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Deep Learning-Based RADEC With a Mini Book for Critical Thinking in Grade 5 Science

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Abstract: The study examined the effectiveness of a Deep Learning-based RADEC (Read–Answer–Discuss–Explain–Create) intervention assisted by a Mini Book for enhancing fifth-grade students' critical thinking in science learning on sound and its properties. A quantitative quasi-experimental nonequivalent control-group design involved 54 students from two intact classes at an anonymized elementary school in Bandung City, Indonesia. The experimental group received three sessions organized through RADEC and oriented toward mindful, meaningful, and joyful learning, with the Mini Book used continuously as concise content, guiding questions, and experimental tasks. The comparison group received contextual learning supported by instructional videos. Critical thinking was measured using a 10-item essay test representing four operational indicators. The experimental mean increased from 64.52 to 81.04, whereas the comparison mean increased from 63.33 to 75.19. The experimental N-gain was 0.4666, indicating a moderate improvement, and the posttest difference was significant, $t(52)=3.099$, $p=.003$. The findings provide context-specific evidence that the integrated intervention was associated with stronger short-term critical-thinking performance than the comparison condition. Because the design did not isolate the separate effects of Deep Learning, RADEC, and the Mini Book, the results should be interpreted as evidence for the intervention package rather than for any single component.

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INTRODUCTION

Contemporary elementary education is expected to develop not only content knowledge but also students' capacity to interpret information, justify claims, evaluate alternatives, and make reasoned decisions. These expectations are particularly important in science because students encounter phenomena that require them to connect observations with concepts and to explain why an event occurs rather than merely recall a definition (Amrina et al., 2024; Astuti, 2024; Barus, 2024). Critical thinking therefore represents a practical learning outcome: it supports students in questioning information, using evidence, drawing defensible conclusions, and solving problems encountered in everyday life (Kusyanto et al., 2022; Wahono et al., 2022). Research in elementary science has consequently emphasized learning experiences that involve inquiry, problem solving, reflection, communication, and contextual activity rather than passive reception of information (Sudarma, 2024; Yamanaka et al., 2024).

The expected profile described above contrasted with the initial condition observed in the participating fifth-grade classes. Students studying sound and its properties tended to wait for the teacher's explanations, were hesitant to ask questions or share ideas, and had difficulty responding to analytical questions. School learning records also showed that only 14 of 27 students in the class who were later assigned to the experimental condition met the school's minimum mastery criterion of 75. Although a mastery score is not itself a direct measure of critical thinking, this classroom evidence, together with the observed difficulty in explanation and analytical response, indicated a need for instruction that provided more systematic opportunities to obtain information independently, formulate

an initial position, test that position through peer interaction, communicate reasoning, and apply concepts in a concrete task.

Critical thinking in this study was conceptually informed by Ennis (2011), who describes a broader framework containing multiple areas and subcomponents. For measurement purposes, however, the present study operationalized only four indicators, as represented in the available essay instrument: providing simple explanations, building basic skills, providing further explanations, and developing strategies or tactics. This distinction is important. The study does not claim to measure the full Ennis framework, and the results should be interpreted as performance on these four operational dimensions rather than as a comprehensive assessment of every dimension of critical thinking. This clarification also establishes a direct alignment between the construct described in the manuscript, the test used in the study, and the interpretation of the findings.

RADEC—Read, Answer, Discuss, Explain, and Create—offers a structured sequence that can provide such opportunities. Read and Answer require students to encounter information and formulate an individual response before classroom interaction. Discuss and Explain shift the learning process toward comparison, justification, and communication of ideas. Create requires students to use what they have understood in a task, product, solution, or experiment. Previous studies have reported favorable critical-thinking outcomes when RADEC was supported by animation, STEAM, augmented reality, metacognitive teaching materials, or question-box media (Afandi et al., 2024; Candraswari & Suniasih, 2024; Jumanto et al., 2024; Maisarah & Rusnilawati, 2026; Setyawan et al., 2023). These studies establish the relevance of RADEC and show that it is frequently implemented alongside other supports. They therefore do not answer whether the particular instructional configuration examined in the present study will function similarly in Grade 5 science learning on sound.

