



Local phenomena-based science learning to enhance science process skills of preservice primary school teachers

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Article info	Abstract
Keywords: Science Process Skills; Local Environmental Phenomena; Contextual Science Learning; Inquiry-Based Learning; Preservice Primary School Teachers	Science process skills (SPS) are essential competencies for preservice primary school teachers because they support scientific inquiry and inquiry-oriented science instruction. However, previous studies indicate limited empirical evidence regarding the use of authentic local environmental phenomena as a field-based inquiry context for developing SPS among prospective teachers. This study aimed to examine how science learning grounded in local phenomena supports SPS development among preservice primary school teachers. A quantitative quasi-experimental design with a pretest–posttest control group structure was employed with 67 participants: an experimental group (n = 34) and a control group (n = 33). The intervention was conducted over six weeks through inquiry activities based on local environmental phenomena in Magetan, East Java, Indonesia. Data were analyzed using descriptive statistics, normalized gain (N-gain), and Analysis of Covariance (ANCOVA). The results showed that the experimental group achieved higher posttest SPS scores (M = 82.47) than the control group (M = 69.32), with greater improvement reflected in N-gain values (0.60 and 0.30, respectively). ANCOVA revealed a significant treatment effect after controlling for pretest differences, $F(1,63) = 30.24$, $p < .001$, partial $\eta^2 = .321$. The largest gains occurred in designing investigations, interpreting data, and predicting. These findings suggest that locally phenomena-based science learning was effective in supporting SPS development within the context of this study. The study contributes to the science education literature by providing empirical evidence on integrating authentic local environmental phenomena into field-based inquiry learning to strengthen SPS among preservice primary school teachers.

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1. Introduction

Science education in the twenty-first century requires learners not only to master scientific concepts but also to develop inquiry competence and the ability to construct knowledge through investigation. These competencies are reflected in science process skills (SPS), which include observing, measuring, predicting, classifying, interpreting data, and drawing conclusions. SPS are central to scientific literacy because they represent how knowledge is generated in science rather than merely what knowledge is acquired. Therefore, the development of SPS among preservice teachers is essential, as their competence in scientific inquiry directly influences the quality of science learning in primary schools (Serbest & Akkuzu Güven, 2023). In addition, SPS are considered foundational competencies for preparing future teachers to facilitate student-centered and inquiry-oriented science learning in elementary classrooms (Akgün & Kaya, 2024). Studies in science education also indicate that strong SPS mastery among teacher candidates contributes positively to their pedagogical competence and their ability to create meaningful scientific learning experiences for students (Astalini et al., 2021).

However, empirical evidence suggests that preservice primary teachers often demonstrate insufficient SPS mastery. Recent studies indicate that prospective teachers tend to rely on procedural laboratory activities rather than engage in genuine inquiry processes, resulting in limited ability to interpret data or design investigations independently (Ramlawati et al., 2022). Similar findings indicate that preservice teachers frequently experience difficulties connecting scientific concepts to real-world contexts, which limits their capacity to facilitate meaningful inquiry-based instruction (Kurniahtunnisa et al., 2023). This issue is particularly concerning because primary education is the initial stage at which students begin developing scientific reasoning, and ineffective teacher preparation may hinder students' scientific literacy development in later stages (Jurečková et al., 2024). In addition, international studies have emphasized that the lack of authentic scientific investigation experiences in teacher education programs may reduce prospective teachers' confidence and readiness to implement inquiry-oriented science instruction in classrooms (Capps & Crawford, 2021; Demirdöğen et al., 2022). Research published in high-impact journals also demonstrates that many preservice teachers still exhibit a fragmented understanding of scientific inquiry and limited competence in applying SPS during real-world problem-solving activities (Evagorou et al., 2023). Supporting this argument, Yolanda et al. (2023) found that inquiry learning implemented in teacher education programs often fails to optimize SPS because learning activities remain classroom-centered and minimally connected to authentic environmental contexts.

