Technology-Integrated Inquiry-Based Learning and Junior Secondary Students' Science Learning Outcomes: A Quasi-Experimental Study

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Abstract

This study examined the effect of technology-integrated inquiry-based learning on science learning outcomes of junior secondary students. A quantitative approach with a quasi-experimental pretest-posttest non-equivalent control group design was employed. The sample comprised 62 eighth-grade students from SMP Negeri 9 Banda Aceh, assigned to experimental ($n = 31$) and control ($n = 31$) groups. The experimental group participated in inquiry-based learning supported by digital simulations and virtual laboratories, while the control group followed conventional lecture-based instruction. The intervention was conducted over four weeks (eight meetings, each 2×40 minutes). A validated science achievement test (20 multiple-choice items, KR-20 = 0.82) was administered as pretest and posttest. Data were analyzed using independent samples t-test with JASP 0.95.4.0. Results showed that the experimental group ($M = 71.61$, $SD = 7.84$) significantly outperformed the control group ($M = 61.94$, $SD = 10.12$) on the posttest, $t(60) = 3.94$, $p < 0.001$, Cohen's $d = 0.98$. The experimental group also demonstrated higher normalized gain ($g = 0.28$) compared to the control group ($g = 0.06$). These findings indicate that technology-integrated inquiry-based learning is effective in improving students' science learning outcomes. The implications suggest that this approach can serve as an innovative strategy for science instruction in junior secondary schools.

Keywords: inquiry-based learning; technology integration; science learning outcomes; quasi-experimental study; junior secondary education.

INTRODUCTION

Science education plays a vital role in preparing students with 21st-century competencies, including creative thinking, communication, and collaboration, which are essential for navigating complex modern challenges (Putra, 2022). In an era marked by rapid scientific and technological advancement, science learning must move beyond conceptual mastery toward developing scientific literacy and process skills (Elisa *et al.*, 2023). This aligns with global education agendas emphasizing adaptive individuals capable of addressing sustainability challenges.

Despite these expectations, students' science learning outcomes remain concerning. Research indicates that students struggle to connect theoretical concepts with real-world applications, perceive science as difficult, and show low engagement (Sartika *et al.*, 2024; Viqri *et al.*, 2024). These challenges are compounded by teacher-centered instruction dominated by lectures, which limits opportunities for exploration and scientific reasoning (Tias, 2017; Fatimah, Wahyuningsih and Syamsuddin, 2019). The gap between curriculum demands emphasizing learner-centered approaches, higher-order thinking, and technology integration and actual classroom practices contributes to suboptimal learning outcomes (Oktalia, Wijayanti and Ernawati, 2018).

Inquiry-based learning offers a promising alternative by positioning students as active knowledge constructors. This approach systematically develops science process skills observation, hypothesis formulation, experimentation, data analysis, and communication (Iswatun *et al.*, 2017) rather than promoting rote memorization. Studies have shown that inquiry-based learning enhances conceptual understanding and critical thinking compared to traditional instruction (Rinarta, Yuanita and Widodo, 2014; Sholikhan *et al.*, 2020). However, the full potential of this approach depends on how effectively it is implemented and supported.

Digital technology can amplify inquiry-based learning by providing interactive platforms for experimentation, visualization of abstract concepts, and data analysis (Nor and Halim, 2023; Uchkurova and Tursinboyeva, 2024). Virtual simulations and multimedia resources enable students to conduct experiments flexibly and safely (Simanullang *et al.*, 2025). However, technology integration in Indonesian science education faces significant barriers, including digital divides, limited infrastructure, and inadequate teacher training (Pahrijal and Novitasari, 2023; Subroto *et al.*, 2023; Soleha and Mujahid, 2024). Moreover, existing studies indicate that technology is often used as a passive tool rather than being pedagogically aligned with inquiry-based approaches (Wahyuni *et al.*, 2022; Hakim and Abidin, 2024).

While previous studies have separately investigated inquiry-based learning (Saregar *et al.*, 2020; Pramana, Suarni and Margunayasa, 2024) or technology-enhanced instruction (Rasul and Zatya, 2025), limited empirical research examines their systematic integration in Indonesian junior secondary science contexts. Most prior work employs simple experimental designs or measures learning outcomes within narrow scopes. Furthermore, research on how technology functions specifically as scaffolding within each stage of the inquiry process remains underexplored. This study addresses this gap by investigating the combined effect of inquiry-based learning and technology integration on science learning outcomes, with a focus on how digital tools support inquiry stages.

