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Contextual Chemistry Practical Training for Secondary Science Teachers: Bridging Infrastructure Deficits Through Problem-Based Learning

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A R T I C L E I N F O

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A B S T R A C T

This article evaluates a 10-hour community-service training program organized by Mulawarman University for 13 junior-secondary (SMP/MTs) science teachers in North Samarinda, Indonesia. The program supported teachers in designing contextual chemistry practicals integrating Problem-Based Learning (PBL), Science Process Skills (SPS), Higher-Order Thinking Skills (HOTS), and Claim–Evidence–Reasoning (CER). The pre-test mean was 96.15/100 (n = 13), whereas the post-test mean was 88.89/100 (n = 9). Post-test item analysis showed strong performance on HOTS classification and worksheet design, but errors remained in identifying dependent variables (44.4%), selecting control variables (33.3%), and selecting quantitative evidence for CER explanations (55.6%). The findings suggest that low-cost contextual practicals offer a feasible basis for teacher professional development, while variable control and quantitative evidence-based reasoning require further guided practice and follow-up support.

INTRODUCTION

Practical laboratory work can connect scientific concepts with observable phenomena and provide opportunities to develop investigative practices (Oliveira & Bonito, 2023; National Academies of Sciences, Engineering, and Medicine [NASEM], 2021). However, practical work does not automatically lead to inquiry: when learners simply follow predetermined steps, they may have limited opportunities to formulate questions, control variables, interpret data, or justify conclusions. Teachers in resource-constrained settings may also face shortages of equipment and materials, as well as limited instructional time, making open-ended practical work difficult to plan and implement (Akuma & Callaghan, 2019). These conditions create a gap between the desired learning environment—where students investigate phenomena and support explanations with evidence—and the practical conditions in which teachers must work.

Contextual activities using locally available or household materials can help address resource limitations, but material substitution alone is insufficient unless the activity is designed around meaningful questions and evidence. Problem-Based Learning (PBL) offers a structure through which teachers can begin with a real-world phenomenon, formulate a testable problem, plan an investigation, collect and interpret data, and communicate a reasoned explanation. Inquiry-oriented teacher development therefore needs to address both practical feasibility and the pedagogical decisions involved in guiding investigation (Strat et al., 2024; Sannert et al., 2026). The Claim–Evidence–Reasoning (CER) framework can further support teachers in distinguishing a claim from the data that support it and the scientific reasoning that links them.

The immediate need addressed by this community-service program was the difference between teachers' reported constraints and the desired implementation of contextual, inquiry-oriented practical science. Although teachers may possess declarative knowledge of science concepts and teaching approaches, they may still need support in translating that knowledge into controlled investigations and evidence-based explanations. The specific gap addressed here is the identification of inquiry sub-skills that remain challenging after a short training intervention, rather than assuming that participation alone demonstrates improved classroom practice. Accordingly, this article aims to (1) describe baseline practical constraints and instructional experience among SMP/MTs science teachers, (2) report descriptive pre- and post-training assessment results, and (3) identify persistent difficulties in experimental design and CER-based evidence selection to guide future professional development.

IMPLEMENTATION AND METHODS

Design and Setting

This article reports a descriptive evaluation of a one-group training program using baseline survey data, a pre-test, a post-test, and written reflections. The workshop was conducted in the Theatre Room of the Student Learning Centre (SLC) and the Basic/Organic Chemistry Laboratories at the Faculty of Mathematics and Natural Sciences (FMIPA), Mulawarman University, Samarinda, Indonesia. There was no comparison group; therefore, the evaluation

describes participant responses and assessment patterns rather than establishing causal effectiveness.

Participants

Thirteen science teachers participated in baseline mapping and pre-testing. Participants represented public and private junior-secondary schools and an Islamic junior-secondary school (SMP/MTs) in North Samarinda, including SMPN 19, SMPN 27, SMPN 34, SMPN 42, SMPN 47, SMP Muhammadiyah 5, SMP Al Azhar Syifa Budi, and MTs Annur. Eight teachers (61.5%) had fewer than five years of teaching experience, four (30.8%) had 11–20 years, and one (7.7%) had more than 20 years of experience. Nine participants completed the post-test. The difference between pre-test and post-test sample sizes is reported explicitly; the available data do not establish the reasons for non-completion.