One promising strategy to address this problem is contextual science learning grounded in local phenomena. Phenomena-based learning situates scientific inquiry in authentic situations drawn from learners' environments, encouraging them to observe, question, and investigate real-world events. From a theoretical standpoint, this approach aligns with constructivist and situated learning perspectives, which emphasize that knowledge is actively constructed through interaction with meaningful contexts (Cirkony, 2023; Scharlott, 2024; Strata et al., 2024). Empirical research in high-impact science education journals demonstrates that contextual and inquiry-based learning significantly improves scientific reasoning, conceptual understanding, and investigative competence compared with traditional instruction (Furtak et al., 2012). Furthermore, contextual learning environments enhance learner engagement and motivation, thereby strengthening the processes underlying scientific inquiry (Delen & Krajcik, 2018; Chen & Chen, 2025). Recent evidence further suggests that place-based and phenomenon-oriented

learning environments support students' ability to transfer scientific knowledge into practical situations and foster deeper conceptual understanding (Strata, 2024; Rahmawati, 2024). Studies in Q1-ranked journals also report that inquiry learning integrated with environmental contexts can improve collaboration, critical thinking, and reflective reasoning among teacher candidates (Jong et al., 2003; Strata, 2024; Scharlott, 2024; Cirkony, 2023). In the Indonesian context, contextual science learning based on local environmental potential has also been shown to improve scientific literacy and inquiry engagement among learners (Suryawati et al., 2020).

In teacher education, integrating local phenomena is particularly important because preservice teachers must learn to translate scientific knowledge into meaningful classroom experiences. Research indicates that engaging teacher candidates in investigations based on authentic environmental issues improves their SPS, pedagogical reasoning, and instructional confidence (Windschitl et al., 2012). Inquiry experiences grounded in local contexts also foster reflective thinking and professional competence, both of which are essential for effective science teaching (Darling-Hammond et al., 2020). These findings suggest that contextual science learning bridges theoretical knowledge and classroom practice by offering opportunities for authentic inquiry. Moreover, recent studies reveal that experiential science learning in natural environments positively influences preservice teachers' environmental awareness, scientific communication, and ability to design contextual learning activities for elementary classrooms (Sönmez, 2022). Similarly, Yasir (2024) and Rediani et al. (2024) demonstrated that integrating science learning with local wisdom and environmental phenomena can significantly improve science process skills and environmental awareness through authentic observation and investigation activities.

In the Indonesian context, the use of local phenomena is highly relevant given the country's ecological diversity and the strong relationship between community life and natural environments. Studies published in nationally accredited journals report that contextual science learning rooted in local ecosystems enhances students' scientific literacy, higher-order thinking skills, and engagement (Sudarmin et al., 2017). Other research highlights that place-based learning enables learners to connect scientific concepts with daily experiences, thereby supporting meaningful understanding and long-term retention (Suastra et al., 2021). Nevertheless, research focusing specifically on how local phenomena-based learning affects SPS among preservice teachers remains limited. Most existing studies focus on school students rather than teacher candidates or examine inquiry learning in controlled laboratory settings rather than authentic environmental contexts (Putri et al., 2022). Existing studies also tend to emphasize conceptual understanding and scientific literacy outcomes while paying less attention to the direct development of SPS components such as observation, investigation design, data interpretation, and scientific communication among preservice teachers (Astalini et al., 2021). Furthermore, few studies have specifically explored the integration of local environmental phenomena from rural and ecological regions such as Magetan into science teacher education programs. Thus, there remains a significant research gap regarding how authentic, locally grounded inquiry-based learning can systematically strengthen SPS among prospective primary school teachers in real-world environmental contexts.

Nevertheless, research focusing specifically on how local phenomena-based learning affects science process skills (SPS) among preservice primary teachers remains limited. Most previous studies have focused on school students, conceptual understanding, or scientific literacy outcomes, while fewer studies have examined the direct development of SPS components through authentic environmental inquiry activities in teacher education contexts (Astalini et al., 2021; Putri et al., 2022). In particular, limited attention has been given to using

local environmental phenomena as a basis for field-based inquiry learning that supports prospective teachers' abilities to observe, investigate, interpret data, and communicate scientific findings in real contexts. Therefore, the main research gap addressed in this study is the limited empirical evidence regarding the implementation of local phenomena-based inquiry learning to support SPS development among preservice primary school teachers.

Magetan Regency in East Java provides a relevant context for implementing contextual science learning, offering diverse natural environments, including mountainous ecosystems, agricultural areas, and local conservation practices. These environments provide authentic opportunities for prospective teachers to engage in direct observation and investigation of ecological interactions and environmental change. The use of familiar local contexts may also help preservice teachers connect scientific concepts with real-life situations encountered in elementary science learning.