The Mini Book in this study was not treated as a stand-alone treatment or as a substitute for the learning model. It was designed as a compact and continuous learning resource that students could revisit across the sequence. During Read and Answer, it provided concise conceptual information and guiding questions. During Discuss and Explain, it served as a common reference point against which students could compare and justify their responses. During Create, it provided task guidance and a place to organize observations. This continuity is pedagogically relevant because a shared resource can reduce fragmentation between individual preparation, collaborative reasoning, and application. Research on Mini Books, e-books, and structured learning resources suggests that concise and accessible materials can support understanding, retention, independent learning, and problem solving (Irawan et al., 2022; Pitri Situmorang et al., 2024; Susanto et al., 2022). Nevertheless, because the comparison group in this study used video rather than an equivalent print resource, the design cannot isolate a unique Mini Book effect.

The intervention was additionally oriented toward the educational Deep Learning approach, which in the Indonesian educational discourse emphasizes mindful, meaningful, and joyful learning. Here, Deep Learning does not refer to artificial intelligence. Mindful learning was operationalized through focused independent engagement with information, deliberate answering, and attention to evidence. Meaningful learning was operationalized through connections between the concept of sound, prior knowledge, discussion, explanation, and observable phenomena. Joyful learning was pursued through collaborative interaction and hands-on experimentation intended to sustain participation without reducing intellectual demand (Nafi'ah & Faruq, 2025; Wicaksono et al., 2026). Thus, Deep Learning supplied a pedagogical orientation, whereas RADEC supplied the instructional sequence and the Mini Book supplied a recurring material support.

The theoretical rationale for integrating the three elements is mechanism-based rather than additive. The intervention was expected to create a chain of cognitive opportunities. First, the Read–Answer phase required retrieval, selection, and initial organization of information, supporting mindful engagement and simple explanation. Second, Discuss–Explain required students to compare responses, identify disagreements, use evidence, and articulate a more defensible account, supporting evaluation and further explanation. Third, Create required transfer of the concept into an experiment and conclusion, supporting strategy use and application. The Mini Book linked these phases by maintaining access to the same conceptual cues and questions. In this configuration, the potential value lies not in claiming that

each component independently causes the development of critical thinking, but in arranging repeated opportunities for students to move from individual preparation to social reasoning and then to application.

This distinction also defines the research gap more precisely. Existing studies provide evidence that RADEC can support critical thinking, that various media can support elementary learning, and that mindful, meaningful, and joyful learning is conceptually relevant to deeper engagement. What remains less documented is how a Deep Learning orientation can be operationalized through a complete RADEC sequence with a continuous Mini Book resource in elementary science, and whether students experiencing that package show stronger short-term critical-thinking performance than students receiving the school's contextual video-supported comparison instruction. The present study therefore does not claim to establish a new instructional model or the independent superiority of any single component. Its contribution is narrower: context-specific empirical evidence about one integrated instructional intervention and a transparent description of the mechanisms through which the components were coordinated.

Accordingly, this study aimed to: (1) describe the implementation of Deep Learning-based RADEC assisted by a Mini Book in Grade 5 science learning; (2) examine changes in students' critical-thinking scores from pretest to posttest in both the experimental and comparison groups; and (3) compare posttest critical thinking outcomes between the experiment and control groups, considering baseline scores when statistically relevant. The study also interprets the magnitude of change cautiously in relation to the short intervention, intact-class design, and the fact that both groups received active instruction.

METHOD

Research Design

This study used a quantitative quasi-experimental nonequivalent control-group design. The design was selected because the school's intact classes could not be reorganized through individual random assignment (Creswell, 2014). Both groups completed a pretest and posttest. Class-level assignment effects, or other pre-existing differences. A nonsignificant pretest difference is treated only as evidence that no statistically detectable baseline difference was observed on the measured outcome; it is not interpreted as proof that the groups were equivalent on all relevant characteristics.

