



Fostering Quality Education (SDG 4): Transforming QR Codes from 'Scanning' to 'Scaffolding' to Enhance Pre-Service Teachers' Critical Thinking

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Abstract: This study addresses the "pedagogical digital gap" by proposing a shift from using technology for content delivery ("scanning") to cognitive support ("scaffolding"). It investigates the effectiveness of a *QR-Code Integrated Inquiry* model on pre-service primary teachers' critical thinking skills. Employing a quasi-experimental design with 60 participants, data were analyzed using ANCOVA. Findings revealed a highly significant difference ($F_{(1,57)} = 847.61, p < .01$) between groups. The experimental group achieved a notably higher adjusted mean (57.43) compared to the control group (34.88), with a massive effect size ($\eta_p^2 = .94$). The intervention successfully reduced extraneous cognitive load, facilitating deep reasoning consistently across genders and science topics. The study concludes that re-engineering simple technology as scaffolding creates a robust, inclusive learning ecosystem for teacher education.

Keywords: Critical Thinking; Inquiry Learning; Pre-service Teachers; QR Code; Scaffolding

Introduction

Achieving the Sustainable Development Goals (SDGs), particularly SDG 4 on Quality Education (Chien & Knoble, 2024; Hamdan et al., 2025; Hossain et al., 2023), relies heavily on educator competence (Affeldt et al., 2018). Target 4.c explicitly demands a substantial increase in the supply of qualified teachers as a key prerequisite for building a resilient future generation (Choir et al., 2025; Sunday & Muhammed, 2025). In the context of the 21st century, the definition of a "qualified teacher" has shifted from a mere content deliverer to a facilitator of higher-order thinking (Bahtiar et al., 2022; Ibrahim et al., 2025; Selaman et al., 2025; Syaokani et al., 2025; Waheed et al., 2025). Consequently, critical

thinking skills are no longer merely a pedagogical option, but a global imperative that every pre-service teacher must possess (Bahtiar et al., 2023; Hildayanti et al., 2025; Ibrahim, Bahtiar, Maimun, & Fauzi, 2024). Without strong reasoning capabilities, it is impossible for teachers to navigate the complexities of sustainability challenges or to teach meaningful scientific literacy to their students (Brophy, 2021; Damopolii et al., 2022).

Despite this global urgency, pre-service primary teacher education in developing countries continues to face serious challenges (Abdullah et al., 2021; Khair et al., 2020). The majority of teacher training programs remain trapped in mechanistic approaches that position pre-service teachers as passive recipients of information rather than active thinkers (Archi Maulyda &

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Wuryandani, 2025). This results in a tangible competence gap: graduates possess adequate content knowledge but fail to design inquiry-based learning that requires logical reasoning. This failure perpetuates a cycle of conventional teaching that hinders the achievement of SDG 4 targets at the primary school level.

In an effort to break this cycle, technology is often adopted as a solution. QR Codes, as a frugal innovation aligned with the spirit of inclusivity, offer significant potential (Kuru Gönen & Zeybek, 2021; Suranti & Alimuddin, 2024; Yupika et al., 2025). However, the literature reveals an implementation anomaly. Current usage of QR Codes is generally limited to administrative functions or serving as digital shortcuts to access static materials a phenomenon termed in this study as the "Scanning" phase (Hanum, 2022). This approach fails to trigger the cognitive dissonance necessary for critical thinking (Adhelachya et al., 2023; Ibrahim, Bahtiar, Maimun, Suranti, et al., 2024; Maimun et al., 2024), as the technology merely digitizes passive information transfer without providing deep intellectual stimulation (Lestari et al., 2025; Syaokani et al., 2025; Yulianti et al., 2025).

This is where the novelty and literature gap is addressed by this research lie. To date, there is a scarcity of empirical research investigating the impact of re-engineering QR Codes from simple access tools into cognitive scaffolding mechanisms integrated within scientific inquiry syntax. To fill this gap, this study aims to examine the effectiveness of the "QR-Code Integrated Science Inquiry" model. Specifically, this research aims to measure whether the transformation of technology usage from "scanning" to "scaffolding" yields a statistically significant impact on PPTs' critical thinking skills compared to conventional methods, and how this model contributes to reducing students' extraneous cognitive load.

This research is urgent to demonstrate that sophisticated and expensive technology is not an absolute prerequisite for quality education. By empowering simple technology through appropriate pedagogical design, teacher education institutions can create learning environments that support higher-order reasoning. The findings of this study are expected to offer a scalable and adaptive model to accelerate the achievement of SDG 4, ensuring that future teachers are not only technically ready to teach but also critically ready to think.