Based on these considerations, the present study aims to examine how science learning grounded in local phenomena in Magetan supports the development of science process skills among preservice primary school teachers. Specifically, the study analyzes how contextual inquiry activities grounded in local environmental phenomena enhance teacher candidates' abilities to observe systematically, design investigations, interpret data, and communicate scientific findings. Consequently, inquiry learning frequently emphasizes procedural completion rather than the contextual construction of scientific understanding. This study lies in the implementation of inquiry-based science learning using authentic local environmental phenomena from Magetan as a context for developing SPS among preservice primary school teachers. Unlike many previous studies that were conducted in classroom or laboratory settings, this study emphasizes direct field-based inquiry experiences situated in local environmental contexts.

2. Literature review

Science process skills (SPS) represent the procedural and epistemic dimensions of science that enable learners to construct knowledge through systematic investigation. These skills include observing, measuring, classifying, predicting, interpreting data, and designing experiments, which collectively form the foundation of scientific literacy because they reflect how scientific knowledge is generated rather than merely accumulated. In teacher education, SPS are particularly crucial because teachers' inquiry competence strongly influences how science is taught in classrooms. Previous studies consistently report that preservice teachers with strong SPS are more likely to implement inquiry-oriented instruction and encourage evidence-based reasoning among students, whereas limited SPS mastery often leads to transmissive teaching practices centered on memorization rather than investigation (Serbest & Akkuzu Güven, 2023; Jurečková et al., 2024). Furthermore, inquiry competence among prospective teachers is closely associated with their ability to facilitate meaningful scientific learning experiences and develop students' higher-order thinking skills (Güler & Şahin, 2019). However, despite broad agreement on the importance of SPS, many teacher education programs still struggle to provide authentic inquiry experiences that allow prospective teachers to practice scientific investigation in meaningful contexts. As a result, preservice primary teachers frequently demonstrate limited competence in designing investigations, interpreting data, and connecting scientific concepts with real-life situations (Ramlawati et al., 2022; Kurniahtunnisa et al., 2024). These findings indicate that science learning in teacher education is often still

limited to procedural, decontextualized activities that do not sufficiently facilitate authentic scientific inquiry.

Inquiry-based science education has long been recognized as an effective approach for improving science process skills because it positions learners as active investigators who formulate questions, design procedures, interpret findings, and construct explanations based on evidence. Meta-analytical studies consistently show that inquiry-oriented instruction improves scientific reasoning, conceptual understanding, and higher-order thinking more effectively than traditional lecture-based approaches (Furtak et al., 2012; Schneider et al., 2022). In teacher education, inquiry learning is also associated with the development of reflective thinking, collaborative investigation skills, and inquiry-oriented pedagogical competence among preservice teachers (Irwanto, 2022). However, despite these theoretical advantages, inquiry learning in teacher education often remains procedural rather than authentic. Many inquiry activities are still conducted through highly structured classroom exercises or laboratory simulations, in which prospective teachers follow predetermined procedures rather than engage in open-ended scientific investigation (Yolanda et al., 2023). Consequently, inquiry learning frequently emphasizes procedural completion rather than the contextual construction of scientific understanding, limiting prospective teachers' opportunities to observe natural phenomena directly, investigate real-world problems, interpret contextual evidence, and communicate scientific findings in authentic situations.

These limitations have encouraged growing attention toward contextual and phenomena-based science learning approaches that situate inquiry within meaningful environmental and social contexts. Phenomena-based learning begins with observable, real-world events that require explanation, thereby encouraging learners to connect scientific ideas with authentic experiences and practical situations (Delen & Krajcik, 2023). From a constructivist perspective, scientific understanding develops more meaningfully when learners actively interact with relevant environmental contexts rather than merely receiving abstract explanations. Empirical evidence further indicates that contextual learning environments improve conceptual understanding, scientific reasoning, learner engagement, and knowledge transfer more effectively than decontextualized instruction (Nashon, 2013; Darling-Hammond, 2020; Rameri, 2025). For preservice teachers, contextual inquiry experiences are particularly important because they not only support SPS development but also strengthen pedagogical reasoning by helping prospective teachers understand how science learning can be connected to students' everyday experiences (Windschitl et al., 2020). Nevertheless, many contextual and phenomena-based learning studies still primarily focus on conceptual achievement and scientific literacy outcomes, while the direct development of SPS through authentic inquiry experiences among preservice teachers remains insufficiently explored.