The experimental condition combined three coordinated elements: Deep Learning as the pedagogical orientation, RADEC as the instructional sequence, and the Mini Book as the supporting learning resource. The comparison condition used contextual learning supported by instructional videos. Both groups studied the same general science topic of sound and its properties during the study period. Because the instructional packages differed in more than one feature, the design estimates the difference between the packages as implemented; it cannot identify the independent contribution of RADEC, Deep Learning, or the Mini Book.

Participants and Research Ethics

The population comprised 54 fifth-grade students distributed across two intact classes at one elementary school in Bandung City, Indonesia, with 27 students in each class. Saturated sampling was used because the entire Grade 5 population available at the site participated. One intact class served as the experimental group and the other as the comparison group. To protect the privacy of minor participants and the institution, the school name is anonymized in the revised manuscript. No individual student names or personally identifying information are reported. The study was conducted within the school's instructional setting. Authors should ensure that the journal submission metadata and supporting documents contain the applicable institutional permission, parental/guardian consent, child assent, and/or ethics approval information required by the journal and their institution.

Intervention and Comparison Condition

The intervention was implemented in three sessions as shown in Table 1. Session 1 comprised Read and Answer; Session 2 comprised Discuss and Explain; and Session 3 comprised Create. During Read, students independently used the Mini Book and other teacher-provided sources to identify information about sound. During Answer, they responded to pre-learning questions using the information

read and their prior knowledge. During Discuss, students compared responses in groups and examined differences in reasoning. During Explain, groups communicated conclusions and responded to questions. During Create, students conducted a simple sound experiment, recorded observations, and formulated a conclusion or solution. The comparison group received contextual learning supported by instructional videos. The short three-session duration was sufficient to examine immediate changes in test performance but was not designed to establish sustained development.

Table 1. Alignment of RADEC Stages with dee Learning Orientations

RADEC stage	Deep Learning orientation	Learning activity	Critical-thinking process addressed
Read	Mindful	Independent reading of Mini Book and other sources	Identify and understand relevant information
Answer	Mindful–meaningful	Answer guiding questions using information and prior knowledge	Provide simple explanations
Discuss	Meaningful–joyful	Compare answers, question ideas, and discuss evidence	Build basic skills and evaluate information
Explain	Meaningful	Present and defend group reasoning	Provide further explanations
Create	Meaningful–joyful	Conduct an experiment and formulate a conclusion/product	Develop strategies or tactics and apply concepts

Instruments and Validation

Data were collected using a critical-thinking essay test and an implementation observation sheet. The critical-thinking test consisted of 10 essay items administered as pretest and posttest. The instrument operationalized four indicators: (1) providing simple explanations, (2) building basic skills, (3) providing further explanations, and (4) developing strategies or tactics for problem solving. Before use, the items were reviewed by experts and trialed with a separate sample to assess validity and reliability. The revised manuscript deliberately limits its construct claims to these four indicators because the available instrument did not operationalize the complete five-area Ennis framework. The observation sheet documented whether planned instructional activities were implemented and described student participation across the three sessions. Because the manuscript does not contain item-level validity coefficients, the reliability coefficient, scoring-rubric statistics, or inter-rater reliability estimates, the measurement evidence should be interpreted as a limitation rather than supplemented with unverified values.

For the observation data, teacher implementation and student implementation were recorded as percentages of planned indicators completed. These percentages are used descriptively to document implementation, not as independent measures of confidence, collaboration, or motivation. Statements about students becoming more comfortable with the sequence are therefore presented as interpretations of observed participation rather than as measured psychological outcomes.

Data Collection Procedures

The procedure comprised preparation, baseline assessment, intervention, outcome assessment, and analysis. During preparation, preliminary classroom observations were conducted, the critical-thinking instrument was prepared and reviewed, and the learning materials and Mini Book were organized. Both groups then completed the pretest. The experimental group participated in the three RADEC sessions, while the comparison group participated in the designated contextual video-supported instruction. The implementation of the experimental sequence was documented on the observation sheet. After the instructional period, both groups completed the posttest. The same overall testing structure for both groups reduced procedural differences, although repeated exposure to the assessment format may have contributed to improvement in both groups. The methodological flow of the study is shown in Figure 1.