Intervention: Program Architecture and Module Design

The intervention comprised 10 hours of training organized around four contextual chemistry practical modules using accessible materials (Table 1). The delivery sequence included an orientation to the contextual phenomenon, discussion of a problem to investigate, formulation of a prediction, identification of variables and controls, practical experimentation or activity design, recording and visualizing data, constructing CER explanations, and reviewing the investigation. The modules addressed food-additive analysis, natural acid–base indicators, inhibition of enzymatic browning in apple slices, and distinguishing chemical from physical changes. Participants engaged with the activities and developed or sequenced classroom worksheets (LKPD). The program emphasized practical design and pedagogical planning; this evaluation did not include follow-up classroom observations to verify implementation after the workshop.

Table 1. Contextual chemistry modules utilized in the workshop

Module	Focus and Sample Activities
1 .Food Detective	Food-additive analysis in commercial products; titrimetric determination of ascorbic acid in fruit beverages; dye adsorption onto activated carbon using Fanta Strawberry/Grape models.
2. Smart pH	Acid–base classification using natural indicators (red cabbage, butterfly-pea flower); serial dilution and neutralization challenges.
3. Mystery Browning	Time-course inhibition of enzymatic browning in apple slices under lemon juice, salt, water, and control treatments, evaluated with a color-scoring matrix.
4. Chemical Reaction Challenge	Distinguishing chemical from physical changes using accessible proxies: gas evolution, thermal dynamics, and milk-protein coagulation.

Instruments and Data Analysis

Data were collected using four instruments: (1) a baseline diagnostic survey containing open-ended questions about teaching experience, practical-work frequency, equipment and material barriers, and instructional practices; (2) a 10-item pre-test addressing science process skills, PBL, CER, and HOTS; (3) a 15-item post-test assessing applied experimental design, variable identification, data interpretation, and HOTS question generation; and (4) written post-training reflections. The article reports the number of respondents available for each assessment. The pre-test and post-test contained different numbers and types of items and were not treated as equivalent forms. Quantitative survey and test data were summarized descriptively using counts, percentages, and mean scores. Item-level error rates were calculated to identify skills that remained difficult. Written reflections were reviewed thematically to inform interpretation; because no detailed coding protocol or independent coder data were available, qualitative findings are not presented as a formal reliability-tested thematic analysis. No paired inferential test or learning-gain statistic was calculated because the assessment instruments differed and the sample size changed from pre-test to post-test.

Quantitative survey and test data were analyzed descriptively using frequencies (n), percentages (%), and mean scores. Item-level error rates were calculated to pinpoint specific conceptual bottlenecks. Qualitative reflections were coded thematically.

RESULTS AND DISCUSSION

Baseline Practical Constraints and Instructional Habits

As shown in Table 2, equipment scarcity was the most frequently reported barrier (11/13; 84.6%), followed by limited chemical materials (9/13; 69.2%) and time constraints (6/13; 46.2%). Two teachers (15.4%) identified classroom management, while one (7.7%) reported reagent cost or sourcing difficulty. Although 61.5% reported access to formal laboratory apparatus, 69.2% also relied on household materials. This combination suggests that access to some laboratory facilities did not eliminate the need for inexpensive, locally available alternatives. Figure 1 visualizes the same barrier data; the values are descriptive and multiple responses were allowed.

