

Enhancing preservice chemistry teachers' critical thinking through Inquiry-Based Instruction Integrated with Ethno-Socioscientific Issues

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Abstract. This study addresses how integrating Ethno-Socioscientific Issues (Ethno-SSI) into inquiry-based instruction can strengthen critical thinking in chemistry teacher education, particularly by linking local sociocultural contexts. Using an explanatory sequential mixed-methods design, we conducted a quasi-experimental non-equivalent control group study with 109 preservice chemistry teachers from a public university in East Java, Indonesia. The intervention group ($n = 56$) received an inquiry-based Ethno-SSI-integrated approach, whereas the comparison group ($n = 53$) received guided inquiry. Quantitative data were collected using a critical-thinking test aligned with Ennis's indicators, and qualitative data were obtained from questionnaires, interviews, and classroom observations to explain the quantitative trends. Test scores were examined using ANCOVA, and effect sizes were estimated using partial eta-squared. Results indicated a statistically significant and substantial effect of the Ethno-SSI-integrated inquiry instruction on critical thinking ($F(1,77) = 64.596, p < .001, \text{partial } \eta^2 = .456$), with higher adjusted posttest means for the intervention group ($M = 81.92$) than the comparison group ($M = 73.10$). Qualitative findings corroborate these results, indicating that the Ethno-SSI context supports meaningful problem framing, evidence evaluation, and argumentation, thus encouraging more analytical and reflective reasoning. This study provides empirical support for the integrated investigation of Ethno-SSI as a pedagogical approach to enhance preservice chemistry teachers' critical thinking through evidence-based and culturally grounded chemical reasoning.

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1 Introduction

Inquiry-based science education and the explicit cultivation of critical thinking are central priorities in twenty-first-century teacher education, including chemistry teacher preparation. International frameworks, such as the OECD's Programme for International Student Assessment (PISA) and the Next Generation Science Standards, highlight that future teachers must be able to interpret evidence, evaluate claims, and make reasoned judgements about complex scientific and socio-environmental problems (1). Critical thinking, therefore, is not only an expected outcome for school students but also a prerequisite capability for preservice teachers who will be responsible for designing and facilitating higher-order learning in their future classrooms.

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In chemistry education, this need is particularly pressing because core concepts (thermochemistry, reaction rates, colloids, and colligative properties) are tightly connected to public issues that are scientifically complex and socially contested, such as food safety, environmental pollution, and health risks. Empirical studies repeatedly show that preservice science and chemistry teachers often demonstrate only moderate levels of critical thinking when faced with ill-structured and controversial problems, especially those that require evaluating evidence and competing claims rather than routine algorithmic procedures. This pattern is often reinforced by lecture-centred teaching and recipe-style laboratory instruction, which prioritise procedural accuracy and algorithmic calculation over argumentation, evidential evaluation, and decision-making in authentic contexts.

Inquiry-based instruction has long been proposed as a pathway to cultivate higher-order thinking by engaging learners in formulating questions, planning investigations, collecting and interpreting data, and constructing evidence-based explanations (2). Research syntheses and meta-analyses demonstrate that inquiry does not consistently improve critical thinking; its effectiveness depends on the authenticity of the problem, the epistemic complexity of the tasks, and the organization of guidance. In practice, college inquiry activities often remain within very structured investigations that yield predictable results. This kind of procedural inquiry can help students learn how to do things without questioning their assumptions, weighing different explanations, or thinking through uncertainty, all of which are important parts of critical thinking.

Socioscientific issues (SSI) pedagogy has been widely advocated to strengthen the authenticity and epistemic demands of science learning by situating concepts within controversial, open-ended problems that include moral, ethical, and socio-political dimensions (3,4). A substantial body of evidence suggests that SSI engagement can promote argumentation quality, epistemic reasoning, and decision-making, while supporting scientific literacy and civic responsibility. Nevertheless, much SSI research and curriculum design tend to prioritise global or national issues and to treat context primarily as a motivational rather than as a knowledge system that shapes how learners interpret evidence and justify claims. Consequently, SSI-based inquiry may still underutilise the cultural and community-specific resources that could enrich reasoning, deepen relevance, and broaden perspectives on what counts as evidence in local settings.