Data Analysis

Data were analyzed using IBM SPSS Statistics 26. Shapiro–Wilk tests were used to examine normality and Levene's test to examine homogeneity of variance. An independent-samples t-test compared the groups. N-gain described the magnitude of pretest-to-posttest improvement, with values of 0.70 or higher interpreted as high, 0.30–0.69 as moderate, and below 0.30 as low. Statistical significance was evaluated at α=.05. The main reported inferential comparison is the posttest independent-samples t-test. Because the design was nonequivalent and the available analysis did not directly adjust posttest scores for baseline through ANCOVA or a mixed model, the findings are interpreted as an association between the implemented condition and posttest performance rather than as definitive causal evidence. From the reported equal-variance t statistic and equal group sizes, Cohen's d can be estimated as $t\sqrt{(1/n_1+1/n_2)}$; with t=3.099 and $n_1=n_2=27$, d≈0.84. This effect-size estimate complements, but does not replace, the limitations of the design.

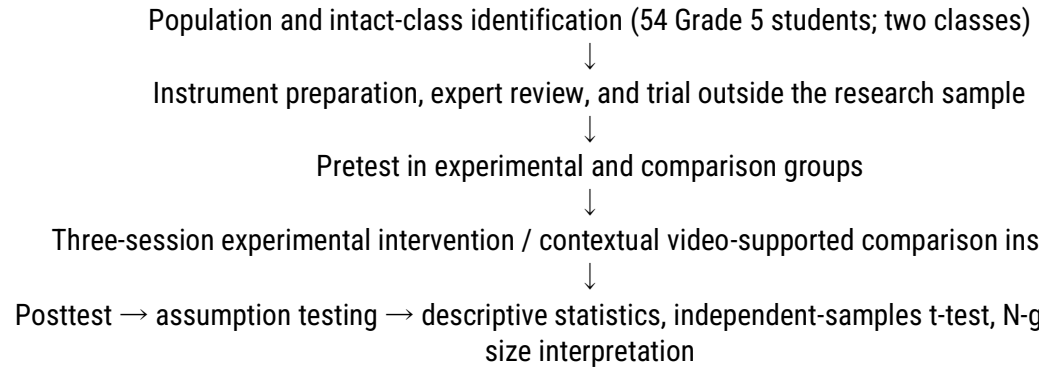


Figure 1. Methodological flow of the study

RESULT

Implementation of the Intervention

The teacher completed the planned RADEC sequence in all three sessions. Student implementation increased from 87% in Read–Answer to 97% in Discuss–Explain and 100% in Create as shown in Table 2. The pattern indicates that a larger proportion of planned student activities was completed as the sequence progressed. It should not be interpreted as direct evidence of increased confidence or motivation because those constructs were not independently measured.

Table 2. Results of RADEC Stages Implementation

Session	RADEC stages	Teacher implementation	Student implementation
1	Read–Answer	100%	87%
2	Discuss–Explain	100%	97%
3	Create	100%	100%

In Session 1, students used the Mini Book and other sources before answering pre-learning questions independently. In Session 2, they compared responses, discussed reasoning, and presented group explanations. In Session 3, they conducted a simple experiment on sound, recorded observations, and formulated conclusions. The increasing completion percentages suggest that the instructional routine became more fully enacted across sessions, although the study did not test whether the increase was statistically significant.

Table 3. Critical-Thinking Outcomes

Group	n	Pretest mean	Posttest mean	Mean increase	N-gain	Interpretation
Experimental	27	64.52	81.04	16.52	0.4666 (46.66%)	Moderate
Comparison	27	63.33	75.19	11.86	0.3037 (30.37%)	Moderate

Table 3 shows that both groups improved from pretest to posttest. The experimental group increased by 16.52 points and obtained an N-gain of 0.4666, while the comparison group increased by 11.86 points and obtained an N-gain of 0.3037. Both N-gain values fall within the moderate category under the criteria used in this study. Accordingly, the result is not improvement versus no improvement; rather, the experimental group showed the larger descriptive gain.