Table 2. Perceived constraints in implementing science practicals among SMP/MTs teachers (n=13; multiple responses allowed)

Constraint Category	Teachers Reporting (n)	Percentage (%)
Equipment scarcity	11	84.6%
Chemical material scarcity	9	69.2%
Time limitations	6	46.2%
Classroom management	2	15.4%
Reagent cost / sourcing difficulty	1	7.7%

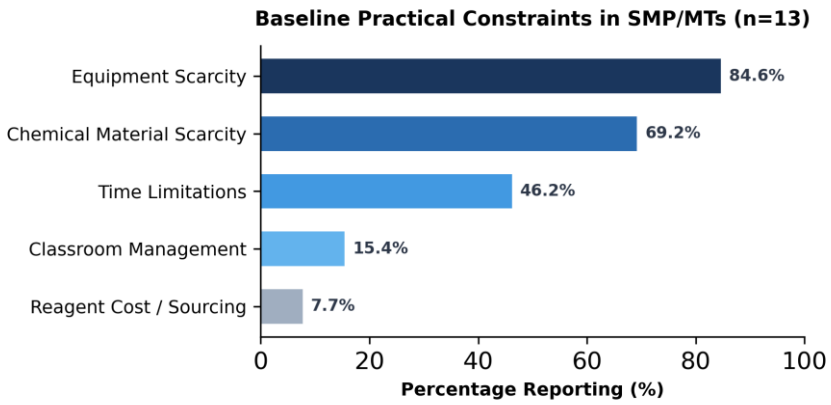


Figure 1. Perceived constraints in implementing science practicals among junior high school teachers (corresponding to data in Table 2).

Baseline teaching approaches were varied but did not consistently emphasize student-led investigation. As summarized in Table 3, six teachers (46.2%) reported never implementing PBL, while another six (46.2%) had used it only simply or occasionally; one (7.7%) reported frequent implementation. Five teachers (38.5%) had never used HOTS questions after practical sessions, seven (53.8%) used them occasionally or at a moderate level, and one (7.7%) reported frequent use. Figure 2 presents these distributions. Together, these results identify a practical professional-development need: support teachers not only in carrying out activities but also in structuring problems and asking students to reason beyond recall.

Table 3. Baseline experience with Problem-Based Learning (PBL) and Higher-Order Thinking Skills (HOTS) among SMP/MTs teachers (n=13)

Category	Level	Teachers (n)	Percentage (%)
PBL Implementation	Never implemented	6	46.2%
PBL Implementation	Simple / occasional	6	46.2%
PBL Implementation	Frequently implemented	1	7.7%
HOTS Post-Lab Questions	Never applied	5	38.5%
HOTS Post-Lab Questions	Occasional / moderate	7	53.8%
HOTS Post-Lab Questions	Frequently applied	1	7.7%

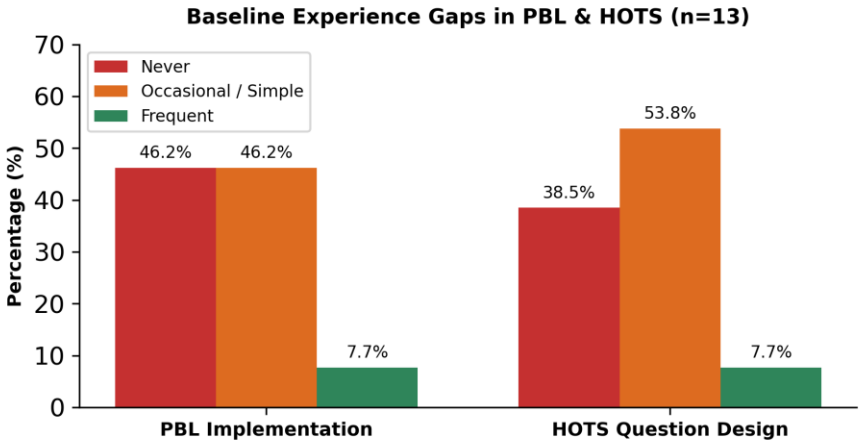


Figure 2. Distribution of baseline teacher experience with Problem-Based Learning (PBL) and Higher-Order Thinking Skills (HOTS) question design (corresponding to data in Table 3).

As depicted in Table 3 and Figure 2, nearly half of the secondary educators (46.2%, n=6) had never implemented PBL in their classrooms, and 38.5% (n=5) had never designed HOTS-level questions following practical sessions.