This problem is especially important in places like Indonesia that are culturally and ecologically diverse and where there is a growing interest in combining ethnoscience and local knowledge to make science learning more meaningful and culturally relevant (5,6). This broader international discourse provides a foundation for the concept of Ethno-Socioscientific Issues (Ethno-SSI) as a conceptual extension of Socioscientific Issues (SSI) and culturally grounded science education. Ethno-SSI pertains to socioscientific issues rooted in local cultural practices, traditional technologies, indigenous food and medicine, and region-specific environmental challenges, wherein local knowledge serves as a foundational basis for scientific inquiry and reasoning. In this framing, Ethno-SSI differs from conventional SSI-based inquiry in at least three important ways. Ethno-SSI emphasises place and culture-grounded problem selection, ensuring that the issue is materially consequential within the learners' community. Ethno-SSI requires explicit epistemic work to connect community explanations, practices, and classifications with disciplinary chemistry concepts and scientific norms of justification, rather than assuming such alignment implicitly. Ethno-SSI foregrounds cultural border-crossing in reasoning that supports learners in evaluating claims that may draw on both indigenous and scientific warrants, thereby increasing the cognitive and epistemic demands central to critical thinking (7). By intensifying authenticity and epistemic complexity, Inquiry integrated Ethno-SSI has the potential to move inquiry beyond procedural investigation toward argumentation-driven evaluation of evidence and claims in socially meaningful contexts.

Empirical research on Ethno-SSI in higher education, and particularly in preservice chemistry teacher education remains limited. Existing studies have largely focused on school settings, examined single topics, or emphasised outcomes such as attitudes and interest rather than critical thinking and teacher professional competencies. Moreover, relatively few studies employ robust quasi-experimental designs with validated measures of critical thinking and complementary qualitative evidence that can illuminate not only whether an intervention works but also how it is enacted and experienced. The literature still lacks clear evidence on whether integrating Ethno-SSI into inquiry-based instruction in core chemistry courses yields measurable gains in preservice teachers' critical thinking and on which pedagogical mechanisms may explain these gains.

The study examines the effectiveness of an inquiry-based instructional model integrated with Ethno-Socioscientific Issues (hereafter, Inquiry-Ethno-SSI) in a Basic Chemistry course at a public university in East Java, Indonesia. The Ethno-SSI contexts include locally grounded practices and issues such as the fermentation of palm-sap beverages, the safety of traditional herbal medicines (*jamu*), the toxicity of spoiled *tempe bongkreng*, and the environmental impacts of batik and liquor waste, each explicitly linked to major chemistry topics, including thermochemistry, reaction rates, colloids, and colligative properties. Conceptually, this study contributes by clarifying Ethno-SSI as a culturally grounded SSI framework that strengthens inquiry through explicit epistemic linking and argumentation. Pedagogically, it offers and evaluates a replicable design for embedding Ethno-SSI within inquiry to foster critical thinking in chemistry teacher education. Accordingly, the study addresses the following research questions:

1. How effective is the Inquiry-Ethno-SSI instructional model in enhancing preservice chemistry teachers' critical thinking skills compared with guided inquiry instruction?
2. How do preservice chemistry teachers perceive the Inquiry-Ethno-SSI learning experience in relation to the development of critical thinking?

2 Method

2.1 Research Design and Validity Considerations

This study used an explanatory sequential mixed-methods design embedded within a quasi-experimental non-equivalent control-group design. The quantitative strand evaluated the effectiveness of the Inquiry–Ethno-SSI model on preservice teachers' critical thinking, while the qualitative strand (observations, questionnaires, and interviews) was used to explain how and why the intervention influenced learning processes and to triangulate quantitative results.

Because intact classes were used, random assignment at the individual level was not feasible. Two existing course sections were therefore designated as groups based on administrative scheduling and class registration. To mitigate threats to internal validity, we implemented the following procedures: (a) the same lecturer taught both classes using comparable time allocation and assessment weighting; (b) both groups covered the same chemistry topics and used the same course learning outcomes; (c) baseline equivalence was examined using pretest critical thinking scores and basic participant; and (d) the post-intervention comparison used ANCOVA with pretest as a covariate to adjust for baseline differences.

The research proceeded in two phases. Phase 1 (design and development) produced the instructional model and learning materials (model guidebook, lesson plan/RPS, worksheet/LKM, and assessment instruments) and established their content validity through expert review and pilot testing. Phase 2 (implementation and effectiveness) applied the validated model in a Basic Chemistry course and compared its impact on critical thinking with guided inquiry instruction.