More importantly, previous inquiry and contextual learning studies frequently lack authentic field-based investigation experiences that allow prospective teachers to engage directly with natural environmental phenomena. Although inquiry learning and contextual learning are theoretically intended to support meaningful scientific investigation, their implementation often remains confined to classroom discussions or laboratory simulations, offering limited opportunities for learners to investigate complex environmental systems in real-world settings. As a result, prospective teachers may develop conceptual understanding of inquiry without fully experiencing how scientific knowledge is generated through direct observation, contextual data collection, environmental interpretation, and evidence-based explanation. This indicates an important research gap because authentic field-based inquiry may play a critical role in strengthening SPS by situating scientific investigation within real environmental contexts where

learners must interact directly with observable phenomena, interpret naturally occurring data, and construct explanations grounded in empirical evidence. Therefore, further research is needed to examine how inquiry learning grounded in authentic local environmental phenomena can support the development of SPS among preservice primary school teachers through direct field-based investigation experiences.

Magetan Regency in East Java provides a particularly relevant setting for addressing these limitations, as it offers diverse natural environments that can serve as authentic resources for science learning. The mountain ecosystems surrounding Mount Lawu, agricultural landscapes, biodiversity, and local environmental conservation practices offer opportunities for direct scientific investigation in real-world contexts. Integrating these local phenomena into inquiry-based science learning may support preservice teachers' SPS by engaging them in authentic activities such as observing ecological interactions, collecting environmental data, interpreting findings, and communicating scientific explanations based on field evidence.

Based on these considerations, this study aims to examine how inquiry-based science learning grounded in local environmental phenomena in Magetan supports the development of science process skills among preservice primary school teachers. Specifically, the study analyzes how contextual field-based inquiry activities facilitate prospective teachers' abilities to observe systematically, design investigations, interpret data, and communicate scientific findings. The novelty of this study lies in the implementation of inquiry-based science learning using authentic local environmental phenomena from Magetan to support the development of science process skills among preservice primary school teachers through direct field-based investigation activities.

3. Method

This study employed a quantitative quasi-experimental pretest–posttest control-group design to examine the effect of local phenomena-based science learning on the science process skills (SPS) of preservice primary school teachers. The design was selected to allow comparison between students who experienced contextual inquiry learning and those who received conventional instruction while maintaining the natural classroom setting. The research was conducted at a teacher education institution whose students frequently undertake field-based learning activities in the Magetan region of East Java, Indonesia. The surrounding environment includes mountainous ecosystems, agricultural systems, and local environmental conservation areas near Mount Lawu, which served as authentic learning contexts in this study.

The study involved 67 preservice primary school teachers enrolled in a teacher education program in Magetan, Indonesia. Participants were divided into two groups: an experimental group ($n = 34$) and a control group ($n = 33$). The experimental group participated in local phenomena-based science learning, whereas the control group received conventional science instruction. Both groups were taught by the same instructor to control for teacher variability and ensure instructional consistency. Prior to the intervention, all participants completed a pretest to measure their initial science process skills, and the pretest scores were used as a covariate to control for baseline SPS differences between groups.

The instructional intervention was implemented over six weeks. In the experimental group, learning activities were structured around authentic local phenomena, including ecosystem interactions, soil and water conditions, and environmental changes observable in the local area. Students worked in small groups to conduct field observations, formulate research questions, collect environmental data, design simple investigations, and present their findings. The

instructional approach followed an inquiry-based approach, consisting of orientation to phenomena, question formulation, investigation planning, data collection, data interpretation, and scientific communication. In contrast, the control group studied the same scientific topics using textbook explanations, lecturer presentations, and guided discussions without direct engagement with local phenomena.

Science process skills (SPS) data were collected using an assessment instrument developed based on widely recognized SPS indicators in science education, including observation, classification, data interpretation, investigation design, and conclusion formulation. The instrument consisted of 20 performance-based, open-ended tasks designed to measure participants' ability to apply scientific processes to local phenomena explored during the learning activities. Sample tasks included identifying biotic and abiotic components of local ecosystems, classifying objects by specific characteristics, analyzing data from field observations, designing simple investigative procedures to address environmental problems, and formulating evidence-based conclusions. Each indicator was assessed using an analytic rubric on a 4-point scale (1-4), with higher scores indicating greater mastery of science process skills. Total SPS scores were obtained by summing the scores across all assessed indicators.

To ensure instrument quality, content validity was evaluated by three expert validators, comprising two science education lecturers and one educational assessment specialist. The validation results indicated that all instrument items met the criteria of relevance, clarity, and alignment with the SPS constructs. In addition, the instrument was piloted with a group of students possessing characteristics similar to those of the study participants to ensure readability and clarity of instructions. Internal consistency reliability analysis yielded a Cronbach's alpha coefficient of 0.86, indicating high reliability and suitability for research purposes.