Pre-Test Diagnostic Knowledge

The pre-test mean was 96.15/100 (n = 13), indicating high overall performance on this 10-item assessment. Item-level errors nevertheless revealed specific areas for attention. Three teachers (23.1%) answered Item 7 incorrectly, which concerned interpretation of null or no-change data; the scenario required distinguishing a lack of observed change from a possible limitation in measurement sensitivity. One teacher (7.7%) answered Item 3 incorrectly, which concerned formulating a testable investigative question linked to controlled variables. These item-level results suggest that a high overall mean can coexist with uncertainty in particular aspects of scientific reasoning.

Post-Intervention Performance and Persistent Misconceptions

Nine teachers completed the 15-item post-test, with a mean score of 88.89/100. All nine answered correctly the items on HOTS cognitive-level classification (Items 11–13), designing a contextual low-cost activity (Item 14), sequencing an investigative worksheet (Item 15), and evaluating anomalous group data (Item 5). These results indicate strong performance on the specific assessed tasks, not universal mastery of the broader competencies. As summarized in Table 4 and Figure 3, errors remained in applied experimental design and evidence selection.

However, as highlighted in Table 4, diagnostic item analysis identified persistent conceptual challenges in applied experimental design and scientific argumentation.

Table 4. Diagnostic item-level error rates on experimental design and evidence construction

Assessment Item	Specific Skill Assessed	Error Rate (%)	Primary Conceptual Deficit
Pre-test Item 7	Interpreting null/no-change data	3.1%	Confounding instrument measurement limits with absence of physical change.
Post-test Item 2	Isolating the dependent variable	44.4%	Confusing manipulated (independent) variables with response (dependent) metrics in Hydrilla trials.
Post-test Item 3	Selecting necessary control variables	33.3%	Omitting essential controlled parameters in photochemical trials.
Post-test Item 6	Constructing CER evidence	55.6%	Defaulting to qualitative impressions rather than citing specific, quantifiable data trends.

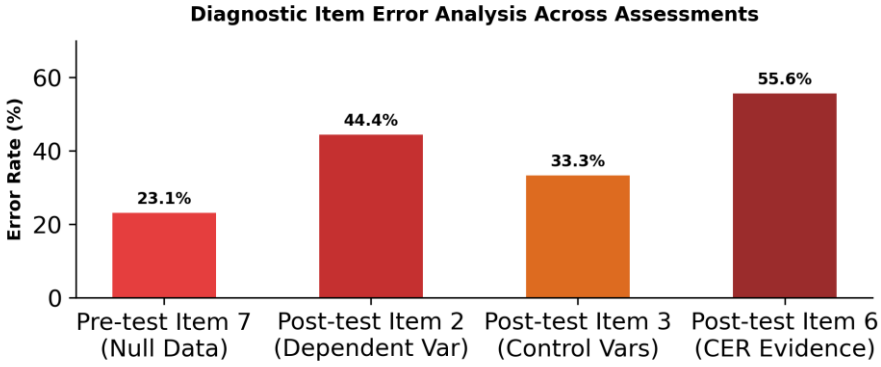


Figure 3. Comparative item error rates highlighting specific diagnostic persistent difficulties in quantitative experimental design and CER evidence construction (corresponding to data in Table 4).

Four of the nine post-test respondents (44.4%) did not correctly identify the dependent variable in the Hydrilla photosynthesis scenario (Item 2). Three (33.3%) had difficulty selecting the necessary control variables in Item 3, and five (55.6%) did not select appropriate quantitative evidence for a CER explanation in Item 6. Hydrilla appeared only in the assessment scenario; it was not one of the four practical modules delivered during the workshop. These results identify specific skills that warrant further practice, particularly distinguishing manipulated, measured, and controlled variables and linking claims to numerical evidence.

