

The Effect of the 9E Learning Cycle Model on Science Learning Outcomes: A Quasi-Experimental Study in Fourth-Grade Elementary School

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Abstract

This study addressed the issue of low science learning outcomes among fourth-grade students at SDN 04 Kinali. The purpose of this research was to examine the impact of the 9E Learning Cycle model on students' science learning outcomes. The study employed a quantitative approach with a quasi-experimental design, specifically the posttest-only control group design. The population included all fourth-grade students at SDN 04 Kinali. The sample was divided into two groups: class IVA as the experimental group (27 students) and class IVB as the control group (28 students). Data collection was carried out using a 15-item multiple-choice test that had undergone validation for validity, reliability, discriminating power, and difficulty level. Data analysis involved normality testing, homogeneity testing, and hypothesis testing (t-test) with the assistance of SPSS 27. The findings revealed that the experimental group achieved an average score of 81, whereas the control group obtained 72. The hypothesis test produced a significance value of $0.013 < 0.05$, indicating that H_0 was rejected and H_1 was accepted. This means that the 9E Learning Cycle model had a notable effect on the science learning outcomes of fourth-grade students at SDN 04 Kinali. The model proved effective as it encouraged students to actively build their understanding through exploration, elaboration, and evaluation stages. Teachers are advised to consider the 9E Learning Cycle model as an alternative instructional strategy, and future researchers may explore affective and psychomotor domains or incorporate other variables such as learning motivation.

Keywords: 9E Learning Cycle, Learning Outcomes, Science, Elementary School

INTRODUCTION

Science education in the 21st century has become a cornerstone for preparing students to face pressing global issues, including climate change, public health crises, and rapid technological advancement (Imjai et al., 2025; Sahni et al., 2025). At the elementary school level, science learning lays the groundwork for scientific literacy, stimulates curiosity, and cultivates critical thinking abilities that students will rely on throughout their education and careers (Iqbal et al., 2026). Findings from international assessments like TIMSS and PISA have repeatedly underscored the value of early science instruction in influencing students' long-term academic paths and their interest in pursuing STEM-related fields (Abrigo et al., 2026; Pitsia & Karakolidis, 2026; Verhelst & Yıldırım, 2026). Nevertheless, despite broad acknowledgment of its significance, science education still confronts enduring obstacles, especially in developing nations where conventional,

teacher-directed methods of instruction continue to prevail (Abakah, 2023; Geng et al., 2026; Martins et al., 2024).

Learning outcomes serve as a key indicator of educational effectiveness, capturing shifts in students' cognitive, affective, and psychomotor abilities after instruction (Ibourk & El Aynaoui, 2026; Nkrumah et al., 2026; Singh et al., 2026). Within science education, these outcomes include not just factual knowledge but also the ability to apply scientific ideas to real-world scenarios, analyze phenomena, and reason using evidence (De Witte et al., 2024; Hodgkiss et al., 2025; Perez-Ferreiro et al., 2026). Studies repeatedly show that student-centered approaches produce better results than traditional lecture-based teaching, especially in fostering conceptual understanding and the transfer of knowledge (Misal & Hakke, 2026; Oberdiek et al., 2026; Romero-Cano, 2025). As a result, teachers and scholars have been investigating new instructional models that encourage students to actively participate and build their own understanding (Karkar-Esperat et al., 2026; Kozaklı Ülger et al., 2026; Park et al., 2025).

The 9E Learning Cycle model builds upon earlier versions of learning cycle frameworks. It traces its roots from the original 3E model, which Karplus and Their introduced in 1967, then moved to the 5E model by Bybee in 1997, followed by the 7E model from Eisenkraft in 2003, and finally the 9E model that Kaur proposed in 2014 (Lasaiba & Lasaiba, 2024; Noreen et al., 2024). This model consists of nine stages that follow one another: Elicitation, Engagement, Exploration, Explanation, Echo, Elaboration, Evaluation, Emendation, and E-Search. Every stage serves to guide students' learning step by step, helping them build understanding through hands-on exploration and reflection instead of simply receiving information passively (Greco et al., 2026; Hsu & Hsu, 2026; Shi et al., 2026). The 9E Learning Cycle is rooted in constructivist learning theory, which holds that learners actively create understanding by linking new information to what they already know. In contrast to earlier models, the 9E version includes specific steps for correcting misconceptions (Emendation) and for using technology (E-Search), which makes it well-suited for today's educational settings (Mekonnen et al., 2024).