In addition to task-based assessment, classroom observations were conducted to obtain complementary data regarding participants' demonstration of science process skills during investigative activities. Observations were conducted by two independent raters with backgrounds in science education and experience in assessing inquiry-based learning. Prior to data collection, both raters participated in training sessions focusing on SPS indicators, rubric implementation, and scoring simulations using sample cases to establish a common understanding of scoring criteria and minimize subjectivity.

Inter-rater reliability was assessed using Cohen's Kappa coefficient. The analysis yielded a κ value of 0.82, indicating a very high level of agreement between the two raters. This result suggests that the observation instrument possessed adequate reliability for research use. Whenever scoring discrepancies occurred, the raters discussed the results based on the established rubric guidelines until a final consensus was reached.

Data were collected through pretests and posttests administered to both groups, classroom observations, and documentation of students' investigation reports. The pretest measured initial SPS levels before the intervention, whereas the posttest assessed SPS development after the six-week instructional period. To ensure comparability, both groups completed identical assessment tasks under similar testing conditions.

Data analysis was conducted using IBM SPSS software at the 0.05 significance level. First, descriptive statistics were calculated to summarize the mean, standard deviation, minimum score, maximum score, and distribution of SPS scores. Second, assumption testing was performed using the Kolmogorov-Smirnov test for normality and Levene's test for homogeneity of variance. Prior to conducting the main analysis, the assumption of homogeneity of regression slopes was examined by testing the interaction between pretest scores and instructional group.

A non-significant interaction indicated that the relationship between the covariate and the dependent variable was equivalent across groups, thereby satisfying the ANCOVA assumption.

Third, Analysis of Covariance (ANCOVA) was employed to examine differences in posttest SPS scores between the experimental and control groups while controlling for pretest scores as a covariate. ANCOVA was selected because it provides a more accurate estimate of treatment effects in pretest–posttest designs by statistically adjusting for initial group differences. Statistical results were reported comprehensively, including degrees of freedom (df), F-statistics, p-values, effect sizes using partial eta squared (η^2p), and 95% confidence intervals. The magnitude of effect sizes was interpreted according to commonly accepted benchmarks for partial eta squared, where values of approximately .01, .06, and .14 indicate small, medium, and large effects, respectively. Additionally, normalized gain (N-gain) analysis was conducted to determine the magnitude of SPS improvement in each group.

In the Results section, descriptive statistics (means and standard deviations for pretest and posttest scores), normality test results, Levene's test results, homogeneity of regression slopes results, and complete ANCOVA outputs (F, df, p, η^2p , and 95% confidence intervals) are reported to provide a comprehensive evaluation of the intervention effects.

Through this methodological approach, the study provides a replicable procedure for implementing and evaluating local phenomena-based science learning in teacher education contexts. The combination of a quasi-experimental design, validated instruments, controlled instructional conditions, and ANCOVA-based statistical analysis enhances the study's internal validity and ensures that the findings can be reproduced and compared across similar educational settings.

4. Results

The results of this study describe the effectiveness of locally phenomena-based science learning in improving preservice primary school teachers' science process skills (SPS). Data were analyzed using descriptive statistics, normalized gain analysis, and Analysis of Covariance (ANCOVA) to examine differences between the experimental and control groups while controlling for pretest scores. The relevant data are presented in Table 2.

Table 1 indicates that both groups had comparable SPS scores at the beginning of the study, suggesting similar initial competence levels. Following the intervention, the experimental group achieved a substantially higher posttest mean score than the control group. The confidence intervals further indicate that the observed differences were consistent across participants.

The normalized gain analysis shows that SPS improvement in the experimental group was approximately twice that of the control group. This finding suggests that learning activities based on local phenomena provided richer inquiry experiences and promoted greater conceptual engagement.

Table 1. Descriptive statistics of sps scores

Group	N	Test	Mean	SD	Min	Max	95% CI
Experimental	34	Pretest	56.21	8.42	40	71	[53.28, 59.14]
Experimental	34	Posttest	82.47	6.18	69	94	[80.32, 84.62]
Control	33	Pretest	55.89	8.75	39	72	[52.79, 58.99]
Control	33	Posttest	69.32	7.05	54	84	[66.82, 71.82]

Table 2. Normalized gain (n-gain) analysis

Group	Mean N-Gain	SD	Category
Experimental	0.60	0.14	Medium–High
Control	0.30	0.12	Low–Medium

Prior to conducting ANCOVA, the assumptions of normality, homogeneity of variance, linearity between the covariate and dependent variable, and homogeneity of regression slopes were examined. Shapiro–Wilk tests indicated that the SPS scores were normally distributed ($p > .05$), Levene's test confirmed homogeneity of variance ($p > .05$), and the interaction between group and pretest scores was not significant ($p > .05$), indicating homogeneity of regression slopes. Therefore, all assumptions required for ANCOVA were satisfied. The relevant data are presented in Table 3.