Based on the theoretical framework and identified gap, this study aimed to quantitatively analyze the effect of technology-integrated inquiry-based learning on students' science learning outcomes. The research hypothesis (H_1) was that eighth-grade students who participate in technology-integrated inquiry-based learning would demonstrate significantly higher adjusted posttest science scores compared to students who follow conventional instruction.

METHODS

Research Design

This study employed a quantitative approach with a quasi-experimental pretest-posttest non-equivalent control group design. This design was selected to examine the causal effect of technology-integrated inquiry-based learning in authentic classroom settings while accommodating the practical constraints of school-based research.

Participants

The research population comprised all eighth-grade students enrolled in science courses at SMP Negeri 9 Banda Aceh during the 2024/2025 academic year. A purposive sampling technique was used to select 62 students (31 experimental, 31 control) based on equivalent academic characteristics, curriculum alignment, and availability of technology facilities. Participants' average age was 13-14 years. The experimental class (15 male, 16 female) and control class (14 male, 17 female) demonstrated comparable initial abilities based on pretest analysis.

Intervention

The intervention was conducted over four weeks (eight meetings, each 2×40 minutes). The learning topic was “Heat and Heat Transfer”, selected for its abstract concepts that benefit from visualization and simulation.

The experimental group received technology-integrated inquiry-based learning following five stages: (1) Problem orientation (guided by interactive questions and PhET simulation demonstrations), (2) Hypothesis formulation (students proposed predictions using digital worksheets), (3) Data collection (students conducted virtual experiments using PhET simulations and virtual labs), (4) Data analysis (students interpreted graphs and simulation results collaboratively), and (5) Conclusion drawing (students synthesized findings and communicated results via digital presentation). Each stage incorporated specific technology tools: PhET Interactive Simulations (https://phet.colorado.edu) for "Energy Forms and Changes" and "Heat Transfer" simulations, Quizizz for formative assessment, and Google Jamboard for collaborative hypothesis development.

The control group followed conventional learning with teacher-centered lectures, textbook-based exercises, and verification experiments using physical laboratory equipment. Both groups were taught by the same experienced science teacher with 12 years of teaching experience to control for teacher effects.

Treatment Fidelity

Treatment fidelity was monitored using structured observation sheets completed by two independent observers during 20% of randomly selected sessions. Inter-observer agreement exceeded 90%, indicating high consistency in intervention implementation.

Instrument

The primary instrument was a science learning achievement test aligned with curriculum competency indicators and learning objectives. The test comprised 20 multiple-choice items with four options, covering cognitive levels C1-C4 (remembering, understanding, applying, and analyzing). Content validity was established through expert judgment involving three subject-matter experts (two science education lecturers and one experienced science teacher). Items were rated on a 1-4 scale for: (a) alignment with indicators, (b) clarity of wording, (c) cognitive level accuracy, and (d) material representativeness. Items with mean scores ≥ 3.00 were retained (18 items), while 2 items were revised based on expert feedback.

Reliability analysis using KR-20 yielded a coefficient of 0.82, indicating acceptable internal consistency. Item difficulty indices ranged from 0.32 to 0.78, and discrimination indices ranged from 0.30 to 0.63, confirming adequate item quality.

Data Collection Procedure

Data collection followed three stages: (1) Pretest administration to both groups one week before intervention to measure initial abilities, (2) Eight-session intervention over four weeks, with observation checks during sessions 2, 4, 6, and 8, (3) Posttest administration one week after intervention completion to measure learning outcomes. Ethical approval was obtained from the school principal, and parental consent was secured for all participants. Students were informed of their right to withdraw at any time without penalty.

Data Analysis

Data analysis was conducted using JASP 0.95.4.0 (JASP Team, 2023). The Shapiro-Wilk test was used because each group's sample size was 31 ($n < 50$), consistent with recommendations for small-sample normality testing. Data were considered normal if $p > 0.05$. Levene's test was used to test homogeneity of variances ($p > 0.05$). An independent samples t-test was used to compare posttest scores between experimental and control groups. Additionally, normalized gain (g) scores were calculated using the formula: g = (posttest - pretest) / (maximum score - pretest) to measure improvement magnitude. Cohen's d was calculated as effect size, with d = 0.20, 0.50, and 0.80 interpreted as small, medium, and large effects, respectively.