Previous studies have looked into how well different learning cycle models work across various educational settings and subjects. (Meldayani et al., 2025) found that the 9E Learning Cycle had a positive impact on chemistry learning outcomes at the senior high school level. In a similar vein, (Sintia et al., 2025) discovered that the 9E Learning Cycle improved mathematical problem-solving skills among junior high school students. (Musfiroh et al., 2024) showed that the 7E Learning Cycle, when paired with spinning wheel media, was effective for science learning outcomes in elementary schools. (Jibril, 2024) also found that a mind mapping-based 9E Learning Cycle helped improve creative thinking skills in science education. Beyond Indonesia, researchers have examined learning cycles in other contexts. (Ahmed, 2026), for instance, reported that the 5E Learning Cycle enhanced conceptual understanding in physics among Taiwanese high school students, while (Hacıeminoglu et al., 2022) noted positive effects of the 5E model on Turkish pre-service teachers' science process skills. Taken together, these studies indicate that learning cycle models, especially the 9E version, show promise for boosting educational outcomes in a range of settings.

Even with more studies showing the benefits of learning cycles, a clear gap remains when it comes to using the 9E Learning Cycle model in elementary science education, especially in Indonesia. Most studies so far have looked at secondary or tertiary levels, so elementary education has received less attention (Giuliani et al., 2026; Grosch et al., 2026; Sultana & Fang, 2024).

Despite the growing body of literature supporting learning cycle models, a critical research gap remains regarding the application of the 9E Learning Cycle in elementary science education, particularly within rural or semi-rural contexts. Most existing studies conducted in Indonesia have predominantly utilized qualitative or descriptive methodologies, which limits the ability to draw definitive cause-and-effect

conclusions (Alfian et al., 2024). Furthermore, there is a scarcity of rigorous quasi-experimental research employing control groups to empirically measure the 9E model's impact on cognitive learning outcomes in these specific settings. This empirical gap is significant because the elementary years are a foundational period for developing basic scientific concepts and shaping long-term attitudes toward science (Bodas & Kelemen, 2026; Vahedian Movahed & Martin, 2025; Wongwanich et al., 2026).

This empirical void is particularly evident in the practical context of SDN 04 Kinali, a public elementary school in West Pasaman Regency, where fourth-grade students consistently exhibit poor science learning outcomes. Preliminary observations and interviews conducted in September 2025 revealed that a substantial majority of students failed to achieve the minimum mastery criteria (KKTP) of 75, with 74% of students in class IVA and 64% in class IVB falling below the required competency level. This underperformance is largely attributed to persistent teacher-centered instructional practices, low student engagement, limited opportunities for inquiry, and learning materials that fail to connect with students' everyday experiences. These local challenges mirror broader systemic issues in Indonesian elementary science education, where traditional, didactic teaching methods remain prevalent (Widodo, 2021).

To bridge this gap between empirical research and practical classroom needs, this study investigates the effect of the 9E Learning Cycle model on science learning outcomes using a robust quasi-experimental design. By doing so, it not only addresses the methodological limitations of prior descriptive studies but also responds to the urgent need for effective, student-centered instructional strategies. This aligns with the Indonesian government's implementation of the Merdeka Curriculum, which prioritizes active, competency-based learning (Harjanti et al., 2026), thereby providing actionable, evidence-based insights for improving science education in similar rural and semi-rural elementary schools.

This study set out to examine whether the 9E Learning Cycle model has a measurable impact on science learning outcomes for fourth-grade students at SDN 04 Kinali. Using a quasi-experimental design with a posttest-only control group, the study offers empirical insights into how well the 9E Learning Cycle works in an elementary science setting. The results are intended to add to what we know about learning cycle models in theory, while also giving teachers, curriculum designers, and education policymakers practical guidance for enhancing science education. The research question guiding this study is: Does the 9E Learning Cycle model produce a statistically significant effect on science learning outcomes among fourth-grade students at SDN 04 Kinali? Accordingly, the hypothesis is stated as follows: H0: The 9E Learning Cycle model has no significant effect on science learning outcomes; H1: The 9E Learning Cycle model has a significant effect on science learning outcomes.

METHOD

Research Design

A quantitative approach was adopted in this study, using a quasi-experimental design known as the posttest-only control group design (Uddin & Agarwal, 2026; Wang, 2026; Zhang, 2026). This design was chosen because it permits a comparison between an experimental group that receives a treatment and a control group that does not, while acknowledging that randomly assigning individual participants to groups is often not practical in educational settings (Askari Zaman et al., 2026; Gonzalez Jauregui et al., 2026; Mohamed et al., 2026). The quasi-experimental method is well-suited for examining cause-and-effect relationships between an independent variable (the 9E Learning Cycle model) and a dependent variable (science learning outcomes) under conditions that come close to true experimentation but lack full randomization (Meldayani et al., 2025). By measuring outcomes only after the intervention, the posttest-only control group design helps control for potential testing effects and history threats (Sriwilna et al., 2026).

