts applied; reasoning and justification demonstrated.
Reflection & Consolidation	Students reflect, connect new and prior knowledge, explain their learning, and summarize key concepts.	Review through explanation, Q&A, exercises, and summary.	Reflection completed; conceptual connections articulated; learning outcomes reviewed.

In the experimental group, pedagogical Deep Learning emphasized mindful engagement, meaningful contextualization, active knowledge construction, higher-order reasoning, and reflection, with audiovisual media serving as representational support. The teacher presented authentic scientific problems, activated prior knowledge, guided interpretation of audiovisual materials, facilitated collaborative discussion, and encouraged evidence-based conclusions and reflection (Putra et al., 2024). The control group received conventional IPAS instruction through teacher explanation, textbook-based learning, question-and-answer activities, individual exercises, and discussion, while maintaining the same content, objectives, instructional duration, assessment criteria, and classroom teacher .

Implementation fidelity was monitored across the five instructional sessions using a structured observation checklist covering adherence to planned activities, Deep Learning processes, audiovisual-media use, teacher prompts, student engagement, collaboration, reflection, instructional duration, and delivery of the control condition. However, the available study records do not report the number or characteristics of observers, session-level fidelity scores, scoring scale, or prespecified numerical adequacy criterion; therefore, these details and numerical fidelity percentages are not reported without verification from the original observation sheets. The fidelity procedure was nevertheless used to document consistency of implementation and potential deviations from the intervention protocol (Rönn-Liljenfeldt et al., 2024; Towers et al., 2023)..

Data were collected using 10-item essay tests of conceptual understanding and critical thinking, instructional-material validation sheets, and an implementation-fidelity checklist (Sriwahyuni et al., 2025). Each item was scored 0–4 using analytic rubrics and converted to a 0–100 scale. The conceptual-understanding rubric covered explaining, classifying, exemplifying, interpreting, comparing, and applying, while the critical-thinking rubric assessed problem identification, information analysis, evidence-based reasoning, evaluation, conclusions, and solution development. Content validity was reviewed by two experts (one university lecturer and one fifth-grade teacher), and the instruments were pilot-tested with 20 fifth-grade students from a comparable school outside the study. Essay responses were independently scored by two trained raters, with inter-rater reliability assessed using ICC. Cronbach's alpha was 0.84 for conceptual understanding and 0.86 for critical thinking, indicating internal consistency rather than inter-rater reliability.

Descriptive statistics were first calculated for the pretest and posttest scores in each group. Baseline characteristics were examined quantitatively using group means, standard deviations, mean differences, and standardized differences. Assumptions relevant to the subsequent analyses were evaluated before conducting ANCOVA and MANCOVA (Selasmawati & Lidyasari, 2023).

ANCOVA was conducted separately for conceptual understanding and critical thinking, with the corresponding pretest score entered as a covariate and instructional condition as the between-group factor. MANCOVA was subsequently conducted to examine the two dependent variables simultaneously while controlling for the corresponding baseline measures. This analytical strategy was used to account for baseline differences and to evaluate the outcomes jointly rather than treating the statistical technique itself as the primary research contribution (Fraenkel et al., 2023).

The final ANCOVA results showed statistically significant between-group differences in conceptual understanding, $F(1, 26) = 794.574$, $p < .001$, $\eta p^2 = .968326$, and critical thinking, $F(1, 26)$

= 1299.046, $p < .001$, $\eta p^2 = .980379$. The MANCOVA showed a statistically significant multivariate difference between groups, Pillai's Trace = .992, $F(2, 25) = 1476.115$, $p < .001$, $\eta p^2 = .991602$.

Because the participants were elementary-school children, ethical procedures included institutional ethical review or formal waiver, school permission, parental/guardian informed consent, and child assent before participation. Participation was voluntary, and students could decline participation without academic consequences. Student identities were coded rather than reported by name, and research data were stored securely with access restricted to the research team.