Method

Research Design

This study employed a quasi-experimental non-equivalent control group design. This specific design

was selected because the participants were organized in pre-existing academic classes, making random assignment of individual students unfeasible. The primary objective was to examine the impact of the QR-Code Integrated Inquiry model on the critical thinking skills of pre-service primary teachers. The experimental design involved two groups: the Experimental Group, which received the scaffolding-based instruction, and the Control Group, which received conventional instruction. Both groups underwent a pre-test (O_1) to measure baseline abilities and a post-test (O_2) after the intervention to assess the treatment effect.

Participants

The study involved a total of 60 Pre-service Primary Teachers (PPTs) enrolled in the "Basic Science Concepts" course at the Department of Primary Teacher Education (PGSD), University of Mataram (UNRAM), Indonesia. The sampling technique utilized was purposive sampling based on intact classes, chosen to maintain high ecological validity within the educational setting. Two classes were randomly assigned to the treatment conditions, resulting in 30 students in the Experimental Group and 30 students in the Control Group. Although this sample size ($N = 60$) is relatively modest, it satisfies the statistical power requirements for detecting medium-to-large effect sizes in quasi-experimental designs. To ensure internal validity and control for instructor bias, both groups were taught by the same lecturer. Furthermore, an initial homogeneity test based on students' prior academic performance (GPA) revealed no significant difference between the two groups ($p > 0.05$), confirming that both groups possessed comparable academic baselines prior to the intervention. Ethical approval for this study was granted by the Department of Primary Teacher Education, Universitas Mataram. Informed consent was obtained from all participants prior to their involvement in the study, ensuring their anonymity and voluntary participation.

Research Procedures

The study followed a systematic procedure spanning from initial participant selection to final data analysis. The central intervention phase consisted of six instructional sessions (each lasting 100 minutes), excluding the pre-test and post-test sessions. The curriculum covered fundamental science topics essential for primary education, as detailed in Table 1. To provide a comprehensive overview of the experimental design and the distinct pathways for the treatment and control groups, the entire research flow is schematically illustrated in Figure 1.

RESEARCH PROCEDURE

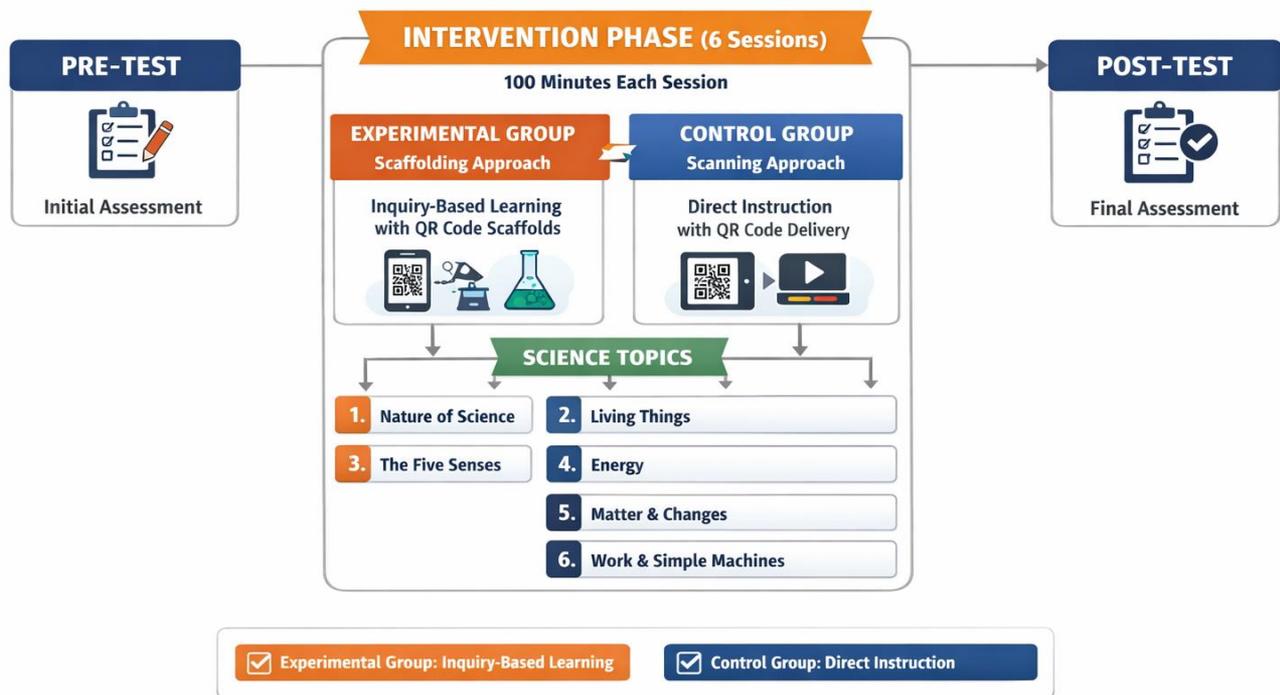


Figure 1. Research Procedure

The distribution of topics and the focus of inquiry for each meeting are presented in Table 1.

