e-ISSN 2964-3325

INDONESIAN JOURNAL OF CHEMICAL CONNECTIONS

Volume Information: Vol. 1, No. 1, pp. 1–12, 2026

DOI: https://doi.org/xx.xxxx/ijcc.v1i1.xxx

Laboratory-Based Inquiry as a Professional Chemistry Learning Environment: Design, Implementation, and Measured Student Impact

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Received	02 April 2026
Revised	15 April 2026
Accepted	22 April 2026
Published	30 April 2026

ABSTRACT

Background: Laboratory courses in chemistry are often organized around procedural completion rather than knowledge construction, which can limit conceptual transfer and scientific reasoning.**Objective:**This study examined whether a laboratory-based inquiry model could strengthen student understanding, analytical performance, and engagement in contextual chemistry learning.**Methods:**A quasi-experimental design was implemented with two undergraduate classes, consisting of a control group receiving conventional practicum guidance and an experimental group participating in inquiry-oriented laboratory sessions. Learning achievement, observation data, and reflective responses were analyzed using descriptive and inferential procedures.**Results:**Students in the inquiry class demonstrated higher post-test performance, stronger interpretation of experimental evidence, and more consistent participation during laboratory discussion.**Conclusion:**The findings indicate that laboratory-based inquiry can function not only as an instructional method but also as a professional learning environment that connects experimentation, interpretation, and disciplinary communication.

KEYWORDS

chemistry education; laboratory practices; inquiry learning; chemical analysis

Research Highlights

- Inquiry-oriented laboratory sessions produced higher post-test and gain scores than conventional practicum instruction.
- Students showed stronger evidence interpretation, collaboration quality, and confidence in discussing chemical phenomena.
- The article presents a journal-ready structure for reporting chemistry education studies in a more editorial format.

e-ISSN 2964-3325

Article Outline

Study focus	Laboratory-based inquiry in undergraduate chemistry education
Design	Quasi-experimental comparison between conventional and inquiry-based practicum classes
Primary outcome	Conceptual understanding, practical performance, and student engagement
Practical implication	Provides a stronger model for designing contextual and discussion-rich laboratory learning

1 Introduction

Laboratory instruction remains one of the most important spaces for connecting chemical concepts with scientific practice. In many undergraduate settings, however, the laboratory is still treated as a place for confirming known theory through rigid procedures. Students often complete experimental steps accurately while remaining weak in interpreting data, defending claims, or linking observations to broader chemical reasoning. This limitation is especially relevant in chemistry education, where meaningful learning depends not only on procedural skill but also on conceptual negotiation, communication, and evidence-based thinking.

Recent scholarship has encouraged a shift from verification-style practicum toward inquiry-oriented laboratory design, particularly in science learning environments that aim to promote analysis and reflection. Inquiry-based laboratory learning positions students as active investigators who must identify patterns, interpret measurements, and defend conclusions from experimental evidence. Such an approach aligns with the broader expectation that chemistry graduates should be able to operate in laboratory settings with both technical competence and intellectual independence.

Despite this promise, many implementations still report uneven outcomes because inquiry tasks are introduced without sufficient instructional structure or because student performance is measured only through final scores. A more useful evaluation should examine whether inquiry-based laboratory work improves not just test results, but also classroom participation, interpretive quality, and confidence in scientific discussion. Based on this context, the present study investigated the effect of a laboratory-based inquiry model on learning achievement and student engagement in contextual chemistry instruction.

2 Method

This study adopted a quasi-experimental design involving two intact classes enrolled in an introductory analytical chemistry course. One class was assigned as the control group and participated in conventional laboratory practice guided by fixed procedural instructions. The second class was assigned as the experimental group and completed inquiry-based laboratory activities that required students to formulate interpretations, compare observations, and discuss explanatory claims before writing conclusions.

e-ISSN 2964-3325

2.1 Research Design

The intervention was conducted over six laboratory meetings. Each inquiry session followed four instructional stages: orientation to the chemical problem, guided planning of experimental steps, interpretation of results through group discussion, and reflective synthesis at the end of the practicum. The control group completed the same chemistry topics and experimental materials but used direct worksheet instructions with limited discussion prompts.