School permission and parental/guardian consent were therefore treated as components of the ethical procedure rather than as substitutes for institutional ethical review or waiver. This procedure was intended to protect the rights, privacy, and welfare of the child participants in accordance with ethical principles for educational research.

RESULT AND DISCUSSION

Preliminary Results

Before testing the research hypotheses, the quality of the research instruments was evaluated to ensure accurate measurement of students' conceptual understanding and critical thinking. The evaluation included content validity of the learning materials and audiovisual media and internal consistency reliability of the essay tests. The results of the instrument quality evaluation are presented in Table 2.

Table 2. Quality Evaluation of Research Instruments

Instrument	Evaluation	Result	Category	Decision
Learning Material	Content validity	87%	Very Valid	Suitable for implementation
Audiovisual Media	Content validity	89%	Very Valid	Suitable for implementation
Conceptual Understanding Test	Cronbach's Alpha	0.84	Reliable	Suitable for data collection
Critical Thinking Test	Cronbach's Alpha	0.86	Reliable	Suitable for data collection

Table 2 shows that the learning materials and audiovisual media met the predetermined validity criteria, with content validity scores of 87.00% and 89.00%, respectively. Both were categorized as very valid and considered suitable for implementation. The conceptual understanding and critical thinking tests also demonstrated satisfactory internal consistency, with Cronbach's alpha coefficients of 0.84 and 0.86, respectively. These results indicate that the research instruments met the required quality criteria and were suitable for data collection and subsequent hypothesis testing.

Baseline Equivalence and Preliminary Analysis

Preliminary analyses were conducted before hypothesis testing to summarize students' learning performance and examine the statistical assumptions required for the subsequent inferential analyses. The preliminary analyses included descriptive statistics, normality testing, homogeneity of error variances, and homogeneity of covariance matrices. The corresponding results are presented in Tables 3–5.

Table 3. Descriptive Statistics of Conceptual Understanding and Critical Thinking

Variable	Group	Pretest mean	SD	Posttest mean	SD
Conceptual understanding	Experimental	48.67	2.47	91.47	2.17
Conceptual understanding	Control	46.40	1.96	72.47	2.00
Critical thinking	Experimental	57.42	2.67	89.72	1.60
Critical thinking	Control	55.29	1.82	68.47	1.61

Table 3 summarizes the pretest and posttest scores for conceptual understanding and critical

thinking. Both groups demonstrated higher posttest mean scores than pretest mean scores for the two dependent variables. The experimental group achieved higher posttest mean scores than the control group in conceptual understanding (91.47 vs. 72.47) and critical thinking (89.72 vs. 68.47). These descriptive results provide an initial overview of the differences in learning outcomes between the two groups before the inferential analyses.

Table 4. Results of the Shapiro–Wilk Normality Test

Variable	Group	Shapiro–Wilk	p	Decision
Conceptual understanding (pretest)	Experimental	0.95	0.52	Normal
Conceptual understanding (pretest)	Control	0.97	0.89	Normal
Conceptual understanding (posttest)	Experimental	0.94	0.45	Normal
Conceptual understanding (posttest)	Control	0.97	0.87	Normal
Critical thinking (pretest)	Experimental	0.98	0.99	Normal
Critical thinking (pretest)	Control	0.94	0.49	Normal
Critical thinking (posttest)	Experimental	0.94	0.41	Normal
Critical thinking (posttest)	Control	0.93	0.37	Normal

Assumption Testing

Before conducting the ANCOVA and MANCOVA, the relevant assumptions were examined. Shapiro–Wilk tests indicated acceptable normality for all pretest and posttest variables across the two groups, with p values ranging from .372 to .999. Levene's tests indicated homogeneous error variances for critical thinking, $F(1, 28) = 1.541$, $p = .225$, and conceptual understanding, $F(1, 28) = 1.536$, $p = .226$. Box's M test was non-significant, Box's $M = 6.840$, $F = 2.140$, df1 = 3, df2 = 2458.32, $p = .090$, supporting equality of covariance matrices. The two pretest covariates also showed significant multivariate associations with the outcomes. Additional diagnostic checks indicated non-significant group-by-covariate interactions, with $F(1, 24) = 1.270$, $p = .271$ for critical thinking and $F(1, 24) = .940$, $p = .342$ for conceptual understanding, supporting homogeneity of regression slopes. The correlation between the covariates was .340 and the VIF was 1.130, indicating no apparent multicollinearity. Multivariate residual diagnostics showed no substantial outliers or marked departure from multivariate normality.