Table 1. Distribution of Topics and Meetings

Meeting	Topic	Focus of Inquiry
1	Nature of Science	Understanding scientific methods, attitudes, and the nature of scientific knowledge.
2	Living Things	Classification, characteristics of organisms, and ecosystem interactions.
3	The Five Senses	Mechanisms of sensory perception and anatomy of sense organs.
4	Energy	Forms of energy, energy sources, and energy transformation principles.
5	Matter and Changes	States of matter, physical changes, and chemical reactions.
	Work and Simple Machines	Mechanics of levers, pulleys, inclined planes, and mechanical advantage.

As depicted in the "Intervention Period" section of Figure 1, to ensure the internal validity of the study, the treatment differed significantly between the two groups regarding the pedagogical function of the technology employed. In the Experimental Group (Scaffolding Approach), QR codes functioned as cognitive scaffolds

integrated into the Inquiry-Based Learning (IBL) syntax. These codes were strategically placed to provide tiered hints, guiding questions, and access to interactive simulations (e.g., virtual labs for simple machines). Instead of providing direct answers, the technology guided students through the processes of data collection, analysis, and hypothesis testing, thereby facilitating active cognitive engagement.

Conversely, in the Control Group (Scanning Approach), the same science topics were taught using a traditional Direct Instruction model. Here, QR codes were utilized solely for content delivery (*scanning*). Students used the codes merely to download static PDF textbooks or watch supplementary video lectures to reinforce the lecturer's explanation. Consequently, the interaction was limited to passive information consumption that mirrors traditional didactic teaching methods.

Data Collection Instrument

To measure the dependent variable, this study employed a Critical Thinking Skills Test (CIST) developed specifically to align with the course curriculum. The instrument consisted of 15 essay items designed to assess pre-service teachers' cognitive abilities in analyzing and solving scientific problems. The essay format was selected to allow participants to construct original arguments and demonstrate their reasoning processes in depth. The design of the test

items was grounded in a comprehensive theoretical framework encompassing four key critical thinking indicators. The assessment focused first on Clarification, which requires the ability to analyze arguments and address fundamental questions, followed by Assessment, which involves evaluating the credibility of information sources. The framework further explicitly included Inference, testing the student's capacity to deduce consequences and induce conclusions, and concluded with Strategies, assessing the skill of deciding upon appropriate actions based on the analysis.

Prior to data collection, the instrument underwent a rigorous content validity process by three experts in science education and evaluation from the University of Mataram. The expert judgment results indicated that the instrument was valid for use. Furthermore, the reliability of the test was established through a pilot study involving students outside the sample, yielding a Cronbach's Alpha coefficient of 0.76, which indicates high internal consistency.

Data Analysis

Quantitative data were analyzed using IBM SPSS Statistics version 26.0. To accurately determine the impact of the intervention, the study employed Analysis of Covariance (ANCOVA). ANCOVA was chosen because it compares the post-test scores of the experimental and control groups while statistically controlling for pre-test scores (covariate). This method reduces error variance and provides a more precise estimate of the treatment effect compared to simple gain scores. Prior to hypothesis testing, assumption tests were conducted, including the Shapiro-Wilk test for normality, Levene's test for homogeneity of variance, and a test for homogeneity of regression slopes. Hypothesis testing was performed at a significance level of $\alpha = 0.05$. Additionally, to measure the practical significance of the impact, the Effect Size was calculated using Partial Eta Squared (η_p^2).

Result and Discussion

This section elucidates the empirical findings derived from the implementation of the *QR-Code Integrated Inquiry* learning model on the critical thinking skills of pre-service elementary school teachers. The data presented herein represent the results of a comprehensive analysis encompassing a comparison of achievements between the experimental and control groups, both in aggregate and through specific categorical lenses. The presentation of results is systematically structured, commencing with a descriptive analysis to map the trends in pretest and posttest score improvements, followed by an in-depth

examination based on gender variables and science subject matter characteristics. Finally, the section concludes with statistical assumption testing and inferential analysis to scientifically verify the significance of the intervention's impact. A general overview regarding the difference in critical thinking skills improvement between the two groups is presented in Figure 1.