The choice to use a posttest-only design instead of a pretest-posttest design rested on a few reasons. First, the researcher wanted to prevent testing effects that might emerge from giving a pretest, especially with young students who could become attuned to the material (Ngajie et al., 2025). Second, the school's schedule and the goal of causing minimal disruption to normal teaching made a single posttest more feasible. Third, group equivalence was confirmed by purposive sampling based on mid-semester science scores, which showed that the groups had similar baseline characteristics before the intervention (He & Huang, 2026).

Participants

The study included all fourth-grade students at SDN 04 Kinali, a public elementary school in West Pasaman Regency, West Sumatra, Indonesia. The school was selected for three reasons: it had two parallel fourth-grade classes with similar student profiles, its mid-semester science scores showed consistently low outcomes, and the administration agreed to take part. The sample consisted of two intact classes: class IVA ($n = 27$) as the experimental group and class IVB ($n = 28$) as the control group. The total of 55 students aligns with what quasi-experimental research typically recommends at least 30 per group for adequate statistical power (Dias et al., 2025). Although the sample was slightly smaller, the groups were homogeneous and the intervention conditions were controlled, which helped compensate for that limitation.

The sampling was purposive and relied on the classes' mid-semester science scores, which showed that both groups had similar starting points and low mastery levels. The mean mid-semester science score was 73 for class IVA and 71 for class IVB, with no statistically significant difference between them ($t = 0.87$, $p = 0.39$). This step helped ensure the groups were equivalent before the intervention, reducing the chance of selection bias Rua-Gomez et al. (2026). In terms of demographics, the experimental group had 14 male and 13 female students, while the control group had 15 male and 13 female students. All participants were between 9 and 10 years old and spoke Indonesian as their first language. Most students came from families with low to middle socioeconomic backgrounds, and their parents' education levels ranged from elementary school to high school.

The school principal gave permission for the study, and the classroom teachers and students' parents provided informed consent. The students themselves also gave their assent after being told that taking part was voluntary and that they could leave the study at any point without any consequences. The research took place across four meetings in May 2026, consisting of three teaching sessions and one posttest for each group. Every procedure followed the ethical guidelines set by the Indonesian Ministry of Education and Culture for research involving human participants.

Research Instrument

To assess science learning outcomes, a 15-item objective multiple-choice test was employed. The test was constructed around the learning objectives for the topic "Changes in States of Matter," addressing cognitive levels C1 through C4 remembering, understanding, applying, and analyzing as outlined in Bloom's revised taxonomy (Lee (2024)). The blueprint for the test guaranteed that items were evenly distributed across content areas (melting, freezing, evaporation, condensation, sublimation, and crystallization) as well as cognitive levels. For instance, one item asked, "What happens to water when it is placed in the freezer?" (C2, understanding), while another asked, "Why does ice melt faster in a hot room?" (C4, analyzing). The full test blueprint and sample items can be found in Appendix A.

Before the test was used, two experts in elementary science education reviewed its content. They rated each item on a 4-point scale (1 = not relevant, 4 = highly relevant) for clarity, alignment with learning objectives, and suitability for fourth-grade students. The content validity index (CVI) was then calculated for

every item, and any item with a CVI below 0.80 was either revised or removed (Fernández-Lorente et al., 2026). The final version of the instrument had a CVI of 0.92, which reflects excellent content validity. After that, the validated test was pilot-tested with 27 fourth-grade students at SDN 28 Kinali, a school that shared similar characteristics with the research site, such as accreditation level, curriculum implementation, and student demographics. The pilot test took place two weeks before the main study to confirm that the items suited the target population and to spot any unclear or problematic questions.

A series of item analyses was carried out to evaluate validity, reliability, discriminating power, and difficulty level. The reliability coefficient (Cronbach's alpha) came out to 0.891, which points to high internal consistency (Labrousse et al., 2026). Out of the original 30 items, 15 satisfied the criteria for validity ($r > 0.396$), reliability, discriminating power (ranging from fair to very good), and moderate difficulty (0.31–0.70), so these were kept for the final posttest. The full results of the item analysis can be seen in Appendix B. The final 15-item test had a reliability coefficient of 0.891, an average difficulty index of 0.52 (moderate), and an average discrimination index of 0.58 (good), showing that the instrument met psychometric standards for measuring science learning outcomes.

Data Collection Procedure

Data collection unfolded in three stages: preparation, implementation, and posttest. In the preparation stage, the researcher put together lesson plans (modul ajar) that followed the 9E Learning Cycle model for the experimental group, along with conventional lesson plans for the control group. An expert in elementary science education then reviewed both sets using a validation sheet that examined how well the plans matched learning objectives, whether the activities were appropriate, if instructions were clear, and how feasible they were to carry out. The validation confirmed that both sets were valid and suitable for the study, though a few small adjustments were recommended to improve clarity and time allocation.