2.2 Participants and Context

The study took place in a chemistry education programme at a public university in East Java, Indonesia. Participants were preservice chemistry teachers enrolled in a Basic Chemistry course covering thermochemistry, colloids, colligative properties, and reaction rates. Two intact classes participated (total $N = 109$): the intervention group ($n = 56$) experienced Inquiry integrated Ethno-SSI, and the comparison group ($n = 53$) experienced guided inquiry. Both classes were taught by the same lecturer to minimise instructor effects.

A separate cohort of 52 preservice chemistry teachers (not included in Phase 2) participated in pilot testing of the critical thinking test to support reliability estimation and item refinement.

2.3 Instructional Intervention

2.3.1 Inquiry integrated Ethno-SSI (intervention)

The Inquiry integrated Ethno-SSI model consisted of six phases that intentionally operationalised critical thinking as problem clarification, evidence evaluation, inference, and warranted judgement, embedded within locally grounded Ethno-SSI contexts.

1. Orientation (problem clarification and framing). Students were introduced to the Ethno-SSI context and explicitly trained to identify issue dimensions (health, environment, culture, religion, and social aspects), clarify key terms, and formulate researchable questions.
2. Exploration (evidence gathering). In small groups (3–4), students designed field data-collection protocols (interview protocol, observation checklist), conducted visits with

local practitioners, collected qualitative/quantitative information, and searched credible scientific sources. Ethical interviewing procedures and data credibility checks were emphasised.

3. Reconstruction (epistemic linking). Students distinguished indigenous/everyday claims from claims that can be interpreted scientifically, then reconstructed explanations using relevant chemistry concepts supported by scientific references. This phase directly targeted evaluating source credibility and building warranted explanations.
4. Elaboration (experiment lab). Groups designed experiment lab to test or illustrate aspects of the Ethno-SSI. The goal was to strengthen the evidential basis of explanations and examine alternative interpretations.
5. Argumentation (claim–evidence–reasoning). Groups developed evidence-based positions and engaged in structured classroom debate, challenging and refining claims using field data, lab evidence, and literature.
6. Evaluation (transfer and judgement). Students synthesised conclusions, transferred reasoning to new Ethno-SSI scenarios, and solved open-ended tasks requiring justification using chemical principles and socio-ethical considerations aligned with critical thinking indicators.

The intervention spanned one semester (12 meetings) and consisted of eight 150-minute classroom sessions and four 200-minute laboratory sessions.

2.3.2 Guided inquiry (comparison)

The comparison group completed the same chemistry topics with the same lecturer and comparable time allocation. Guided inquiry activities involved structured laboratory experiments and problem-solving tasks based on textbook/lecturer-generated scenarios. However, field exploration, explicit Ethno-SSI integration, and structured whole-class argumentation were not included. Problems were framed primarily in decontextualised scientific terms.

2.4 Instruments and Scoring Procedures

2.4.1 Critical Thinking Test

Critical thinking was measured using a 25-item test embedded in 15 Ethno-SSI contexts. Items were developed using Ennis's indicators (clarifying questions, assessing credibility, making and evaluating inferences, drawing warranted conclusions). Content validity evidence was obtained through expert review (CVI and S-CVI indices), and pilot testing ($n = 52$) supported internal consistency (Cronbach's $\alpha = 0.96$).

Scoring rubric and rater training. Each item was scored using an analytic rubric aligned with Ennis indicators, with performance levels 0–4 (0 = no relevant reasoning; 4 = accurate, well-justified reasoning with credible evidence and coherent warrants). Two raters were trained using anchor responses and calibration sessions.

2.4.2 Validation of Learning Materials and Model

The model guidebook, lesson plan, and students worksheet were reviewed by three experts in chemistry education and assessment. The Inquiry integrated Ethno-SSI model obtained an average appropriateness rating of 3.52/4 and high content validity indices (S-CVI/Ave \approx

0.90). LKM and RPS also met high content validity (S-CVI/Ave \approx 0.92–0.96) and were deemed suitable with minor revision.

2.4.3 Implementation Fidelity Observation

Two observers used a structured checklist aligned with the six instructional phases. Observers received joint training and calibration to standardise interpretation. Fidelity was computed as the mean score, and the percentage of implementation was estimated across observed sessions. Inter-observer agreement was estimated using the Kappa coefficient.