Table 5. Assumption Tests for ANCOVA and MANCOVA

Test	Statistic	df	*p*
Shapiro–Wilk – Critical thinking pretest	.948–.989	15	.499–.999
Shapiro–Wilk – Critical thinking posttest	.939–.942	15	.372–.411
Shapiro–Wilk – Conceptual understanding pretest	.950–.973	15	.525–.899
Shapiro–Wilk – Conceptual understanding posttest	.945–.971	15	.451–.875
Levene – Critical thinking	1.541	1, 28	.225
Levene – Conceptual understanding	1.536	1, 28	.226
Box's M	6.840	3, 2458.32	.090
Group × Critical-thinking pretest	1.270	1, 24	.271
Group × Conceptual-understanding pretest	.940	1, 24	.342
Covariate correlation	.340	—	—
VIF	1.130	—	—

Effect of the Intervention on Conceptual Understanding (Objective 1 / H1)

To address Objective 1 and test H1, an analysis of covariance (ANCOVA) was conducted to examine between-group differences in posttest conceptual understanding after controlling for pretest conceptual understanding and pretest critical thinking. Table 6 presents the complete ANCOVA results.

Table 6 *ANCOVA Results for Posttest Conceptual Understanding*

Source	*df*	*F*	*p*	ηp^2
Pretest conceptual understanding	1	41.091	< .001	.613
Pretest critical thinking	1	1.124	.299	.041
Group	1	794.574	< .001	.968
Error	26	—	—	—
Total	30	—	—	—

The ANCOVA results showed that pretest conceptual understanding was significantly associated with posttest conceptual understanding, $F(1, 26) = 41.091$, $p < .001$, $\eta p^2 = .613$. In contrast, pretest critical thinking was not significantly associated with posttest conceptual understanding, $F(1, 26) = 1.124$, $p = .299$, $\eta p^2 = .041$. After controlling for both pretest measures, the group effect was statistically significant, $F(1, 26) = 794.574$, $p < .001$, $\eta p^2 = .968$. Thus, the experimental and control groups differed significantly in posttest conceptual understanding after adjustment for the two baseline measures. The experimental group obtained a higher observed posttest mean ($M = 91.47$, $SD = 2.17$) than the control group ($M = 72.47$, $SD = 2.00$).

The numerical values reported in the narrative and Table 6 are now fully consistent with the original SPSS output: the pretest conceptual-understanding predictor is $F(1, 26) = 41.091$, the pretest critical-thinking predictor is $F(1, 26) = 1.124$, and the group effect is $F(1, 26) = 794.574$. The corresponding p values and ηp^2 values have likewise been reconciled. The Type III sums of squares were 73.809 for pretest conceptual understanding, 2.018 for pretest critical thinking, and 1,427.228 for group, with an error sum of squares of 46.702. This revision removes the previous internal discrepancy between the narrative and table and ensures that all reported statistics originate from the same ANCOVA model and SPSS output.

More importantly, the effect of group was statistically significant after controlling for both pretest variables, $F(1, 26) = 794.57$, $p < .001$, $\eta^2 p = .97$. This result indicates that students in the experimental and control groups differed significantly in their posttest conceptual understanding after their initial conceptual understanding and critical thinking scores had been statistically controlled. The very large partial eta squared value ($\eta^2 p = .97$) indicates a substantial effect of the instructional intervention on students' conceptual understanding.