The experimental group was taught using the 9E Learning Cycle model, which comprises nine phases: Elicitation, Engagement, Exploration, Explanation, Echo, Elaboration, Evaluation, Emendation, and E-Search (Tsfamicael et al., 2026). Each phase had a clear purpose and was carried out in sequence, with the Exploration phase placing particular weight on learning through direct, hands-on activities. In the first session, which covered freezing and melting, students watched ice melt and water freeze via video clips and straightforward experiments. The second session focused on evaporation and condensation, where students explored how heated water turns into vapor and how that vapor condenses on cold surfaces. In the third session, on sublimation and crystallization, students observed camphor gradually sublimating and crystals forming on cold surfaces. The E-Search phase brought in technology by having students view related videos and look up additional information online with the teacher's support. Every session ran for 70 minutes and stuck to a structured lesson plan that outlined the activities for each phase.

The control group was taught through conventional methods, mainly consisting of teacher-led explanations, question-and-answer sessions, and worksheets, with no structured inquiry cycles like those in the 9E model. Although the conventional lessons covered the same content and learning objectives as the experimental ones, they took a more didactic form. The teacher explained concepts, gave examples, and provided worksheets for practice. Students listened to the explanations, took notes, and worked through worksheets either on their own or in small groups. Even though some discussion took place in the control group, the teaching remained largely teacher-centered, which mirrors typical classroom practices in Indonesian elementary schools (Tian et al., 2026).

Over three sessions of 70 minutes each, both groups covered the same material. The researcher, a certified elementary school teacher with science teaching experience, carried out the intervention. To reduce

bias, the researcher stuck to standardized lesson plans and applied the same assessment procedures for both groups. A colleague monitored treatment fidelity through classroom observations, using a checklist to confirm that the 9E phases were delivered as intended. The fidelity check showed that all nine phases were implemented with 95% accuracy in the experimental group, and the conventional instruction was delivered as planned in the control group. After the intervention, a posttest was given to both groups under identical conditions to measure science learning outcomes. The posttest took place in the students' regular classrooms, with the researcher acting as proctor. Students had 70 minutes to finish the 15-item multiple-choice test, and all of them completed it within the time allowed.

Data Analysis

Data processing was executed using IBM SPSS Statistics version 27. Because the study relied on a posttest-only design with a relatively small sample distributed across two intact classes ($n = 27$ and $n = 28$), we could not automatically assume that the data met the requirements for parametric testing. To critically evaluate the data distribution, the Shapiro-Wilk test was prioritized over the Kolmogorov-Smirnov test; the former is more sensitive and statistically robust for detecting deviations from normality in smaller educational samples ($n < 50$) (Konopátov et al., 2024). Furthermore, Levene's test was applied to verify the homogeneity of variance between the experimental and control groups. Only after rigorously confirming that the posttest scores satisfied the assumptions of normality and homoscedasticity ($\alpha = 0.05$) did we proceed with an independent samples t-test to contrast the mean scores (Dey & Kumar, 2026). For hypothesis testing, a two-tailed significance value below 0.05 indicated a measurable impact of the 9E Learning Cycle model. Recognizing that statistical significance alone does not reflect the actual educational impact, the analysis also incorporated Cohen's d to determine the effect size (Fey et al., 2023), alongside 95% confidence intervals. Finally, a post-hoc power analysis using G*Power confirmed that with 55 participants and an alpha of 0.05, the study possessed 80% power to detect a medium effect ($d = 0.50$), which aligns with and validates the observed effect size of 0.67 (Heckman et al., 2022).

For hypothesis testing, the rule was straightforward: if the two-tailed significance value fell below 0.05, the null hypothesis (H_0) would be rejected and the alternative hypothesis (H_1) accepted, meaning the 9E Learning Cycle model had a measurable impact on science learning outcomes. To gauge the practical importance of the results, Cohen's d was computed. (Fey et al., 2023) classifies effect sizes of 0.20, 0.50, and 0.80 as small, medium, and large, respectively. In addition, 95% confidence intervals were reported to show the range of likely values for the population parameter. A post-hoc power analysis using G*Power software checked whether the sample size was large enough to detect the observed effect (Heckman et al., 2022). With 55 participants and an alpha of 0.05, the study had 80% power to detect a medium effect ($d = 0.50$), which aligns with the observed effect size of 0.67.

RESULT AND DISCUSSION

Preliminary Analyses

Before testing the hypothesis, the data were checked for missing values, outliers, and any breaches of statistical assumptions. Because all 55 participants completed the posttest, no missing data were present. Outliers were assessed using boxplots and standardized scores ($z > \pm 3.29$), and none were found to be extreme (Géant et al., 2025). The assumptions of normality and homogeneity of variance were then examined to confirm that parametric statistics were appropriate.