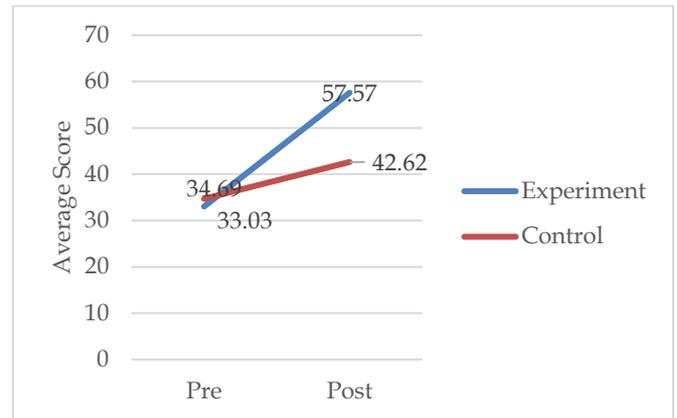


Figure 1. Mean Pretest and Posttest Scores for Experimental and Control Classes

The evaluation of the *QR-Code Integrated Inquiry* model's effectiveness begins by reviewing the macro-level performance disparity displayed in Figure 1. The data visualization reveals that at the pretest stage, both groups commenced learning with a relatively equivalent baseline of critical thinking capabilities, exhibiting no conspicuous differences. However, post-intervention, a sharp divergence in achievement occurred; the experimental group experienced a statistically significant surge in scores, leaving the control group behind with only a gradual or moderate improvement graph. This phenomenon indicates that the administered intervention successfully facilitated a cognitive transition in students from basic understanding to higher-order thinking skills effectively.

Theoretically, this finding aligns with the latest meta-analysis by Aslan, (2021) and Baharom et al. (2020), which asserts that inquiry-based learning (IBL) yields a substantial impact on cognitive outcomes when supported by relevant technology. In the context of this study, QR codes function as crucial digital scaffolding that reduces students' extraneous cognitive load. As elucidated in the study by Ma, (2021), mobile technology acts as an "epistemic bridge," enabling instant access to scientific evidentiary resources. This ease of access frees up students' working memory capacity, allowing them to allocate greater mental resources to processes of analysis and evaluation, rather than merely expending time on procedural information retrieval. Furthermore, to examine the consistency of the model's effectiveness

across different gender groups, comparative data is presented in Figure 2.

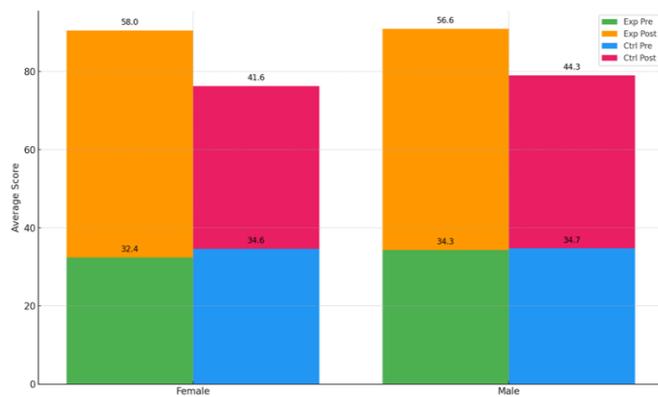


Figure 2. Mean Pretest and Posttest Scores Based on Gender

The effectiveness of the model, having been proven generally, was subsequently tested for inclusivity through a gender-based analysis, as presented in Figure 2 above. Descriptive statistical data reveal a consistent pattern of score improvement for both male and female students in the experimental class. The graph indicates that the learning progress lines for both genders move in parallel, with an insignificant difference in final

achievement. This serves as empirical evidence that the QR-code-based inquiry model possesses an inclusive nature, is capable of accommodating diverse learning needs, and provides equal benefits to all students regardless of gender.

This finding regarding gender equality dispels longstanding stereotypes concerning the dominance of a specific gender in scientific literacy and logical reasoning. Literature support from El-Ghonaimy, (2015); Alaulamie & Alshwiah, (2021); and Sekano et al. (2020) strengthens the argument that educational technology which decentralizes information access can act as an equalizer. When learning resources can be accessed autonomously through QR code scanning, the academic self-efficacy of female students rises to a level equivalent to that of males. This creates an equitable learning environment, where social or psychological barriers that frequently influence gender participation in science discourse can be minimized through direct interaction with technology.

In addition to the gender aspect, the model's effectiveness was also reviewed based on science learning topics. The distribution of pretest and posttest scores across various subject matters is displayed in Figure 3.