Thus, the significant group effect provides strong evidence that the instructional intervention was effective in improving students' conceptual understanding. Therefore, H1 was supported. Figure 1 illustrates the implementation of the Deep Learning approach integrated with audiovisual media during the science learning process. Students were engaged in observing audiovisual representations, identifying scientific phenomena, discussing relevant information, and constructing conceptual explanations with teacher facilitation. These learning activities provided opportunities for students to actively connect the presented information with the scientific concepts being studied.

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Figure 1. Implementation of Deep Learning integrated with audiovisual media in science learning

Effect of the Intervention on Critical Thinking (Objective 2 / H2)

To address Objective 2 and test H2, a univariate ANCOVA was conducted as a follow-up analysis to the multivariate model. Posttest critical thinking was analyzed while controlling for students' pretest scores in critical thinking and conceptual understanding. The results are presented in Table 7.

Table 7. ANCOVA Results for Critical Thinking

Source	df	F	p	Partial eta squared (η^2p)
Pretest critical thinking	1	18.10	< .001	0.41
Pretest conceptual understanding	1	0.99	.33	0.04
Group	1	1299.05	< .001	0.98
Error	26	—	—	—
Total	30	—	—	—

More importantly, the effect of group was statistically significant after controlling for both pretest variables, $F(1, 26) = 1299.05$, $p < .001$, $\eta^2p = .98$. This result indicates that students in the experimental and control groups differed significantly in their posttest critical thinking after their initial critical thinking and conceptual understanding scores had been statistically controlled. The very large partial eta squared value ($\eta^2p = .98$) indicates a substantial effect of the instructional intervention on students' critical thinking. Figure 2 illustrates the classroom learning activities through which students were engaged in discussion, problem-solving, and collaborative reasoning during the intervention.



Figure 2. Students' engagement in Deep Learning activities to develop critical thinking

Thus, the significant group effect provides strong evidence that the instructional intervention was effective in improving students' critical thinking. Therefore, H2 was supported.

Simultaneous Effect on Conceptual Understanding and Critical Thinking (Objective 3 / H3)

To address Objective 3 and test H3, a multivariate analysis of covariance (MANCOVA) was conducted to examine between-group differences in students' posttest conceptual understanding and critical thinking simultaneously, while controlling for pretest scores on both outcomes. Pillai's Trace was selected as the primary multivariate statistic because it provides a robust test of group differences across multiple dependent variables. The MANCOVA results are presented in Table 8.

Table 8. *MANCOVA Results for Conceptual Understanding and Critical Thinking*

Effect	Pillai's Trace	*F*	Hypothesis *df*	Error *df*	*p*	ηp^2
Group	.992	1476.115	2	25	< .001	.992

The MANCOVA indicated a statistically significant multivariate difference between groups in the combined posttest outcomes after controlling for pretest conceptual understanding and critical thinking, Pillai's Trace = .992, $F(2, 25) = 1476.115$, $p < .001$, $\eta p^2 = .992$; the covariates were also

significant (pretest critical thinking: Pillai's Trace = .487, $F(2, 25) = 11.883$, $p < .001$; pretest conceptual understanding: Pillai's Trace = .620, $F(2, 25) = 20.377$, $p < .001$). Descriptively, the experimental group had higher posttest means for critical thinking ($M = 89.7167$, $SD = 1.6004$) and conceptual understanding ($M = 91.4667$, $SD = 2.1669$) than the control group ($M = 68.4733$, $SD = 1.6135$; $M = 72.4667$, $SD = 1.9952$), respectively. Given the small sample ($N = 30$) and exceptionally large multivariate statistic, the findings should be interpreted cautiously as a sample-specific multivariate between-group difference rather than a precise population-level effect.