Table 4. Results of Normality, Homogeneity, and Independent Samples t-Test Analyses

Analysis	Statistic	p-value	Interpretation
Shapiro–Wilk, experimental pretest	0.939	0.113	Normal
Shapiro–Wilk, experimental posttest	0.942	0.140	Normal
Levene test	0.859	0.358	Homogeneous
Independent t-test, pretest	t=0.490; df=52	0.626	No statistically significant initial difference
Independent t-test, posttest	t=3.099; df=52	0.003	Statistically significant difference

Table 4 shows that the pretest comparison was not statistically significant (p=.626). The posttest comparison yielded t(52)=3.099, p=.003, with a mean difference of 4.815 points and a 95% confidence interval from 1.698 to 7.932. The estimated standardized mean difference was Cohen's d≈0.84, indicating a sizeable between-group posttest difference under conventional descriptive benchmarks. This estimate should nevertheless be interpreted in conjunction with the intact-class design, the small single-school sample, and the absence of baseline-adjusted modeling.

DISCUSSION

The central empirical pattern is that students in both instructional conditions improved, while the experimental group obtained a higher posttest mean and a larger N-gain. The statistically significant posttest difference, together with an estimated Cohen's d of approximately 0.84, indicates that the difference was not only detectable statistically but also substantial in standardized-score terms within this sample. At the same time, the experimental N-gain remained moderate rather than high. These two observations are compatible: the experimental group can differ meaningfully from the comparison group at posttest while still showing only moderate normalized improvement from its own baseline. The result therefore supports a cautious claim of stronger short-term performance under the integrated intervention, not a claim of complete or high-level transformation in critical thinking.

The learning sequence offers one plausible explanation for the pattern. Read and Answer positioned students as active preparers rather than recipients of an initial teacher explanation. Students first had to locate relevant information and commit to an answer. Discuss then made those individual responses visible to peers, creating a reason to compare claims and evidence. Explain required students to organize and communicate reasoning publicly. Create moved the activity from verbal explanation to an experiment in which students observed sound-related phenomena and formulated a conclusion. This progression is consistent with the four measured indicators because it repeatedly asks students to explain, use basic evidence, elaborate reasoning, and determine a strategy for completing a task. This alignment provides a reasonable explanation for the greater improvement seen in the experimental group, even though the impact of each specific learning stage was not examined separately.

The results generally align with earlier research examining RADEC across various teaching strategies. Afandi and others in 2024 examined the use of animation to support RADEC; Setyawan and others in 2023 studied RADEC with a STEAM approach; Candraswari and Suniasih in 2024 explored the use of question boxes; and Maisarah and Rusnilawati in 2026 examined RADEC with augmented reality assistance. These studies show how RADEC is used in different teaching settings. This study builds on previous research by exploring RADEC, which focuses on mindful, meaningful, and joyful learning experiences, supported by a Mini Book used throughout the instructional process. However, the results should not be taken as proof that this setup is better than the ones looked at in earlier research, since

differences in the people involved, the learning resources used, the length of the intervention, the tools used to measure progress, and the conditions used for comparison could all influence the results. A proper comparison of effectiveness would need studies that have similar designs and methods of measurement.

The Deep Learning orientation helps explain the intended quality of these activities but should not be treated as an independently tested causal component. Mindful learning was represented by deliberate engagement with reading and guiding questions; meaningful learning by connecting information, prior knowledge, peer reasoning, and observable sound phenomena; and joyful learning by collaborative and hands-on participation. These qualities were embedded in the RADEC stages rather than delivered as a separate treatment. Consequently, the present evidence shows how a Deep Learning orientation can be operationalized within RADEC, but it cannot establish that adding the label or orientation of Deep Learning independently increased scores beyond what RADEC itself would have produced. This distinction directly addresses the conceptual overlap between the two constructs.

The Mini Book likewise functioned as an embedded support rather than an independently evaluated medium. Its main instructional role was continuity. The same compact resource was available during individual preparation, group comparison, explanation, and experimentation. This may have reduced the need to shift between unrelated sources and may have helped students return to questions and concepts when justifying an answer. Such use is consistent with prior work describing structured print and digital resources as supports for understanding and problem solving (Irawan et al., 2022; Susanto et al., 2022). However, because the comparison condition used video-supported contextual learning, the study cannot determine whether a Mini Book is superior to an equivalent print resource or whether the observed difference reflects the broader instructional package.