Table 3. ANCOVA results for posttest sps scores

Source	SS	df	MS	F	p	Partial η^2
Pretest (Covariate)	428.56	1	428.56	8.37	.005	.115
Group	1547.82	1	1547.82	30.24	< .001	.321
Error	3225.74	63	51.20			
Total	5202.12	65				

The ANCOVA results revealed a statistically significant effect of instructional treatment on posttest SPS scores after controlling for pretest differences, $F(1, 63) = 30.24$, $p < .001$, partial $\eta^2 = .321$. The effect size indicates that approximately 32.1% of the variance in posttest SPS scores was attributable to the local phenomena-based science learning intervention. According to commonly accepted benchmarks, this represents a large effect size, demonstrating the substantial contribution of the instructional approach to students' inquiry competence.

Table 4. Improvement of SPS indicators

SPS Indicator	Experimental Pretest	Experimental Posttest	Gain	Control Pretest	Control Posttest	Gain
Observing	61.50	87.80	26.30	60.90	74.60	13.70
Classifying	57.20	80.40	23.20	56.80	69.10	12.30
Measuring	54.60	79.50	24.90	55.10	68.70	13.60
Predicting	52.40	81.70	29.30	53.00	64.90	11.90
Interpreting Data	50.80	82.90	32.10	51.60	67.50	15.90
Designing Investigation	47.30	81.50	34.20	48.20	60.40	12.20
Communicating Findings	59.10	83.50	24.40	58.70	71.80	13.10

Furthermore, the significant covariate effect indicates that pretest SPS scores were associated with posttest performance, supporting the appropriateness of ANCOVA for controlling initial differences among participants.

Table 4 provides detailed numerical evidence of SPS improvement across all indicators. The largest gains in the experimental group occurred in designing investigations (34.20 points), interpreting data (32.10 points), and predicting (29.30 points). These indicators represent higher-order inquiry skills that require students to formulate questions, analyze evidence, evaluate findings, and construct scientific explanations. In contrast, the control group demonstrated relatively modest gains across all indicators, particularly in designing investigations, where improvement was limited to 12.20 points.

The findings indicate that local phenomena-based science learning was especially effective in developing integrated science process skills rather than merely enhancing basic observational abilities. The authentic environmental contexts used during instruction appear to have encouraged students to engage more actively in scientific inquiry, thereby strengthening their higher-order scientific reasoning and problem-solving competencies.

Overall, the results support the research hypothesis that science learning based on local phenomena significantly improves preservice primary school teachers' science process skills. The ANCOVA results demonstrated a significant treatment effect even after controlling for initial SPS differences, while the large partial η^2 value indicated substantial practical significance. Combined with the higher normalized gain scores and consistent improvements across all SPS indicators, these findings provide strong empirical evidence that contextual learning grounded in local environmental phenomena is an effective approach for fostering scientific inquiry competence among future primary school teachers.

5. Discussion

The findings of this study indicate that local phenomena-based science learning was associated with significant improvements in preservice primary school teachers' science process skills (SPS). Participants in the experimental group achieved higher posttest scores, greater normalized gain values, and significantly better performance across all SPS indicators than those in the control group. After controlling for pretest differences through ANCOVA, the instructional treatment remained statistically significant, suggesting that the intervention contributed to the observed improvement in SPS.

The greatest improvements were found in higher-order SPS indicators, particularly designing investigations, interpreting data, and predicting. These skills require learners to formulate questions, analyze evidence, identify relationships among variables, and construct explanations based on empirical findings. The inquiry activities implemented in this study required participants to engage directly with environmental phenomena, collect field data, and justify their conclusions using evidence. From a constructivist perspective, such experiences may facilitate deeper knowledge construction by enabling learners to connect prior understandings with observations from authentic contexts actively. This interpretation is consistent with previous studies that have reported that inquiry-oriented learning environments can enhance scientific reasoning and investigative competence.