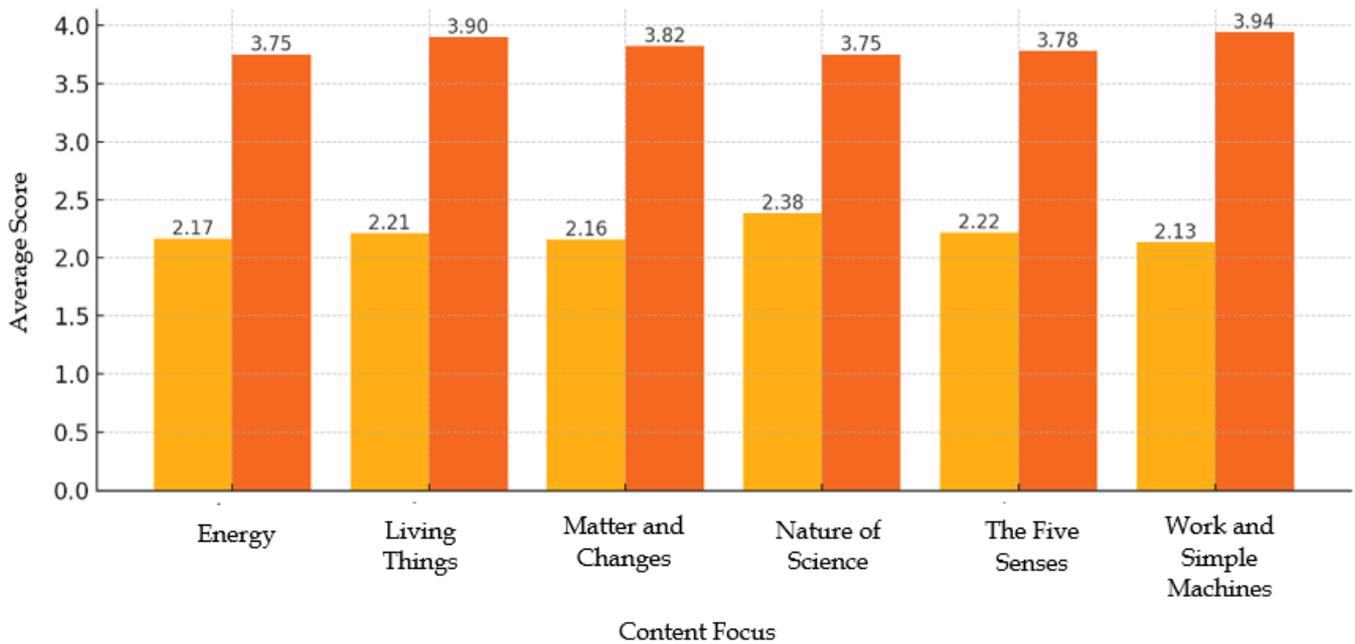


Figure 3. Mean Pretest and Posttest Scores Based on Learning Materials

The robustness of this model was also tested across a spectrum of science learning materials, as shown in Figure 3. Improvements in critical thinking skills were recorded across all taught topics; however, the sharpest score increase was specifically observed in materials that are abstract and complex in nature, such as energy concepts or microscopic systems. Compared to

conventional methods, which often fail to bridge this abstraction gap, the experimental class demonstrated consistently superior performance in every sub-topic, signaling the learning model's adaptability to varying levels of content difficulty.

This phenomenon can be explained through the perspective of Situated Learning and Dual Coding

theory. Multimedia features (video simulations, interactive articles) linked via QR codes are highly effective in concretizing abstract concepts, thereby facilitating students' logical reasoning processes. In line with findings by (Chen, 2023; Chigorimbo, 2024) regarding the Pj4CS model, the multimodal presentation of material combining text, audio, and visuals has been proven to reinforce memory retention and information

processing. The availability of these rich visual representations becomes a fundamental prerequisite for students to conduct critical analysis of complex science content, which was previously difficult to achieve through verbal explanation alone. A more in-depth analysis regarding the interaction between subject matter and critical thinking indicators is visualized in Figure 4.