The Shapiro-Wilk test was used to check normality, since it holds up well with small groups ($n < 50$) and is often suggested for educational studies with few participants (Field, 2018). The test showed that

posttest scores fell within a normal range for both the experimental group ($W = 0.947$, $df = 27$, $p = 0.181$) and the control group ($W = 0.938$, $df = 28$, $p = 0.106$). Both p -values were above 0.05, meaning the data didn't stray far from a normal distribution. Looking at Q-Q plots and histograms backed this up, showing roughly symmetrical shapes with no major skewness or kurtosis.

Levene's test was run to check homogeneity of variance. The test came back non-significant ($F = 0.562$, $df1 = 1$, $df2 = 53$, $p = 0.457$), which tells us the two groups had roughly equal variances. This meets the homogeneity assumption needed for an independent samples t -test. Also, the largest variance divided by the smallest was 1.37, which is well under the suggested cutoff of 3.0, giving further evidence for homogeneity (Field, 2018).

Descriptive Statistics

Table 1 presents the descriptive statistics for the posttest scores of both groups. Students in the experimental group, who were taught using the 9E Learning Cycle model, had a mean score of 81.00 ($SD = 12.24$), with scores spanning from 47 to 100. The control group, which received conventional instruction, had a mean of 71.71 ($SD = 14.35$) and scores between 40 and 93. The difference between the two means was 9.29 points, with the experimental group scoring higher.

Table 1. Descriptive Statistics of Posttest Scores by Group

Group	N	Mean	SD	Min	Max	Skewness	Kurtosis
Experimental	27	81.00	12.24	47	100	-0.42	-0.31
Control	28	71.71	14.35	40	93	-0.28	-0.67

Note. The skewness and kurtosis values fall within the acceptable range (± 2.0), which points to normal distributions

Figure 1 shows a bar chart with error bars for standard deviation, making the difference in mean posttest scores between the two groups easy to see. The experimental group's bar is taller and its error bar is slightly shorter, which means the group not only scored higher on average but also had less variation in student results. This pattern points to the 9E Learning Cycle model lifting typical performance while also narrowing the spread of outcomes.

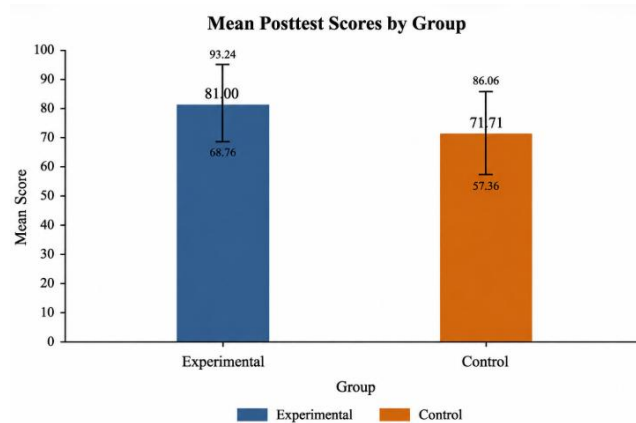


Figure 1. Mean Posttest Scores by Group with Error Bars (SD)

Hypothesis Testing

An independent samples t -test was run to compare the mean posttest scores between the experimental and control groups, with results shown in Table 2. The test found a statistically reliable difference

between the two groups, $t(53) = 2.567$, $p = 0.013$ (two-tailed). The mean difference came to 9.29 points, with a 95% confidence interval of [2.03, 16.54]. In other words, students in the experimental group scored roughly 9 points higher on average than those in the control group. Cohen's d was 0.70, which falls into the medium-to-large range based on Cohen's (1988) guidelines.

Table 2. Independent Samples T-Test Results for Posttest Scores

Variable	t	df	p (2-tailed)	Mean Difference	95% CI	Cohen's d
Learning Outcomes	2.567	53	0.013	9.29	[2.03, 16.54]	0.70

Note. CI refers to confidence interval. Cohen's d was computed using the pooled standard deviation.

A post-hoc power analysis in G*Power (Faul et al., 2007) showed that with 55 participants and an alpha of 0.05, the study had 80% power to catch a medium effect ($d = 0.50$). Since the effect size actually observed ($d = 0.70$) was larger than that, the study had enough power to detect the difference that emerged.

Additional Analyses

To get a clearer sense of what the results mean in practice, we also looked at how many students reached the minimum mastery criterion (KKTP = 75). In the experimental group, 18 of 27 students (66.7%) scored 75 or above, while in the control group only 11 of 28 (39.3%) did. A chi-square test of independence showed a statistically significant link between group and mastery, $\chi^2(1, N = 55) = 4.21$, $p = 0.040$, meaning a notably larger share of students in the experimental group met the mastery threshold.