Although the findings support the effectiveness of locally phenomena-based science learning, the results should not be interpreted as evidence that the intervention alone was responsible for all observed improvements. Several factors may have contributed to the outcomes. First, although the experimental and control groups showed comparable pretest

means, individual differences in prior scientific knowledge, inquiry experience, and academic ability may still have influenced students' responsiveness to the intervention. The significant covariate effect identified in the ANCOVA analysis suggests that initial SPS levels were associated with posttest performance, indicating that students entered the intervention with varying capacities that may have affected learning outcomes.

Second, differences in learning motivation may also represent a potential confounding factor. The local environmental contexts used during instruction were closely tied to students' surroundings and may have increased interest and engagement independently of the inquiry process. Consequently, part of the observed improvement may have been influenced by heightened motivation and participation rather than solely by the instructional design. Previous studies have shown that contextual learning environments can enhance learners' perceived relevance and engagement, which, in turn, may positively affect academic performance and participation in inquiry.

Third, prior field-based learning experiences may have affected participants' performance. Some students may have previously participated in environmental observations, community projects, or outdoor learning activities that facilitated adaptation to field investigations. Because prior field experiences were not systematically measured, it is difficult to determine the extent to which they contributed to SPS development during the intervention. Similarly, individual characteristics such as self-regulation, communication skills, collaboration abilities, and confidence in conducting investigations may also have influenced the learning process and outcomes.

Another possible explanation for the observed results relates to the novelty effect. Students in the experimental group experienced a learning approach that differed substantially from conventional classroom instruction. Exposure to a new and relatively unfamiliar instructional format may have increased attention, enthusiasm, and participation during the intervention period. Consequently, some of the observed gains may reflect students' positive responses to the novelty of the learning experience rather than the exclusive influence of local phenomena-based inquiry itself. Future studies employing longer intervention periods may help determine whether the observed effects are sustained after the novelty of the instructional approach diminishes.

The findings also suggest that authentic environmental contexts may provide advantages beyond those typically available in classroom-based or laboratory-based inquiry activities. Nevertheless, this interpretation should be approached cautiously. The present study did not directly compare local phenomena-based inquiry with other forms of contextual inquiry or alternative active-learning approaches. Therefore, while the results indicate positive outcomes, it cannot be concluded that local phenomena-based learning is necessarily superior to all other inquiry-based instructional models. Comparative studies involving multiple inquiry approaches would be required to establish the relative effectiveness of different instructional designs.

An important contribution of this study relates to its novelty. Previous studies examining inquiry-based learning and contextual science education have predominantly focused on school students, conceptual understanding, or scientific literacy outcomes. In contrast, this study specifically investigated the development of science process skills among preservice primary school teachers through direct engagement with authentic local environmental phenomena. As identified in the Introduction, limited research has examined how local environmental phenomena from ecological regions such as Magetan can be integrated into teacher education programs to strengthen SPS development. Therefore, the novelty of this study lies not merely in the use of inquiry learning but in the implementation of field-based inquiry grounded in authentic

local environmental phenomena as a context for developing SPS among prospective primary school teachers. This contribution addresses a previously identified gap concerning the limited use of real environmental contexts in preservice teacher science education.

Despite these contributions, several limitations should be acknowledged. The study was conducted within a single teacher education institution and involved a relatively small sample of 67 participants. Consequently, the findings may reflect characteristics specific to the participants, the institutional culture, the instructional environment, and the local context. Furthermore, the intervention lasted six weeks, limiting conclusions about the long-term sustainability of SPS improvements. Because the study employed a quasi-experimental design rather than random assignment, unmeasured participant characteristics may also have influenced the results.

These limitations affect the generalizability of the findings. The results should be interpreted primarily within the context of preservice primary school teachers participating in local phenomena-based science learning in Magetan. Although the underlying instructional principles of contextual inquiry and authentic investigation may be applicable in other educational settings, further research is necessary before broader conclusions can be drawn. Replication studies involving different institutions, geographical regions, participant populations, and longer intervention periods are needed to determine the consistency and transferability of the observed effects.

Future research should also examine the interaction between local phenomena-based learning and variables such as motivation, prior inquiry experience, environmental attitudes, self-efficacy, and collaborative learning skills. Investigating these factors may provide a more comprehensive explanation of how and why contextual inquiry influences SPS development. Longitudinal studies are additionally required to determine whether improvements in SPS during teacher preparation are maintained when participants enter professional teaching practice.