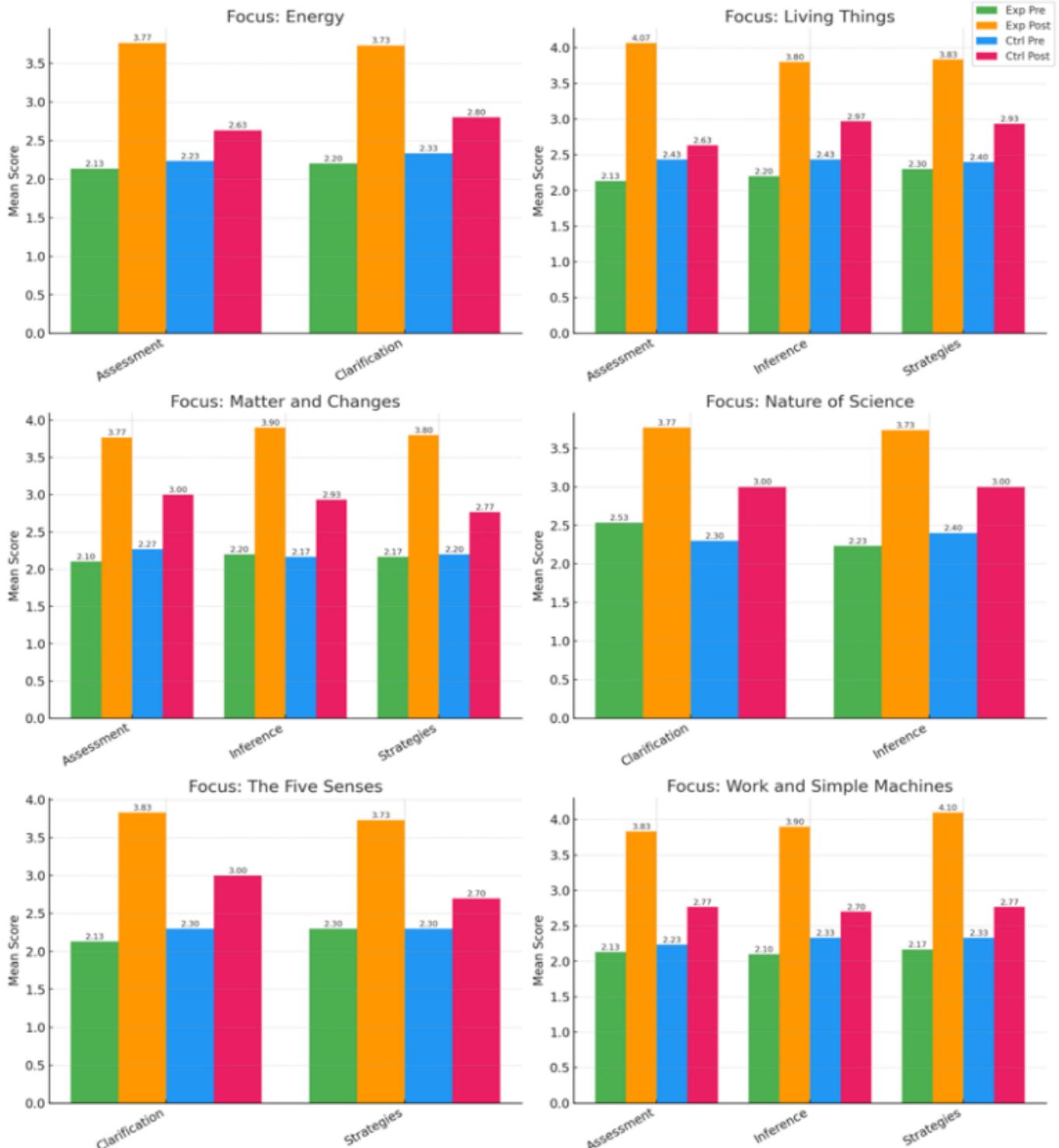


Figure 4. Mean Scores for Each Subject Matter Per Indicator

To understand the anatomy of this improvement more deeply, Figure 4 dissects the achievement of specific critical thinking indicators for each subject matter. This detailed analysis reveals an intriguing pattern where materials rich in empirical and experimental data triggered the highest increases in the 'Analysis' and 'Evaluation' indicators within the experimental class. Conversely, in the control class, scores for these high-level indicators tended to stagnate or only increase marginally on the same materials, demonstrating the limitations of conventional methods in facilitating depth of thought.

This pattern underscores the role of QR codes not merely as content presenters, but as procedural scaffolds

that guide the students' thinking flow. Referring to research by Aditya, (2021); Affeldt et al. (2018); and Ahmadi, (2018), the use of technology to provide structure to complex tasks can significantly enhance students' ability to dissect arguments. QR codes guide students in navigating the stages of inquiry ranging from problem orientation to hypothesis verification for each specific topic, ensuring that cognitive processes such as analyzing variables and evaluating data validity occur in a structured and directed manner. In aggregate, the recapitulation of improvements in each critical thinking sub-skill can be observed in Figure 5.