Discussion

The baseline survey revealed a dual implementation gap involving both material resources and pedagogical practice. Equipment scarcity was reported by 84.6% of participants and chemical-material shortages by 69.2%, while 46.2% had never implemented Problem-Based Learning (PBL) and 38.5% had never used higher-order thinking skills (HOTS) questions following practical activities.

These findings suggest that the challenges faced by the participating teachers extended beyond access to laboratory resources to include opportunities to structure practical work around scientific inquiry and higher-order reasoning. The training addressed these needs through four contextual chemistry modules using accessible materials and an investigative sequence involving problem formulation, experimental planning, data recording, and scientific explanation. This design is consistent with the argument that practical work is most educationally meaningful when its objectives, activities, and assessment are deliberately aligned with intended learning outcomes, rather than when experimentation is treated as an end in itself (Oliveira & Bonito, 2023). The contribution of the present program therefore lies in combining resource-conscious practical activities with an explicit inquiry-oriented instructional structure. Nevertheless, the findings demonstrate the relevance of this approach to the identified needs and its implementation during the workshop; they do not establish that resource constraints were overcome in participants' schools or that sustained changes in classroom practice occurred.

The assessment findings further highlight the importance of distinguishing general conceptual knowledge from the application of scientific inquiry skills. Although the mean pre-test score was 96.15/100 and the mean post-test score was 88.89/100, the assessments differed in item number and emphasis, and the number of respondents decreased from 13 to 9. Consequently, these means are descriptive summaries of the respective assessment groups and cannot be interpreted as evidence of improvement or decline. Item-level post-test results nevertheless identify specific areas requiring further support: 44.4% of respondents answered incorrectly on dependent-variable identification, 33.3% on selecting control variables, and 55.6% on identifying quantitative evidence for Claim–Evidence–Reasoning (CER). These difficulties are pedagogically important because conducting an experiment requires more than following procedures: teachers must distinguish manipulated, measured, and controlled variables and use empirical observations to justify scientific claims. The findings therefore suggest that professional development should provide explicit modeling and repeated opportunities to design investigations, interpret data, and construct evidence-based explanations. This interpretation aligns with Strat et al. (2024), whose systematic review highlights challenges in translating inquiry experiences into teaching practice, and with Sannert et al. (2026), who emphasize the importance of professional development activities that connect teachers' learning with classroom application and reflection. A short workshop can introduce contextual experimental designs and instructional scaffolds, but follow-up support and classroom-based evaluation would be necessary to determine whether teachers subsequently implement these practices consistently.

CONCLUSIONS AND RECOMMENDATIONS

This community-service program addressed reported resource and pedagogical constraints by introducing four contextual chemistry practical modules and a structured inquiry sequence for SMP/MTs science teachers. Baseline mapping showed that equipment scarcity (84.6%) and chemical-material shortages (69.2%) were common, while 46.2% of participants had never implemented PBL. In the post-test, respondents performed strongly on the assessed HOTS classification and worksheet-design items, but errors persisted in identifying dependent variables (44.4%), selecting control variables (33.3%), and choosing quantitative evidence for CER explanations (55.6%). These findings support targeted professional development focused on applied investigation design, rather than relying on conceptual explanation alone. Because the study had no comparison group, post-test participation was lower than pre-test participation, and the instruments were not equivalent, the findings should be interpreted as descriptive program-evaluation evidence rather than proof of causal impact. Future programs should include repeated variable-control and CER exercises, classroom follow-up or mentoring, and equivalent pre/post measures with participant-level matching where feasible.

Recommendations for future professional development:

1. Variable-identification practice: provide repeated exercises in distinguishing independent, dependent, and controlled variables across unfamiliar experimental scenarios.
2. Quantitative CER scaffolding: use guided templates and data sets that require teachers to select numerical evidence and explain how it supports a claim.
3. Classroom follow-up: add mentoring, classroom observations, or teacher-submitted lesson artifacts to assess whether training designs are implemented in practice.
4. Stronger evaluation design: use aligned assessment instruments, document attendance and attrition, and where feasible collect matched participant data over time.

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