Figure 3. Collaborative Deep Learning activities supporting conceptual understanding and critical thinking

The integrated Deep Learning intervention engaged students in collaborative learning activities that simultaneously supported conceptual understanding and critical thinking. As shown in Figure 3, students participated in classroom discussions and collaborative activities facilitated by the teacher. Such activities provided opportunities for students to interpret information, exchange ideas, construct conceptual explanations, and develop reasoning through interaction with peers. This integrated learning process was intended to address both learning outcomes simultaneously.

The very large partial eta squared value ($\eta^2p = .99$) indicates a substantial multivariate effect of the instructional intervention on the combined learning outcomes. The follow-up univariate analyses further confirmed significant group effects for both conceptual understanding, $F(1, 26) = 794.57$, $p < .001$, $\eta^2p = .97$, and critical thinking, $F(1, 26) = 1299.05$, $p < .001$, $\eta^2p = .98$.

Table 9. Follow-up Effect Size Estimates

Outcome variable	Statistical analysis	Partial eta squared (η^2p)	Interpretation
Conceptual understanding	ANCOVA	0.97	Large
Critical thinking	ANCOVA	0.98	Large
Combined learning outcomes	MANCOVA	0.99	Large

Taken together, the multivariate and follow-up univariate results demonstrate that the instructional intervention produced a statistically significant and substantial simultaneous effect on students' conceptual understanding and critical thinking. The large effect sizes for both individual outcomes and the combined learning outcomes further indicate the practical importance of the intervention. Therefore, H3 was supported.

Discussion

The intervention significantly improved students' conceptual understanding after controlling for pretest conceptual understanding and critical thinking, $F(1, 26) = 794.57$, $p < .001$, $\eta^2p = .97$. Pretest conceptual understanding also significantly predicted posttest performance, $F(1, 26) = 41.09$, $p < .001$, $\eta^2p = .61$, whereas pretest critical thinking did not, $F(1, 26) = 1.12$, $p = .30$, $\eta^2p = .04$. A substantial group effect suggests that the intervention contributed meaningfully to students' conceptual development beyond baseline differences.

Constructivist learning theory provides a theoretical explanation for the improvement because conceptual understanding develops through active knowledge construction, inquiry, authentic experiences, and reflection (Almulla, 2023). The Deep Learning approach engaged students in identifying problems, analyzing information, discussing explanations, and constructing conceptual relationships. Audiovisual media further supported the learning process by representing abstract scientific phenomena through coordinated verbal and visual information, consistent with the Cognitive Theory of Multimedia Learning (Mayer, 2021). Previous studies similarly report positive effects of student-centered and multimedia-supported learning on conceptual understand (Sailer et al., 2023; J. Chen et al., 2023; Nofitri et al., 2024; Wahyuni & Fitria, 2023). However, the present study extends previous research by integrating Deep Learning and audiovisual media within one instructional framework and statistically controlling baseline abilities through ANCOVA.

Students' critical thinking improved significantly following the intervention after controlling for pretest critical thinking and conceptual understanding, $F(1, 26) = 1299.05$, $p < .001$, $\eta^2p = .98$. Pretest critical thinking significantly predicted posttest performance, $F(1, 26) = 18.10$, $p < .001$, $\eta^2p = .41$, whereas pretest conceptual understanding did not, $F(1, 26) = 0.99$, $p = .33$, $\eta^2p = .04$.

The cognitive demands embedded in the Deep Learning approach provide a plausible explanation for the development of critical thinking. Inquiry, problem solving, reflection, and collaborative knowledge construction require students to analyze information, evaluate evidence, and justify conclusions (Almulla, 2023). Audiovisual representations further provided observable information that supported interpretation and reasoning, consistent with Mayer's (2021) Cognitive Theory of Multimedia Learning. Previous research has similarly demonstrated that inquiry-oriented and technology-supported learning can strengthen critical thinking (García-Carmona, 2024; Wahyuni & Fitria, 2023). The contribution of the present study lies in combining these approaches within an integrated instructional framework and demonstrating significant effects after controlling students' initial abilities through ANCOVA.