2.4.4 Questionnaire and Interviews

A Likert questionnaire assessed perceived relevance, engagement, cognitive challenge, and perceived benefits. Semi-structured interviews with purposively selected participants explored changes in evidence use, issue analysis, and connections between chemistry and context.

2.5 Data Collection and Analysis

2.5.1 Quantitative analysis

Both groups completed the critical thinking test as a pretest (week 1) and posttest (end of semester). Assumptions were evaluated (normality via Shapiro–Wilk/Kolmogorov–Smirnov; homogeneity via Levene’s test). The primary effectiveness test used ANCOVA, with posttest critical thinking score as the dependent variable and pretest score as the covariate, and groups were compared at $\alpha = 0.05$. Effect size was reported using partial eta squared (partial η^2).

2.5.2 Qualitative analysis and trustworthiness

Qualitative data (observation notes, open-ended questionnaire responses, interview transcripts) were analysed using thematic analysis. The procedure included: (1) interview transcript, (2) initial coding, (3) theme development, (4) theme review and refinement, and (5) definition and naming of final themes. Coding was performed by [R1], [R2], etc; disagreements were resolved through discussion and audit trails. Trustworthiness was strengthened through triangulation across sources (observations–questionnaires–interviews), peer debriefing within the research team, and (when feasible) member checking of summary interpretations with interviewees.

2.6 Ethical Procedures

All participants were informed that participation was voluntary and would not affect course grades. Written informed consent was obtained prior to data collection. Participant identities were anonymised, and data were stored securely with access limited to the research team.

3 Result and Dissussion

3.1 Effectiveness of Inquiry-Ethno-SSI on Critical Thinking

3.1.1 Quantitative Findings

Before testing the effectiveness of the Inquiry integrated Ethno-SSI model, prerequisite analyses were conducted. The Kolmogorov–Smirnov normality tests on pretest scores indicated that the distribution of students' critical thinking scores did not deviate significantly from normality ($p = 0.200 > 0.05$), so the normality assumption was met. Levene's tests showed that the pretest scores had homogeneous variances across groups ($p = 0.607 > 0.05$), whereas the posttest scores did not ($p = 0.019 < 0.05$). Therefore, ANCOVA with pretest as covariate was used to compare posttest critical thinking scores between the Inquiry-Ethno-SSI and guided inquiry groups, which is appropriate when there is inequality of posttest variances but comparable baseline distributions. Table 1 presents the ANCOVA results for posttest critical thinking scores with pretest as a covariate.

Table 1. ANCOVA summary for posttest critical thinking scores

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	1389,839	1	1389.839	64.596	0.000	0.456
Error	1656,716	77	21.516			

The ANCOVA indicates a statistically significant effect of instructional model on posttest critical thinking scores, $F(1, 77) = 64.60$, $p < 0.001$, partial $\eta^2 = 0.456$. In line with common benchmarks Cohen (1988), this value represents a large effect, meaning that nearly 46% of the variance in adjusted posttest scores is attributable to the difference between Inquiry-Ethno-SSI and guided inquiry.

This result confirms that, after controlling for initial critical thinking ability, preservice chemistry teachers in the Inquiry-Ethno-SSI condition significantly outperformed those in the guided inquiry condition. This supports the argument that embedding Ethno-Socioscientific Issues within inquiry-based instruction can substantially strengthen students' reasoning, evaluation of evidence, and decision-making in chemistry contexts. Table 2 summarises the adjusted posttest means for critical thinking in both groups, as estimated in the ANCOVA.

Table 2. Adjusted posttest means for critical thinking scores by group.

Class	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Inquiry-Ethno-SSI	81.921	0.645	80.636	83.206
Guided inquiry	73.099	0.882	71.342	74.855

The adjusted mean posttest score for the Inquiry-Ethno-SSI group ($M = 81.92$) is almost nine points higher than for the guided inquiry group ($M = 73.09$), with non-overlapping confidence intervals. This difference is not only statistically significant but also educationally meaningful, indicating that students in the Inquiry-Ethno-SSI class, on average, achieved a higher level of critical thinking performance. In the context of preservice teacher education, such a gap suggests that the Inquiry-Ethno-SSI model more effectively engages students in analysing complex information, weighing evidence, and constructing justified conclusions, competencies that are essential for future chemistry teachers expected to facilitate higher-order thinking in their own classrooms.