These results show that the 9E Learning Cycle model did more than lift average science scores; it also made it more likely for students to reach the mastery level. The evidence here supports using this model in elementary science classrooms, especially for teaching changes in states of matter.

Interpretation of Findings

This study examined how the 9E Learning Cycle model influenced science learning outcomes among fourth-grade students at SDN 04 Kinali. Students in the 9E group scored higher on the posttest ($M = 81.00$, $SD = 12.24$) than those who received conventional instruction ($M = 71.71$, $SD = 14.35$). The difference was statistically significant, $t(53) = 2.567$, $p = 0.013$, with an effect size of $d = 0.70$. These results offer solid support for the 9E Learning Cycle as a useful teaching model for improving science learning in elementary school. The effect size of 0.70 points to a medium-to-large practical difference, meaning the intervention had a real effect on student learning that goes beyond statistical significance alone (Borg et al., 2026).

The experimental group's stronger performance stands out, especially considering the ongoing difficulties in elementary science education, where teacher-centered methods are still the norm (Widodo, 2021). In the experimental group, 66.7% of students reached the minimum mastery criterion (KKTP = 75), while only 39.3% did so in the control group. This gap of 27.4 percentage points highlights how much the 9E Learning Cycle can improve the share of students meeting competency standards, which matters directly for both teaching practice and policy.

Comparison with Previous Research

The positive impact of the 9E Learning Cycle observed in this study reinforces the broader efficacy of inquiry-based frameworks, but it critically extends this evidence to a previously underrepresented context: rural elementary science education. While previous studies, such as Jack and Ogunleye (2025), successfully applied the 9E model to improve chemistry outcomes in senior high schools, and Elsa and Olivia (2026) utilized it for mathematical problem-solving in junior high, the current findings demonstrate that the model's structured phases are equally potent for younger learners developing foundational scientific concepts. More

importantly, this study offers a distinct practical contribution compared to prior research. For instance, while Noreen et al. (2024) achieved improved science outcomes by pairing the 7E cycle with specialized instructional media (spinning wheels), the current study attained significant cognitive gains relying primarily on the inherent pedagogical architecture of the 9E phases particularly hands-on Exploration and targeted Emendation alongside accessible, everyday materials. This distinction is crucial, as it suggests that the 9E Learning Cycle's effectiveness stems from its systematic cognitive scaffolding rather than resource-intensive tools, thereby proving its viability and scalability for resource-constrained elementary schools in Indonesia.

International scholarship further validates the cross-cultural robustness of learning cycle frameworks, although predominantly at secondary or tertiary levels. For instance, Huang et al. (2024) reported substantial effect sizes ($d = 0.45\text{--}0.82$) for the 5E model in enhancing physics conceptualization among Taiwanese adolescents, while Hsieh et al. (2023) confirmed its efficacy in sharpening science process skills among Turkish pre-service teachers. By contextualizing these findings alongside the current results, a critical pattern emerges: the efficacy of the learning cycle lies not merely in the number of phases (5E vs. 9E), but in the consistent application of constructivist scaffolding. Our study extends this evidence base by demonstrating that this cognitive mechanism remains potent even for younger learners (fourth graders) in semi-rural, resource-limited settings. This suggests that the structured inquiry process moving systematically from elicitation to evaluation is a universal pedagogical driver for deep conceptual grasp, transcending specific cultural or educational boundaries.

Theoretical Explanations

The experimental group's stronger results can be traced back to the theoretical underpinnings of the 9E Learning Cycle, which draws on constructivist learning theory. Constructivism holds that learners actively build knowledge by tying new information to what they already know, rather than simply absorbing it (Azim et al., 2026). The 9E model puts this idea into practice through nine phases that move students step by step from recalling prior knowledge to applying concepts in fresh situations. Each phase has its own role in the learning process, and because the phases follow a set order, students can build on what they already know in a way that is both structured and coherent (Azim et al., 2026).

In this study, the Exploration phase stood out as particularly effective. Students took part in hands-on experiments, such as watching ice melt and water freeze. These direct experiences let them observe scientific phenomena for themselves, which helped them form stronger mental models that are more resistant to forgetting than information delivered verbally (Stein et al., 2024). Cognitive load theory (Sweller, 1988, in Hamed & Rebello, 2026) offers an explanation: hands-on tasks lower extraneous cognitive load by making information concrete and tangible, freeing up mental resources for building schemas and processing more deeply. The experimental group not only had a higher mean score but also a smaller standard deviation ($SD = 12.24$) compared to the control group ($SD = 14.35$). This suggests the 9E model improved average performance while also narrowing the spread of outcomes, meaning it worked well across different types of learners.