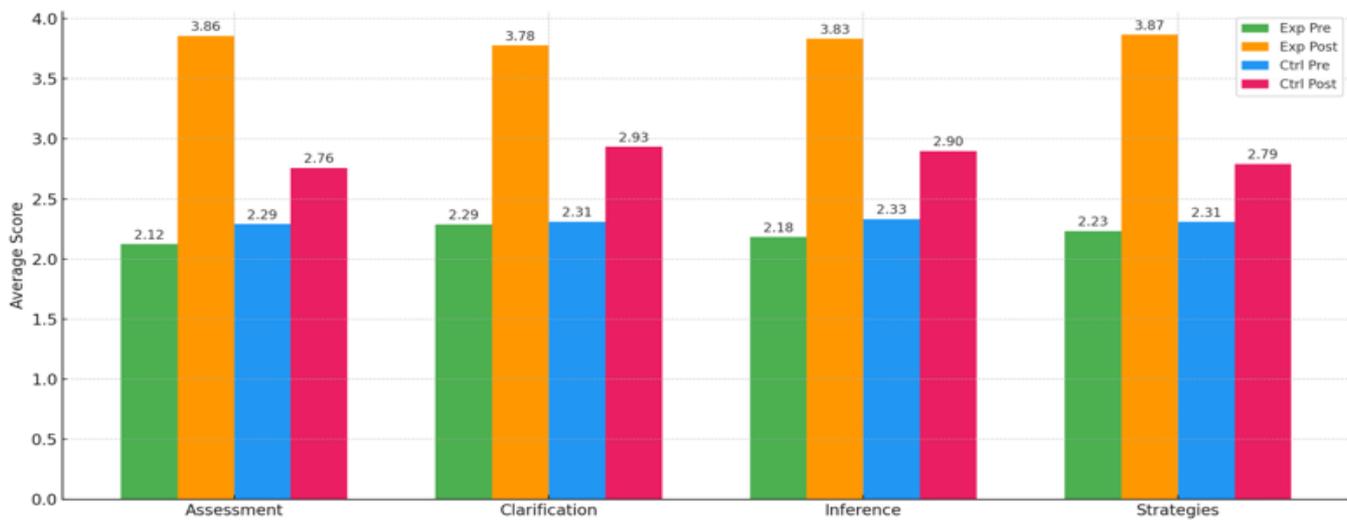


Figure 5. Mean Scores Based on Critical Thinking Indicators

As seen in Figure 5, although all critical thinking indicators experienced improvement, the 'Inference' (concluding) and 'Evaluation' (judging) indicators experienced the most dramatic rise in the experimental group. The bar graph shows a wide margin compared to the control group, particularly in the ability to draw logical conclusions from given premises. This indicates that the intervention successfully targeted the core of critical thinking skills: the ability to process information independently and generate valid judgments.

The specific increase in these two indicators is closely related to the 'elaboration' phase in the inquiry cycle. According to a study by Amelia & Purwaningsih, (2021) and Cantú-Ortiz et al. (2020), digital technology compels students to engage in intense cognitive regulation when synthesizing information from various digital sources. The process of comparing data from one QR code with another before drawing a conclusion is a direct exercise for inference and evaluation skills. Thus, this model is proven effective in transforming students from passive information receivers into active and critical information evaluators. Before proceeding to

hypothesis testing, data analysis prerequisites were examined first. The data distribution for the normality test is presented in Figure 6.

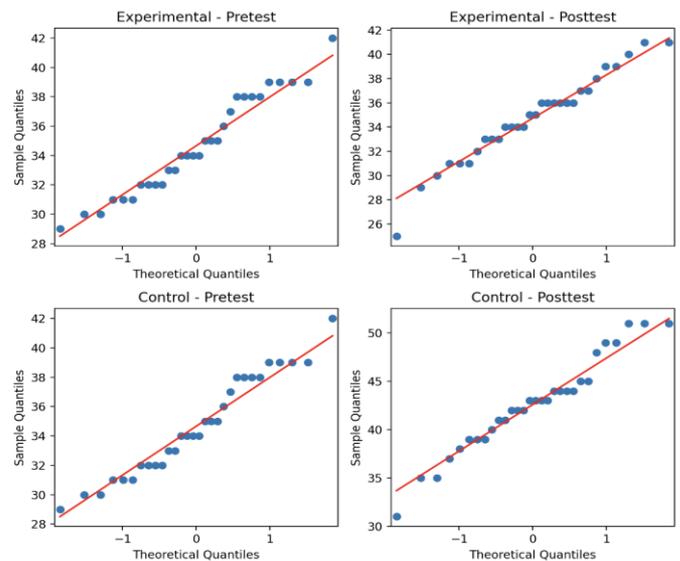


Figure 6. Data Normality Plot (Q-Q Plot)

The validity of all the descriptive findings above is reinforced by the fulfillment of rigorous statistical assumptions, commencing with the normality test in Figure 6. The Quantile-Quantile (Q-Q) plot displays a distribution of data points that closely follows the diagonal line for both groups. This visual confirmation, supported by statistical tests, indicates that the learning outcome data are normally distributed and the sample used is representative without any extreme outliers that could bias the results.

Methodologically, the fulfillment of this normality assumption provides legitimacy for the use of parametric statistical tests (ANCOVA) in subsequent analyses. In the context of quantitative educational research for the 2020-2025 period, transparent reporting of analysis prerequisites has become a non-negotiable standard of rigor. This ensures that the conclusions drawn later are a pure reflection of the phenomenon under study, not an artifact of data distribution errors. In addition to the normality test, a homogeneity of variance test was also conducted to ensure the equality of variances between groups, as shown in Figure 7.

Furthermore, Figure 7 confirms the homogeneity of variance between groups through a scatter plot showing a uniform data spread (homoscedasticity). This signifies that the variability of both initial and final abilities between the experimental and control groups is equivalent. In other words, both groups started from a

comparable level of diversity, so the comparison of mean scores performed is a fair comparison.