3.1.2 Qualitative Findings

The quantitative patterns described above are strongly supported by the qualitative data. Classroom observations, questionnaires, and interviews provided further evidence of the effectiveness of the Inquiry integrated Ethno-SSI model in enhancing preservice chemistry teachers' critical thinking skills. Observations revealed that students in the Inquiry-Ethno-SSI group were more actively engaged in data collection, field visits, and the reinterpretation of local knowledge through chemical concepts. Specifically, the exploration and transformation phases of the instructional model prompted students to critically examine real-world Ethno-SSI issues, such as traditional beverages and herbal medicines, and relate them to formal chemistry concepts. This process of connecting local practices with scientific principles enhanced students' ability to think critically and engage with the material in a meaningful way.

Students' responses from questionnaires and interviews further corroborated this engagement, as many participants expressed that the Ethno-SSI contexts made the learning experience more relevant and challenging compared to traditional guided inquiry. They noted that the opportunity to evaluate everyday claims such as the safety of traditional beverages or the effectiveness of herbal medicines enabled them to question assumptions and critically evaluate information, which is central to critical thinking (6–8). In particular, students appreciated the chance to seek scientific evidence to support or challenge these claims, which helped them refine their reasoning skills.

In terms of implementation, classroom observations showed that the Inquiry-Ethno-SSI sessions were executed with high fidelity across the six phases of the model, with observer ratings averaging in the "very good" category and an overall implementation score of approximately 88.44%. During the exploration and transformation phases, students actively collected data from community settings and reinterpreted local practices using appropriate chemical concepts, in line with the model's design. In the argumentation phase, students were required to present and defend their positions on Ethno-SSI cases, such as the environmental impact of local industries or the safety of traditional medicines, drawing on empirical findings from their fieldwork and laboratory activities, as well as relevant literature. These phases not only deepened students' understanding of scientific principles but also reinforced their ability to engage in evidence-based reasoning and argumentation, key components of critical thinking (9–11).

These findings align with previous research suggesting that inquiry-based learning, especially when embedded in socioscientific contexts, promotes critical thinking by encouraging students to evaluate evidence, consider multiple perspectives, and engage in reflective reasoning (12–14). Thus, the Inquiry-Ethno-SSI approach was perceived as both relevant and effective in supporting the development of critical thinking skills among preservice chemistry teachers.

3.2 Students Perception of Inquiry-Ethno-SSI learning experience for critical thinking

In order to understand how preservice chemistry teachers perceive the Inquiry-Ethno-SSI learning experience, data from student questionnaires and semi-structured interviews were analyzed. The questions were designed to assess their perceptions of the relevance, engagement, and support for critical thinking that the Inquiry integrated Ethno-SSI model provided compared to more traditional instructional methods, such as guided inquiry. The findings from both the quantitative and qualitative data provide insight into how the students viewed the learning experience.

3.2.1 Quantitative Findings

The students' perceptions of the Inquiry-Ethno-SSI learning experience were measured using a Likert-scale questionnaire, which asked them to rate the relevance of the learning activities, the level of engagement they felt, and the extent to which the approach supported their critical thinking development. Table 3 below presents questionnaire results on perceptions category.

Table 3. Questionnaire results on perceptions category

Item	Mean	Std. Deviation
Relevance of the learning content	4.52	0.68
Engagement during learning	4.61	0.56
Support for critical thinking	4.48	0.61

The results in Table 3 indicate that preservice teachers rated the relevance, engagement, and support for critical thinking highly, with all mean scores above 4.5. Specifically, the item regarding engagement during learning received the highest mean score of 4.61, indicating that students found the Inquiry-Ethno-SSI experience to be very engaging. The mean for support for critical thinking was 4.48, suggesting that students felt that the model helped them develop their critical thinking skills. The relevance of the learning content also scored highly (4.52), implying that students found the Ethno-SSI contexts to be highly relevant to their learning and future teaching practices.