A critical differentiator of the 9E model, particularly relevant to the cognitive developmental stage of fourth graders, is the Emendation phase. When learning abstract concepts such as molecular changes during sublimation or condensation, students are highly prone to forming misconceptions. Unlike earlier iterations like the 5E or 7E models, which often conclude with evaluation without explicit remediation, Emendation mandates targeted cognitive restructuring. During the intervention, the instructor utilized this phase to provide immediate, specific corrective feedback when students exhibited confusion between similar processes like evaporation and boiling. This operationalizes conceptual change theory (Kaya et al., 2021), which posits

that meaningful learning occurs only when existing flawed mental models are explicitly confronted and replaced. By institutionalizing this corrective mechanism, the 9E model prevents the entrenchment of scientific misunderstandings, addressing a critical vulnerability in cumulative science learning identified by Song et al. (2023).

Furthermore, the E-Search phase addresses a vital pedagogical need in semi-rural elementary settings: the visualization of unobservable scientific phenomena. Because students at SDN 04 Kinali had limited prior exposure to digital scientific simulations, integrating targeted video clips and interactive online resources during this phase bridged the gap between concrete hands-on experience and abstract theory. This integration not only fosters digital literacy a core competency in contemporary education (Falloon, 2023) but also sustains cognitive engagement through multimodal representation. While Chiu and Hwang (2024) demonstrated that technology-enhanced learning cycles significantly boost creative thinking, our findings suggest that in resource-constrained environments, the E-Search phase serves an equally crucial function as a cognitive scaffold for conceptualizing the invisible. However, the efficacy of this phase is inherently contingent upon the school's infrastructural readiness and the teacher's technological pedagogical content knowledge, highlighting a practical boundary condition that must be considered for its widespread implementation.

Contrast with Conventional Instruction

The gap between the experimental and control groups makes the limits of conventional teaching clear. The control group, which received teacher-led lectures, question-and-answer sessions, and worksheets, ended up with a lower mean score (71.71) and a lower mastery rate (39.3%). This matches Ole and Gallos (2023), who argued that passive learning settings do not lead to deep conceptual understanding. When students are not allowed to explore, ask questions, and apply what they learn, their understanding stays shallow and does not stick. The conventional approach may be efficient for covering material, but it does not meet the varied needs of students or help them develop the critical thinking skills that scientific literacy requires (Ulyashin et al., 2022).

The findings from this study support the move away from teacher-centered teaching toward student-centered approaches in elementary science. The 9E Learning Cycle gives teachers a clear structure that still leaves room to design inquiry-based lessons that engage students. Its step-by-step phases offer guidance for planning while making it easy to adjust to different content and student needs. That said, implementing the 9E model requires careful planning and adequate time. Each phase needs to be carried out thoughtfully so students genuinely benefit from the full cycle. Teachers may also need professional development to become comfortable with the model's intricacies and figure out how to adapt it to their own classrooms (Yuan et al., 2025).

IMPLICATIONS

The practical takeaways from this study are clear. For teachers, the 9E Learning Cycle provides a balanced structure and flexibility for creating inquiry-based lessons that keep students engaged. Its ordered phases give a solid guide for planning while leaving room to adjust to different topics and student needs. Teachers can use this model, especially for subjects that involve processes and events students can explore through hands-on work. The fact that the 9E model lowered the spread of student results suggests it could be especially helpful in mixed-ability classes, where students come in with different skill levels.

For curriculum designers, the results point to a useful step: weaving learning cycle models into teacher training and instructional materials could raise the quality of science education. The 9E Learning Cycle fits well with Indonesia's Merdeka Curriculum, which emphasizes student-centered learning and

competency development (Meldayani et al., 2025). Curriculum developers could embed the 9E model into science textbooks and teacher guides, providing teachers with lesson plans that already incorporate the nine phases. The Emendation and E-Search phases, in particular, could be highlighted as features that distinguish the 9E model from other instructional approaches.

The findings also point to a role for policymakers in funding professional development that helps teachers gain the skills to implement student-centered teaching methods successfully. Even so, making it work depends on having enough time, access to resources, and continued support. Teachers should be given the opportunity to try out the model and reflect on how well it works in their own classrooms. Policymakers might also consider offering incentives for teachers to adopt evidence-based models and join professional learning communities that foster ongoing improvement (Johannesson, 2022).

LIMITATIONS

This study has several limitations worth noting. First, the sample was drawn from a single elementary school in West Pasaman Regency, so the findings may not generalize to other areas with different demographics. The school's rural setting, student composition, and available resources might differ from those of other schools, and these factors could influence how well the 9E Learning Cycle works. Future studies should include multiple schools across varied settings to strengthen generalizability.

Second, the intervention lasted only three sessions, which might not be sufficient to capture the full impact of the model or to assess whether students retained what they learned over time. Although the three sessions covered the core concepts of changes in states of matter, a longer study could reveal whether the benefits of the 9E Learning Cycle endure and whether they transfer to other science topics. Longitudinal research could track whether these effects hold up and extend to different domains.