The present findings are broadly consistent with earlier RADEC research, but the contribution is best described as an extension in context and configuration rather than proof of a wholly new model. Afandi et al. (2024) reported improved critical thinking with animation-assisted RADEC; Setyawan et al. (2023) reported favorable outcomes for STEAM-based RADEC; Candraswari and Suniasih (2024) examined question-box support; and Maisarah and Rusnilawati (2026) examined augmented-reality-assisted RADEC. Together, these studies suggest that RADEC can be paired with different supports. The current study adds evidence from Grade 5 elementary science on sound and its properties, using a Deep Learning orientation and a Mini Book that remained active throughout the sequence. What is new is therefore the documented instructional configuration and its context-specific outcome, not evidence that the three components have unique or synergistic effects.

The moderate N-gain deserves particular attention. Three sessions are a short exposure for a complex outcome such as critical thinking. Students must become accustomed not only to the science content but also to independent preparation, peer comparison, public explanation, and application. The increase in student implementation from 87% to 100% is compatible with the interpretation that the routine became easier to enact over time, but it does not demonstrate a psychological change in confidence or collaboration. Longer implementation could allow repeated cycles of Read–Answer–Discuss–Explain–Create and provide more opportunities for feedback, revision, and transfer across topics. The current findings therefore represent immediate performance following a brief intervention rather than evidence of sustained critical-thinking development.

The improvement in the comparison group is equally important. Its N-gain of 0.3037 was also moderate. Contextual learning supported by video was therefore neither inactive nor ineffective. The more defensible interpretation is that both groups benefited during the instructional period, while the experimental group showed the larger gain and higher posttest performance. This framing avoids equating a lower N-gain with instructional failure and recognizes that conventional or comparison teaching can also support learning. It also reduces the risk of attributing every observed improvement to the experimental package.

The findings should be interpreted in relation to the observed differences between the two teaching methods. Although no significant difference was observed between the two groups on the pretest, the experimental group showed greater improvement on the posttest. This pattern is consistent with the possibility that the coordinated sequence of individual preparation, collaborative discussion,

explanation, and experimentation provided students with repeated opportunities to practice critical-thinking processes. These activities were aligned with the four indicators assessed in this study by requiring students to formulate explanations, examine information, elaborate their reasoning, and apply strategies. However, the observed difference should be interpreted as an association with the integrated intervention rather than definitive evidence that the intervention alone caused the improvement.

The improvement in both groups also provides an important context for interpreting the findings. The comparison group's moderate N-gain indicates that contextual learning supported by videos also accompanied an improvement in students' critical-thinking scores. The larger gain in the experimental group may reflect the structured progression of RADEC activities and the continuous use of the Mini Book as a reference for individual preparation, discussion, and application. On the contrary, these explanations remain plausible interpretations because the study did not isolate the effects of the individual components. In addition, repeated exposure to the assessment format may have contributed to some of the improvement observed in both groups. Thus, the findings suggest a more favorable short-term performance pattern for the integrated intervention within this sample, while the relative contributions of instructional activities, learning resources, and assessment familiarity remain uncertain.

The findings have practical implications for learning design. First, critical-thinking opportunities can be distributed across an instructional sequence rather than concentrated in a final "higher-order" question. Individual preparation can be followed by peer comparison, public explanation, and application. Second, a supporting resource can be designed to ensure continuity across phases rather than used once and then abandoned. Third, teachers can make the relationship between activity and reasoning explicit: students should know when they are expected to identify evidence, justify a claim, challenge an explanation, or devise a strategy. These design principles can be applied without assuming that every school must adopt the identical Mini Book used in this study.