Overall, the findings suggest that science learning grounded in local phenomena is a promising approach for supporting SPS development among preservice primary school teachers. However, the results should be interpreted within the specific context of the study and in consideration of potential confounding variables and methodological limitations. While the evidence indicates positive effects on SPS development, further investigation is required to verify the robustness, sustainability, and broader applicability of these findings across diverse educational contexts.

6. Conclusion and implications

The findings of this study indicate that local phenomena-based science learning was effective in supporting the development of science process skills (SPS) among preservice primary school teachers in this research context. Participants in the experimental group achieved higher posttest scores, greater normalized gain values, and significantly better performance across SPS indicators than those in the control group. The largest improvements were observed in higher-order SPS components, particularly designing investigations, interpreting data, and predicting, suggesting that contextual inquiry activities grounded in authentic environmental phenomena may provide meaningful opportunities for developing scientific reasoning and investigative competence.

These findings address the research objective of examining how inquiry-based science learning grounded in local environmental phenomena can support SPS development among prospective primary school teachers. In particular, the study provides empirical evidence that

field-based inquiry activities situated within the environmental context of Magetan were associated with improvements in participants' abilities to observe systematically, investigate scientific problems, interpret evidence, and communicate findings.

The contribution of this study lies in addressing the research gap identified in previous literature regarding the limited use of authentic local environmental phenomena in preservice teacher education for SPS development. Unlike many previous studies conducted primarily in classroom or laboratory settings, this study examined the implementation of inquiry learning through direct engagement with local environmental phenomena as a context for strengthening SPS among prospective primary school teachers.

Nevertheless, the findings should be interpreted cautiously. Because the study involved participants from a single teacher education institution, used a relatively small sample, and was conducted over a limited intervention period, the results are context-specific and should not be generalized broadly without further evidence. In addition, factors such as differences in motivation, prior inquiry experience, and individual learner characteristics may have contributed to the observed outcomes.

From a practical perspective, the findings suggest that integrating contextual inquiry activities grounded in local environmental phenomena could enrich science learning experiences in teacher education programs. Future studies involving larger samples, multiple institutions, diverse geographical contexts, and longer implementation periods are needed to verify the consistency and sustainability of the effects observed in this study. Such research would provide stronger evidence of the broader applicability of local phenomena-based science learning for supporting the development of science process skills among preservice teachers.

7. Limitation

This study has several limitations that should be considered when interpreting the findings. First, the research was conducted within a limited institutional and geographical context, which may influence the generalizability of the results to other teacher education programs with different environmental resources or curricular structures. Second, the intervention was relatively short, focusing on immediate improvements in science process skills rather than on long-term retention or transfer into professional teaching practice. Third, the study relied primarily on performance-based assessments and observational data, which, although suitable for measuring inquiry competence, may not fully capture participants' conceptual change or pedagogical transformation over time. Additionally, the effectiveness of local phenomena-based learning depends on the availability of accessible environmental contexts and instructors' ability to design structured inquiry activities; thus, implementation quality may vary across settings. Future research is therefore recommended to employ longitudinal designs, involve multiple institutions, and examine how contextual inquiry experiences influence classroom practices once preservice teachers enter the teaching profession.

Declaration and Statement

CRedit Authorship Contribution Statement

Marheni Rayung Puspaningrum: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. Devi Anggi Friani: Supervision, Validation, Methodology, Resources, Writing – review & editing. Arina Wanawati: Validation, Visualization, Project administration, Resources, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request. Because the data include human participant information, they are not publicly available in order to protect participant privacy and confidentiality.

Ethical Declaration

This study involved human participants and adhered to the ethical principles of the Declaration of Helsinki. According to the applicable institutional regulations, formal ethical approval was not required for this educational research involving voluntary participation, anonymous data collection, and minimal risk to participants. Nevertheless, all participants provided informed consent before participation. They were informed about the purpose of the study, research procedures, and their right to withdraw at any stage without consequence. Participant anonymity and data confidentiality were maintained throughout the study.

Informed Consent Statement

Informed consent was obtained from all participants before their participation in the study. The participants were informed about the purpose and procedures of the study, the voluntary nature of their participation, and their right to withdraw at any time without consequence.

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Declaration of Generative AI and AI-Assisted Technologies

Portions of this manuscript were edited and refined using ChatGPT (OpenAI) to improve language clarity, organization, and academic coherence. All AI-assisted outputs were carefully reviewed, revised, and validated by the authors, who take full responsibility for the final manuscript.

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