In addition to the questionnaire data, qualitative data collected from semi-structured interviews and classroom observations provided a deeper understanding of students' perceptions. When asked about the relevance of the Inquiry integrated Ethno-SSI learning experience, many students expressed that the inclusion of local and culturally relevant issues made the learning more applicable to their lives and future teaching contexts. One participant noted:

“The topics we discussed, like traditional beverages and local environmental issues, felt really connected to what’s happening in our community. It made chemistry feel more relevant and real.”

This quote reflects the broader sentiment that the integration of local Ethno-SSI contexts helped students see the connection between chemistry concepts and real-world issues. This aligns with research that suggests that linking scientific content to local contexts can enhance relevance and make learning more meaningful.

Regarding engagement, many students reported that the inquiry-based approach, combined with fieldwork and collaborative activities, made the learning process more dynamic and interactive. One participant stated:

“I liked how we could actually go into the community and collect data. It made me feel like a real scientist, not just someone who memorizes information.”

This response highlights how the hands-on, real-world application of chemistry concepts through fieldwork and the inquiry process fostered engagement. This finding is consistent with previous studies indicating that inquiry-based learning, especially when it includes real-world contexts, increases student engagement by providing authentic learning experiences (10).

In terms of critical thinking, students overwhelmingly agreed that the Inquiry-Ethno-SSI approach helped them develop critical thinking skills (5). Many students mentioned that the

requirement to analyze complex socioscientific issues and engage in argumentation was a key aspect of the learning experience. For example, one participant explained:

“Arguing about the safety of herbal medicines or the impact of local industries on the environment really made me think about both sides of an issue. I had to use evidence to back up my opinion, and that’s something I’ll definitely need as a teacher.”

This statement demonstrates how the integration of argumentation and evidence-based reasoning in the Inquiry integrated Ethno-SSI model supported the development of critical thinking skills. Students reported that the need to evaluate evidence, consider multiple perspectives, and formulate coherent arguments challenged them to think more deeply and critically. These findings align with research suggesting that inquiry-based teaching that involves argumentation and socioscientific issues enhances critical thinking and decision-making abilities.

Evidence from student questionnaires and interviews further corroborated these observations. Preservice teachers reported that the Inquiry integrated Ethno-SSI learning experiences were more relevant, challenging, and engaging than conventional instruction, and that these experiences encouraged them to critically examine everyday claims about local products and practices, to actively seek and evaluate scientific evidence from journals, books, and other credible sources, and to connect formal chemistry concepts with the socio-cultural and environmental dimensions of real issues in their communities.

4 Dissussion

Inquiry integrated Ethno-SSI moved inquiry beyond procedural investigation toward epistemically demanding reasoning. In guided inquiry, students may engage in controlled experiments and structured problem solving with predictable outcomes and limited need to evaluate competing claims. Ethno-SSI contexts are inherently ill-structured and value-laden, requiring learners to weigh evidence, detect uncertainty, and justify conclusions processes aligned with core critical thinking indicators such as clarifying problems, evaluating source credibility, making inferences, and drawing warranted conclusions.

Local Ethno-SSI cases such as fermentation practices, herbal medicine safety, and environmental waste issues are typically include competing narratives and incomplete or ambiguous evidence. This creates productive tension between everyday explanations, community beliefs, and scientific accounts, a condition known to stimulate deeper evaluation rather than the routine application of formulas. In this sense, Inquiry–Ethno-SSI plausibly increases the frequency and intensity of epistemic decisions, thereby supporting the development of critical thinking.

The reconstruction phase is pedagogically consequential because it explicitly requires students to negotiate the relationship between indigenous/everyday knowledge and disciplinary chemistry explanations. Rather than treating context as a motivational hook, reconstruction demands translating community claims into chemical representations and warrants supported by scientific sources. This process operationalises culturally grounded pedagogy as an epistemic activity: students must articulate assumptions, evaluate credibility, and justify links between phenomena and concepts (thermochemistry, reaction rates, colloids, colligative properties).

The argumentation phase likely served as a mechanism for consolidating critical thinking. Whole-class debate requires students to externalise their reasoning, respond to counterarguments, and refine their claims based on critique, processes strongly connected to socioscientific reasoning and the development of epistemic cognition. Argumentation also serves a social regulatory function: learners must make warrants explicit, anticipate

objections, and adjust conclusions, thereby strengthening inferential and evaluative thinking beyond what is typically elicited by individual written tasks (11).