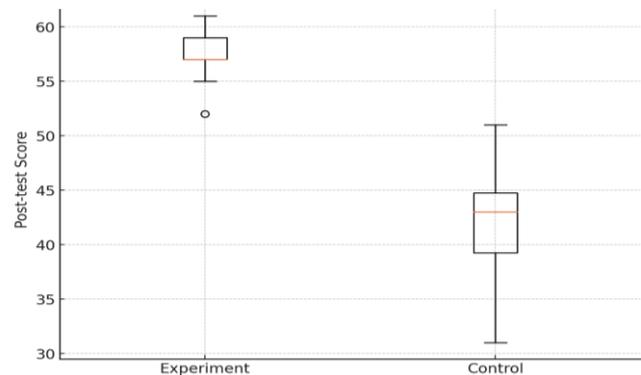


Figure 7. Homogeneity of Variance Test

The fulfillment of this homogeneity assumption is crucial for the internal validity of the research. If variances are not homogeneous, there is a risk that differences in posttest scores are caused by differing group characteristics, rather than by the treatment itself. With this assumption met, we can confidently state that any significant differences in learning outcomes can be fully attributed to the effectiveness of the *QR-Code Integrated Inquiry* learning model, minimizing the threat of sample selection bias. Based on the fulfillment of the prerequisite assumptions above, inferential analysis using ANCOVA was conducted. A summary of these statistical results is outlined in Table 2.

Table 2. Results of Analysis of Covariance (ANCOVA) on the Effect of Learning Model on Critical Thinking Skills

Source	SS	df	MS	F	ρ	η_p^2
Corrected Model	7190.67	2	3595.33			
Pretest (Covariate)	18.95	1	18.95	2.24	0.14	0.04
Group (Treatment)	7171.72	1	7171.72	847.61	< 0.001*	0.94
Error (Residual)	482.28	57	8.46			
Total		60				

Note: SS = Type III Sum of Squares; df = degrees of freedom; MS = Mean Square; η_p^2 = Partial Eta Squared. Asterisk (*) denotes significance at the $\rho < 0.05$ level. Adjusted Mean: Experimental Class = 57.43 (SE = 0.38); Control Class = 34.88 (SE = 0.38).*

As the pinnacle of empirical confirmation, the inferential statistical analysis in Table 2 demonstrates highly significant results. The ANCOVA test yielded an F-value of $(1,57) = 847.61$ with a probability value of $\rho < 0.01$. This finding confirms that after controlling for students' initial ability (covariate), there is a distinct difference between the inquiry group utilizing QR-codes and the conventional group.

The Adjusted Mean data highlight a substantial divergence: the experimental class achieved a corrected mean score of 57.43, far outperforming the control class at 34.88. Notably, the Standard Error (SE) for both groups is remarkably low (SE = 0.38). This low variability indicates that the intervention produced a consistent effect across all participants in the

experimental group, suggesting that the scaffolded structure of the QR-based inquiry benefited students uniformly, regardless of their baseline characteristics.

Furthermore, the analysis reveals a Partial Eta Squared of $\eta_p^2 = 0.937$. While this effect size is exceptionally large by educational standards, it reflects the sharp pedagogical contrast between the two conditions: active, scaffolded cognitive processing versus passive information retrieval. Within the framework of Vygotsky social constructivism, this magnitude suggests that when procedural barriers to information access are removed by technology (Baharuddin et al., 2020; Zhou, 2022), the reduction in extraneous cognitive load allows for a drastic and uniform leap in higher-order reasoning. The data

converges to confirm that the QR-Code Integrated Inquiry model is not merely a methodological alternative, but a robust pedagogical solution that successfully bridges the gap between digital access and deep cognitive processing.

Conclusion

This study conclusively demonstrates that the *pedagogical function* of technology is more determinant of learning outcomes than its mere physical presence in the classroom. The findings reveal that transforming QR codes from passive information delivery tools (scanning approach) into integrated cognitive scaffolds significantly enhances the critical thinking skills of pre-service primary teachers compared to conventional direct instruction. The superiority of the scaffolding model lies in its ability to manage extraneous cognitive load, thereby freeing up mental resources for deeper analytical processes within scientific inquiry syntax.

Ultimately, these findings underscore that integrating rapid scanning technology within a constructivist framework successfully bridges the gap between mere information access and meaningful cognitive processing. Instead of making a broad claim for all educators, this study specifically concludes that the QR-Code integrated inquiry model is an effective, scalable approach to cultivate the specific reasoning competencies required by pre-service primary teachers to prepare for their future roles in addressing complex educational demands.

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Author Contributions

Conceptualization, I.I. and N.N.; methodology, N.M.Y.S.; formal analysis, N.M.Y.S. and I.I.; investigation, I.I. and N.A.; resources, N.N. and N.A.; data curation, I.I. N.A.; writing original draft preparation, I.I., N.M.Y.S., and N.N.; writing review and editing, N.M.Y.S. and I.I.; visualization, N.A. I.I.; funding acquisition, I.I. All authors have read and agreed to the published version of the manuscript

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Conflicts of Interest

No conflict interest

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