For curriculum development, the study suggests that critical thinking can be embedded in ordinary elementary science content such as sound rather than treated as a separate subject. A curriculum can sequence opportunities for preparation, dialogue, explanation, and experimentation within topic units. The Deep Learning principles of mindful, meaningful, and joyful learning are most useful when translated into observable instructional decisions rather than retained as general slogans. Mindfulness can be supported through purposeful questions and independent preparation; meaningfulness through connections among prior knowledge, scientific concepts, and observable phenomena; and joy through intellectually purposeful interaction and hands-on work. Curriculum documents and teacher guides can therefore specify what students are expected to think and do at each stage.

At the policy level, the results should not be used to mandate a single instructional package based on a single-school study. Their more appropriate relevance is to implementation support. If education policy encourages Deep Learning, teachers need concrete examples of how its principles can be enacted through existing instructional models, materials, assessment tasks, and classroom routines. Professional development should emphasize alignment among pedagogical orientation, instructional sequence, learning resources, and assessment. Policy evaluation should also distinguish implementation fidelity from student outcomes: completing every planned stage is useful information, but it is not itself evidence that critical thinking has improved.

Limitations

Several limitations constrain the interpretation and transferability of the findings. First, the study involved 54 students in two intact classes from one elementary school. The sample is institutionally and geographically narrow, and class assignment was not randomized. Second, the intervention lasted only three sessions and addressed one science topic, so the study captures immediate performance rather than sustained development or transfer across topics. Third, the experimental and comparison conditions differed in multiple instructional features; therefore, the separate effects of Deep Learning, RADEC, and the Mini Book cannot be isolated. Fourth, the principal inferential analysis compared posttest scores without a baseline-adjusted ANCOVA or mixed-effects model. Fifth, the essay instrument represented four critical-thinking indicators, and the manuscript does not provide complete item-level validity, reliability, scoring rubric, or inter-rater statistics. Sixth, the implementation observation percentages were

descriptive and do not constitute validated measures of confidence, motivation, or collaboration. Finally, pretest–posttest familiarity may have contributed to improvement in both groups.

Recommendations

Future studies should replicate the intervention across multiple schools, teachers, and student populations and should extend implementation over repeated RADEC cycles. Baseline-adjusted analyses, multilevel models where appropriate, and delayed posttests would strengthen inference about change and retention. Comparative or factorial designs could include RADEC-only, Deep Learning-oriented RADEC without the Mini Book, and equivalent-media conditions to examine whether individual components or their interaction account for differences. Future instrument reporting should include item validity, reliability, scoring rubrics, and inter-rater agreement, and should either operationalize the complete critical-thinking framework or state clearly which dimensions are measured. Parallel assessment forms could reduce testing effects. For practice, teachers are encouraged to adapt the sequence of independent preparation, collaborative reasoning, explanation, and application to local science topics while monitoring whether students are actually engaging in the intended reasoning processes.

CONCLUSION

This study provides context-specific evidence that a Deep Learning-based RADEC intervention assisted by a Mini Book was associated with higher short-term critical-thinking performance in Grade 5 science learning on sound and its properties than the contextual video-supported comparison condition. The experimental mean increased from 64.52 to 81.04, with a moderate N-gain of 0.4666, while the comparison mean increased from 63.33 to 75.19, with a moderate N-gain of 0.3037. The posttest difference was statistically significant, $t(52)=3.099$, $p=.003$, and the estimated standardized difference was Cohen's $d\approx0.84$.

The instructional contribution lies in the coordinated design: Deep Learning provided the orientation toward mindful, meaningful, and joyful learning; RADEC organized preparation, discussion, explanation, and creation; and the Mini Book provided a continuous resource across these activities. The design does not establish that any one component independently caused the difference, nor does it demonstrate a unique synergistic effect of the three components. Given the intact classes, single-school sample, three-session duration, measurement limitations, and non-baseline-adjusted analysis, the findings should be treated as promising evidence for the intervention package that warrants more rigorous and extended replication.

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AI USE STATEMENT

The authors utilized a generative artificial intelligence (AI) tool to help with editing academic language. This assistance was focused on enhancing the clarity and structure of specific parts of the manuscript. The authors carefully examined and revised all AI-assisted content and are fully accountable for the accuracy, originality, and interpretation of the research results, as well as the final version of the manuscript.

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