RESULTS AND DISCUSSION

Result

The content validity test based on expert opinion for the test instrument was conducted by three experts competent in science education and learning evaluation. The validation process included an assessment of the suitability of the questions with competency indicators, clarity of wording, accuracy of cognitive level, and representativeness of the material in accordance with the curriculum. Results showed that all items in the instrument were valid and suitable for use, with minor suggestions for improvement in wording.

Descriptive Statistics

TABLE 1. Descriptive Statistics for Pretest Scores in the Experimental and Control Classes

Statistics	Experimental	Control
N	31	31
Mean	60.81	59.35
Standard Deviation	8.76	8.73
Range	40-80	35-80
Minimum	40	35
Maximum	80	80

The descriptive statistical analysis of pretest data showed that the experimental group (M = 60.81, SD = 8.76) had a slightly higher mean than the control group (M = 59.35, SD = 8.73). The small difference and nearly identical standard deviations indicate that students' initial abilities in both groups were at a comparable level.

TABLE 2. Descriptive Statistics for Posttest Scores in the Experimental and Control Classes

Statistics	Experimental	Control
N	31	31
Mean	71.61	61.94
Standard Deviation	7.84	10.12
Range	50-85	45-80
Minimum	50	45
Maximum	85	80
Gain (Δ)	+10.80	+2.59
g	0.28	0.06

The normalized gain (g) for the experimental group was 0.28 (low-medium category), while the control group showed g = 0.06 (low category). This indicates that the experimental class achieved substantially higher improvement relative to their maximum potential gain.

Normality and Homogeneity Tests

TABLE 3. Results of the Shapiro-Wilk Normality Test

	W	p	Description

post-tests	0.963	.056	Normal

Based on the table above, the normality test results show that the posttest data for both groups had p = 0.056, indicating normal distribution (p > 0.05).

TABLE 4. Results of Levene's Test for Homogeneity

	F	df_1	df_2	p
posttest	0.603	30	30	0.441

The homogeneity test shows p = 0.441, indicating that the variance of both groups is homogeneous (p > 0.05). Thus, the data meets the prerequisites for parametric analysis.

Hypothesis Testing

TABLE 5. Independent Samples T-Test

	t	df	p	Cohen's d
posttest	3.943	60	< .001	0.98

Hypothesis testing using the independent samples t-test on posttest scores shows p < 0.001, indicating a significant difference between the experimental and control classes. The effect size (Cohen's d = 0.98) represents a large effect, suggesting that technology-integrated inquiry-based learning has strong practical significance on science learning outcomes.

Learning Outcomes Comparison

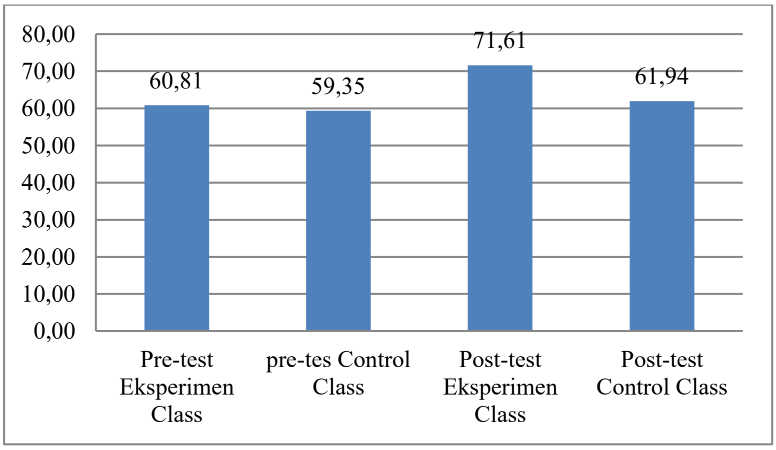

FIGURE 1. Comparison of Average Pre-test and Post-test Scores for the Experimental and Control Groups

The average student scores show that at the initial stage (pretest), the initial abilities of students in both classes were at a relatively equal level. The average pretest score for the experimental class was 60.81, while that for the control class was 59.35. After the learning process, there was a difference in the posttest results. The average posttest score of the experimental class increased to 71.61, while the average posttest score of the control class was 61.94. The increase in the experimental class score of 10.80 points indicates a significant improvement in learning outcomes, while the increase in the control class was relatively low, at 2.59.