SSI-oriented learning can enhance argumentation quality, epistemic reasoning, and decision-making, and that inquiry effectiveness depends strongly on task authenticity and epistemic complexity. However, the present study extends prior work by highlighting Ethno-SSI as a design orientation that may strengthen SSI-based inquiry through place and culture grounded issues and explicit epistemic linking between community practices and disciplinary chemistry. This positioning is important for international audiences because it connects localised cultural contexts with widely recognised goals in science education such as developing evidence-based judgement in complex and contested situations (12,13).

The findings should be interpreted cautiously, given studies reporting more modest effects of inquiry on higher-order outcomes. One possible explanation for the comparatively large effect is that Inquiry integrated Ethno-SSI combined multiple high-leverage features: field-based evidence gathering, reconstruction, mini-experiments, and argumentation, creating a synergy that is less common in typical inquiry implementations (14,15).

The effectiveness of Inquiry integrated Ethno-SSI is likely conditional rather than universal. Its success may depend on (a) the availability of locally meaningful Ethno-SSI cases that can be credibly linked to core chemistry concepts; (b) lecturer expertise in facilitating epistemic dialogue and argumentation without reducing tasks to rote debate; (c) sufficient time and institutional support for field exploration and iterative refinement of explanations; and (d) student readiness to engage with uncertainty and socio-ethical dimensions. In contexts where local partners are difficult to access, course schedules are constrained, or argumentation norms are weak, the intervention may yield smaller gains or require adaptation.

Cultural context also shapes how learners interpret and negotiate knowledge claims. In some settings, challenging community practices may be socially sensitive, and students may experience tension between respect for local wisdom and scientific critique. Thus, implementations should consider culturally responsive facilitation and ethical engagement with communities to avoid superficial or extractive use of local practices.

Several limitations should be acknowledged. First, the study used intact classes; therefore, selection bias cannot be fully ruled out despite pretest adjustment (ANCOVA). Second, the intervention is multi-component (fieldwork, reconstruction, experiment, argumentation). Third, results depend on scoring reliability; thus, reporting inter-rater reliability and scoring procedures is essential to strengthen interpretive confidence. Fourth, improvements might partially reflect increased time-on-task, novelty effects, or heightened motivation due to culturally familiar contexts, rather than deeper reasoning alone. Finally, the study was conducted within one programme at one institution; therefore, generalisation should be framed as transferability to contexts with similar resources, curricular structures, and sociocultural conditions rather than as universal applicability.

The findings suggest practical and theoretical implications. Pedagogically, the results support designing chemistry teacher education experiences that intentionally integrate (a) culturally grounded, locally consequential issues, (b) explicit epistemic linking between community claims and chemical explanations, and (c) structured argumentation routines. Theoretically, the study contributes to the discourse on culturally grounded SSI by suggesting that inquiry integrated Ethno-SSI may strengthen critical thinking through epistemic conflict and justification demands, rather than through relevance alone.

5 Conclusion

This study examined the effectiveness of Inquiry integrated Ethno-SSI in enhancing preservice chemistry teachers' critical thinking in a basic chemistry course. Quantitative

results showed that the intervention group outperformed the guided inquiry group on posttest critical thinking, with a large effect size (partial $\eta^2 = 0.456$), while qualitative evidence indicated that participants found the learning relevant, engaging, and supportive of evidence-based reasoning and meaningful connections between chemistry concepts and authentic local issues. The findings suggest that Ethno-SSI strengthens inquiry by treating local cultural knowledge and community problems as epistemic resources, requiring explicit reconstruction of indigenous/everyday claims into scientific explanations and structured classroom argumentation that intensifies evaluation, inference, and judgment. Pedagogically, the study implies that chemistry teacher education can cultivate critical thinking more effectively when inquiry is designed around culturally consequential, ill-structured problems and supported by validated materials and assessment rubrics aligned with critical thinking indicators. Future research should test these mechanisms more directly (argumentation quality, epistemic cognition measures, or process data) and examine scalability across institutions, topics, and levels of teacher preparation.

Acknowledgment

We thank to Directorate General of Higher Education, Ministry of Education and Culture of the Republic of Indonesia for financial support this research. The research conducted in this study received financial support from the Directorate General of Higher Education, Ministry of Education and Culture of the Republic of Indonesia through the Dissertation Research Scheme (Decree Number: 040/E5/PG.02.00.PL/2023 on June 19, 2023).

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