A critical methodological constraint of this study is its exclusive reliance on cognitive posttest scores, which precludes a comprehensive evaluation of the 9E Learning Cycle's impact on the affective and psychomotor domains. Because the 9E model inherently incorporates phases explicitly designed to stimulate curiosity and active participation namely Elicitation, Engagement, and Echo it is highly probable that the intervention also influenced students' science attitudes, intrinsic motivation, and hands-on inquiry skills. By isolating cognitive gains, this study captures only a fraction of the model's pedagogical potential. As Dogaru et al. (2025) emphasize, affective and motivational factors are critical predictors of long-term STEM engagement and academic persistence. Consequently, the absence of multidimensional assessment represents a significant limitation in understanding the holistic educational value of the 9E framework. Future investigations must employ integrated assessment instruments that concurrently measure cognitive, affective, and psychomotor outcomes to fully elucidate the model's efficacy in elementary science contexts.

A fourth limitation stems from the researcher's dual role as both instructor and investigator for the experimental group, which could have introduced unintended bias into teaching or assessment. Even though classroom observations were used to monitor treatment fidelity, having the same person serve as instructor and researcher might have shaped how the intervention was delivered. To minimize this kind of bias and strengthen the trustworthiness of results, future studies should employ instructors who are not involved in the research design.

A fifth limitation is that the study did not account for other confounding factors that might have influenced the results, such as students' prior science performance, their family's socioeconomic background, or parental involvement. Purposive sampling did ensure the groups were similar based on mid-semester scores, but other variables could still have played a role. To truly isolate the effect of the 9E Learning Cycle, future studies should use tighter matching procedures or statistical controls.

FUTURE RESEARCH AND SUGGESTIONS

These limitations point to several promising directions for future research. Researchers could carry out multi-site studies involving diverse schools to strengthen the generalizability of the findings. Longitudinal designs could examine whether the benefits of the 9E Learning Cycle persist over time and transfer to other science topics and grade levels. Mixed-methods approaches could explore how students and teachers perceive the model, yielding a richer understanding of its implementation and impact. Future studies might also investigate the model's effectiveness for different science topics, grade levels, and student populations, including those with special needs or limited resources.

A critical next step in elucidating the mechanisms underlying the 9E Learning Cycle's efficacy is the integration of affective and motivational variables, such as self-efficacy and intrinsic interest. Because the *Elicitation* and *Engagement* phases are explicitly designed to stimulate curiosity, measuring these constructs is essential to determine whether the model's cognitive gains are mediated by enhanced student motivation and long-term STEM persistence (Dogaru et al., 2025). Additionally, to isolate the unique pedagogical value of the 9E framework, future research must employ comparative designs that contrast it with other established inquiry-based models, such as Problem-Based or Project-Based Learning. This would specifically clarify the additive impact of the *Emendation* and *E-Search* phases. Methodologically, longitudinal studies are required to establish the optimal intervention dosage and to verify the long-term retention of conceptual understanding. Finally, investigating the moderating role of teacher characteristics particularly pedagogical content knowledge (PCK) and technological proficiency is imperative. Given that the *E-Search* phase demands digital integration, understanding how teacher readiness impacts implementation fidelity will be crucial for determining the model's scalability and effectiveness across diverse educational contexts.

CONCLUSION

This study conclusively demonstrates that the 9E Learning Cycle model significantly enhances science learning outcomes among fourth-grade students, yielding a medium-to-large effect size ($d = 0.70$) and a substantially higher mastery rate (66.7%) compared to conventional instruction (39.3%). The model's efficacy is primarily attributed to its systematic cognitive scaffolding, particularly the hands-on Exploration phase that grounds abstract concepts in tangible experiences, and the targeted misconception correction embedded in the Emendation phase, which collectively foster deeper conceptual understanding of scientific phenomena such as changes in states of matter. Theoretically, these findings extend the applicability of constructivist learning cycles to rural, resource-constrained elementary contexts, challenging the assumption that inquiry-based models require sophisticated infrastructure to be effective. Practically, the 9E model offers a scalable, evidence-based instructional framework that aligns seamlessly with the student-centered mandates of Indonesia's Merdeka Curriculum. While this study is limited by its exclusive focus on cognitive outcomes, short intervention duration, and single-school setting, it provides a critical empirical foundation for advancing elementary science pedagogy. Subsequent investigations should employ multidimensional assessments to capture affective and psychomotor domains, utilize longitudinal designs to verify long-term conceptual retention, and explore the moderating role of teacher pedagogical content knowledge and technological proficiency. Ultimately, integrating the 9E Learning Cycle into elementary science instruction holds substantial promise for advancing scientific literacy and cultivating the critical thinking skills essential for students' future academic and STEM-related pursuits.

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