2.2 Materials and Instruments

The laboratory topics included acid-base analysis, precipitation reactions, and simple gravimetric measurements. Instruments used in the study consisted of a 20-item achievement test, an observation rubric for laboratory participation, and a brief reflective response sheet administered after the intervention. Standard laboratory glassware and reagents were used according to institutional safety procedures. The instructional materials for the inquiry class were designed to emphasize prediction, interpretation, and argumentation rather than procedural replication alone.

2.3 Data Analysis

Achievement scores were summarized using mean values and normalized gain, while observational data were converted into categorical performance indicators. To express laboratory yield analysis in the reporting style of chemistry studies, the following equation may be used:

$$\eta = (m_{actual} / m_{theoretical}) \times 100\% \quad (1)$$

In this expression, η represents percentage yield, $m_{a}{}^{c}$□$_{ua}$□ is the measured mass obtained from the experiment, and $m^{tyeoret}{}_{i}{}^{c}{}_{a}$□ is the expected mass calculated from stoichiometric relations. Comparative interpretation between groups was based on the overall score pattern, classroom observation records, and student reflections.

3 Results and Discussion

The inquiry-based laboratory class produced more favorable learning outcomes than the conventional practicum class across the measured indicators. Students in the experimental group demonstrated stronger performance in post-test achievement, more active collaboration during experimental sessions, and greater fluency when connecting measurements to conceptual explanations. These patterns suggest that inquiry in laboratory instruction offers benefits beyond simple task completion.

3.1 Learning Achievement

Table 1 shows that the two classes started from nearly identical pre-test conditions, while the inquiry class finished with a markedly higher post-test mean and gain score. This pattern indicates that the instructional differences observed at the end of the intervention are more plausibly associated with the learning design than with initial group disparity.

e-ISSN 2964-3325

Group	Pre-test	Post-test	Normalized gain
Control	45.2	68.4	0.42
Experimental	44.8	79.6	0.63

Table 1. Comparison of student achievement between groups

3.2 Participation and Scientific Discussion

Observation results strengthen the quantitative findings. Compared with students in the control group, learners in the inquiry class were more likely to question inconsistent data, explain sources of error, and participate in interpretation-focused discussion. These behaviors indicate that inquiry-based laboratory sessions can support the formation of a more professional scientific learning culture, where evidence, explanation, and peer interaction are integral to the practicum experience.

Indicator	Control group	Experimental group
Asking analytical questions	Moderate	High
Interpreting measurement results	Moderate	High
Collaborative discussion quality	Moderate	High
Confidence in presenting conclusions	Low to moderate	High

Table 2. Observed laboratory participation indicators

3.3 Example of Journal-Themed Graph

This graph illustrates a simple visual style that may be used consistently in publication. The recommended approach is to keep charts clean, limit the number of colors, and prioritize the template palette so tables, figures, and graphs appear visually coherent within the same article.

Control 68.4 | **Experimental** 79.6 |

Figure 1. Example bar chart using the template's journal color palette

3.4 Visual Summary of the Intervention Model

Figure 2 may be replaced with a process diagram showing the sequence from problem orientation to reflective conclusion. In a full manuscript, such a figure can help editors and readers understand the instructional logic of the intervention more quickly. Overall, the findings support the view that laboratory inquiry is effective when it is designed as a structured environment for guided reasoning rather than as unbounded discovery.

[Figure 2 placeholder: Suggested placement for a visual model of the inquiry laboratory cycle]

Figure 2. Suggested placement for a visual model of the inquiry laboratory cycle

e-ISSN 2964-3325

4 Conclusion

Laboratory-based inquiry improved student learning achievement, strengthened interpretation of experimental evidence, and increased participation in scientific discussion. The model appears especially valuable for chemistry instruction that aims to connect procedural work with conceptual reasoning. Future studies may extend this design to larger samples, different chemistry topics, and mixed-method evaluation strategies in order to capture how students experience inquiry across varied laboratory contexts.

Acknowledgment

The authors thank the laboratory assistants, course coordinators, and students who participated in the implementation of this instructional design.

Author Contributions

First Author developed the instructional design, conducted the intervention, and drafted the manuscript. Second Author contributed to observation design, data analysis, and content review. Third Author supervised the study and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Funding

This research received no external funding.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.