Discussion

The results demonstrated that technology-integrated inquiry-based learning significantly improved students' science learning outcomes compared to conventional instruction. The experimental group's

10.80-point gain (from 60.81 to 71.61) substantially exceeded the control group's 2.59-point gain (from 59.35 to 61.94). This differential improvement, supported by a large effect size (d = 0.98), confirms the effectiveness of the integrated approach.

Several mechanisms explain why technology-enhanced inquiry learning outperformed conventional instruction. First, the inquiry process systematically engaged students in scientific reasoning from problem identification to conclusion drawing which aligns with constructivist principles that knowledge is actively constructed through experience (Pramana, Suarni and Margunayasa, 2024). Second, technology functioned as cognitive scaffolding at each inquiry stage: PhET simulations enabled visualization of abstract heat-transfer concepts (e.g., molecular movement during conduction), which is difficult to observe directly in physical experiments. Third, immediate feedback from digital tools (Quizizz) and collaborative platforms (Jamboard) facilitated real-time correction of misconceptions, unlike conventional instruction where feedback is delayed.

These findings support Vygotsky's sociocultural theory, where technology serves as a mediating tool that bridges students' current understanding and their potential development level. The interactive nature of simulations allowed students to manipulate variables, observe outcomes, and build mental models a process that mirrors authentic scientific investigation. This aligns with the nature of science as a discovery process emphasizing direct experience (Sholikhan *et al.*, 2020).

Consistent with (Saregar *et al.*, 2020), who reported improved critical thinking through STEM-inquiry, and (Rasul and Zatya, 2025), who found enhanced concept mastery in inquiry-based practicums, this study extends previous work by empirically demonstrating the synergistic effect of technology and inquiry. Unlike earlier studies that examined inquiry and technology separately, this research shows that technology amplifies inquiry effectiveness by providing flexible experimentation opportunities and reducing barriers to understanding abstract concepts. However, findings contrast with (Simanjuntak, Sari and Barus, 2024), who found limited technology integration due to teacher unpreparedness underscoring that effective implementation requires both pedagogical and technical support.

The findings have important implications for science education. First, technology integration should be pedagogically aligned with inquiry stages, not merely added as a supplementary tool. Second, teacher training should emphasize how to use technology as scaffolding rather than a replacement for inquiry. However, the study's limitations single-school context, small sample, and focus on cognitive outcomes suggest cautious generalization. Future research should examine affective and psychomotor outcomes, employ longitudinal designs, and explore diverse school contexts.

CONCLUSION

This quasi-experimental study examined the effect of technology-integrated inquiry-based learning on eighth-grade students' science learning outcomes at SMP Negeri 9 Banda Aceh. Sixty-two students participated in either technology-enhanced inquiry learning (n = 31) or conventional instruction (n = 31) over four weeks. Results showed that the experimental group significantly outperformed the control group on posttest scores ($t(60) = 3.94$, $p < 0.001$, Cohen's $d = 0.98$). The experimental group demonstrated substantially higher learning gains ($\Delta = 10.80$ points, $g = 0.28$) compared to the control group ($\Delta = 2.59$ points, $g = 0.06$). These findings indicate that under the study conditions, technology-integrated inquiry-based learning was associated with superior science learning outcomes compared to conventional instruction.

The findings imply that science teachers should consider integrating digital tools, particularly simulations and virtual laboratories, systematically within inquiry stages to enhance conceptual understanding and student engagement. School administrators should support technology infrastructure and professional development programs that focus on pedagogical integration of technology. However, the study's limitations including single-school setting, relatively small sample size, and focus on cognitive outcomes suggest that results should be interpreted cautiously. Future research with larger samples, diverse school contexts, and measurements of affective and psychomotor outcomes is recommended to strengthen generalizability and understanding of this approach's comprehensive impact.

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