A significant simultaneous effect emerged for conceptual understanding and critical thinking, as indicated by Pillai's Trace = .99, $F(2, 25) = 1476.12$, $p < .001$, $\eta^2p = .99$. Follow-up analyses confirmed substantial effects on conceptual understanding, $F(1, 26) = 794.57$, $p < .001$, $\eta^2p = .97$, and critical thinking, $F(1, 26) = 1299.05$, $p < .001$, $\eta^2p = .98$. The magnitude of the multivariate effect indicates that the intervention influenced both cognitive outcomes simultaneously rather than producing an isolated effect on one competency.

Conceptual understanding and critical thinking represent complementary dimensions of meaningful science learning: conceptual knowledge provides a foundation for interpreting scientific phenomena, whereas critical thinking enables students to evaluate evidence and apply knowledge to problems. Constructivist learning theory supports such integration by emphasizing active knowledge construction through authentic inquiry and reflection (Nirmala et al., 2026). Coordinated verbal and visual information can further facilitate cognitive processing within such learning experiences, consistent with the Cognitive Theory of Multimedia

Learning (Engida & Iyasu, 2023). Although previous studies have examined these outcomes separately or evaluated instructional models and digital media independently (García-Carmona, 2024; Lin et al., 2024), the present findings indicate higher simultaneous posttest performance under the combined pedagogical Deep Learning and audiovisual-media condition after controlling for baseline measures. However, because the study evaluated the two components as a bundled instructional package, the findings do not establish the separate contribution or mechanism of pedagogical Deep Learning or audiovisual media. Component-specific effects therefore remain unknown, and the observed differences should be interpreted as associated with the integrated instructional condition rather than attributed independently to either component. MANCOVA provided a multivariate assessment of this combined outcome while accounting for baseline performance.

Theoretical significance emerges from the combination of active knowledge construction and multimedia-supported cognitive processing in meaningful learning (Aulia et al., 2023). Methodologically, sequential ANCOVA and MANCOVA provide a comprehensive approach for evaluating multidimensional learning outcomes (Fraenkel et al., 2023; Muchammad Tholchah, 2025).

Practical application may involve integrating audiovisual media within inquiry-oriented instructional activities resembling the conditions of the present study, particularly when teachers provide structured support for students to investigate problems, interpret evidence, construct explanations, and communicate their reasoning. Under these conditions, the combined use of pedagogical Deep Learning and audiovisual media may support students' scientific literacy and higher-order thinking while contributing to SDG 4. However, these implications should not be generalized to audiovisual media used independently, because the present study evaluated audiovisual media as part of a bundled instructional condition.

Limited sample size and the use of a single elementary school restrict the generalizability of the results. Measurement was also limited to the intervention period, preventing evaluation of long-term retention and transfer. Future studies should involve larger and more diverse samples, longitudinal assessments, and different science topics and educational levels to examine the scalability and durability of the intervention.

CONCLUSION

The findings indicate statistically significant adjusted between-group differences in both conceptual understanding and critical thinking, individually and simultaneously, after controlling for pretest conceptual understanding and critical thinking. These findings provide empirical evidence of higher posttest outcomes under the combined pedagogical Deep Learning and audiovisual-media condition within the studied elementary science context. However, because the study used a small, nonrandom matched quasi-experimental design, the results should not be interpreted as definitive causal evidence. The separate contribution of pedagogical Deep Learning and audiovisual media also remains unknown because the two components were implemented as a bundled instructional condition.

Within conditions resembling the present study, the findings suggest that inquiry-oriented activities supported by teacher guidance, audiovisual representations, evidence interpretation, explanation construction, and reasoning opportunities may be relevant for supporting conceptual understanding and critical thinking. No claim of feasibility is made because feasibility was not directly measured. Future research should use larger and more diverse samples, randomization or stronger comparison designs where feasible, and component-specific conditions to examine the independent contributions of pedagogical Deep Learning and audiovisual media across science topics and educational contexts.

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