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The effect of the nature of science activities on 5th-grade students' scientific process skills

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Abstract

The Nature of Science (NOS) and Scientific Process Skills (SPS) are central components of science education, as they play a crucial role in fostering students' scientific reasoning, inquiry competence, and understanding of how scientific knowledge is constructed. This study aimed to investigate the effects of NOS-based activities implemented in science classes on the development of fifth-grade students' scientific process skills. The research employed a single-group pretest-posttest quasi-experimental design with fifth-grade students from a public school in Denizli/Beyağaç, Türkiye, over an eight-week period. The NOS activities were designed to introduce students to scientific processes, promote scientific thinking, and facilitate the integration of science into everyday life. Data were collected using the Basic Skills Scale and the Scientific Process Skills Evaluation Form (SPSEF). The analysis of the Basic Skills Scale indicated a significant improvement in posttest scores compared to pretest levels. In addition, the analysis of activity-based data collected through the SPSEF revealed improvements in higher-order skills, including problem identification, variable recognition, hypothesis formulation, experimental design, and data interpretation.

These findings suggest that integrating explicit-reflective NOS activities into science instruction can effectively support the development of both basic and emerging higher-order scientific process skills at early grade levels, while also enhancing students' understanding of the epistemic nature of scientific knowledge.

Keywords

Science education
Science Process Skills (SPS)
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Introduction

We are currently in a time of rapid change, not only in science but also across many other areas of human life. In this era of rapidly expanding information, technological advancements have greatly enhanced access to data (Barut, 2023). Individuals must develop the capacity to critically evaluate information, organise and apply it appropriately, and generate new insights (Yanarateş & Yılmaz, 2022). Education plays a crucial role in equipping individuals to navigate complex, constantly evolving information landscapes, both in daily life and in broader societal contexts. In this respect, science

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education should focus on how students and the general public understand scientific issues, arguments, and reasoning in various contexts (Tytler & Ferguson, 2023).

National and international initiatives aimed at reforming science education have increasingly centered on the concept of scientific literacy (Ministry of National Education [MoNE], 2024; National Research Council [NRC], 2012; NGSS Lead States, 2013). Scientific literacy includes several core components: content knowledge (e.g., astronomy, biology, chemistry, geology), understanding of scientific inquiry (methods for developing scientific knowledge), and awareness of the Nature of Science (NOS) as a systematic way of knowing (Roberts, 2008). Consequently, the Nature of Science (NOS) and Scientific Process Skills (SPS) constitute two complementary pillars of scientific literacy. A scientifically literate individual can ask questions derived from daily experiences, seek evidence-based explanations, interpret scientific texts, and participate in public discussions concerning socio-scientific issues. Such individuals evaluate the reliability of data based on its source and methodology and can construct arguments supported by empirical evidence. Within this framework, the Türkiye Yüzyılı Maarif Modeli advances a comprehensive vision of scientific literacy by prioritising learners who actively engage in inquiry, employ scientific process skills in authentic problem-solving contexts, critically interrogate information sources, and integrate scientific understanding with ethical, cultural, and societal dimensions of knowledge (MoNE, 2024).

Understanding science correctly and enhancing scientific literacy are essential responsibilities of science educators (Hodson, 1999). Therefore, teachers should consider the epistemic and cultural nature of scientific knowledge and reflect these characteristics in their teaching practices. Scientific knowledge is dynamic, tentative, creative, and influenced by social and cultural factors (Dagher & Erduran, 2017). A superficial grasp of scientific facts and procedures is insufficient for understanding how science truly operates. Instead, understanding depends on how individuals conceptualise the nature of knowledge itself (Ünal-Çoban, 2010). As social and technological transformations continue, conceptions of science have evolved from static and authoritative notions toward collaborative, theory-laden, and evidence-based perspectives. Hence, students must be equipped to critically evaluate knowledge claims through both epistemic reflection and process-oriented reasoning.

Building on this perspective, the Nature of Science (NOS) can be understood as a way of knowing that encompasses not only empirical practices and logical reasoning but also the underlying values, assumptions, and norms that guide scientific inquiry (Abd-El-Khalick & Lederman, 2000; Erduran & Dagher, 2014). It involves how scientific knowledge is produced, justified, and refined over time through evidence and theory (Ioannidou & Erduran, 2021). Understanding NOS is essential for cultivating a scientific mindset, engaging effectively in inquiry, and making informed, evidence-based decisions in everyday life (Stefanidou & Kechagias, 2018; Namakula & Akerson, 2024).

The NOS literature includes multiple paradigmatic approaches. The widely used consensus view conceptualises NOS through generalisable characteristics and is valued for its pedagogical accessibility and suitability for K-12 contexts (Lederman, 2007). However, it has been criticised for oversimplifying the complexity of scientific practice and presenting NOS as decontextualised lists of features (Allchin, 2011; Duschl & Grandy, 2013; Irzik & Nola, 2011). In response, alternative frameworks such as the Family Resemblance Approach (FRA) and its extended form (RFN) have been proposed to provide more comprehensive and discipline-sensitive accounts of science (Erduran & Dagher, 2014).

In this study, the consensus-based "Lederman Seven" framework was adopted. However, its implementation moved beyond a declarative, list-based treatment by employing explicit-reflective instructional practices that situate NOS concepts within inquiry contexts. In this way, the study benefits from the developmental appropriateness and pedagogical clarity of the framework while addressing its commonly noted limitations.

Developing an accurate understanding of how science operates also requires mastery of scientific process skills (SPS)—the procedural and cognitive tools that enable inquiry and reasoning. These skills include observing, predicting, measuring, classifying, inferring, hypothesising, designing experiments, interpreting data, and drawing conclusions (McComas et al., 1998). Martin (1997) classified them as basic skills (e.g., observation, measurement, classification) and integrated or advanced skills (e.g., variable control, hypothesis formulation, modelling, data interpretation). Since higher-order skills build upon foundational ones, they should be cultivated collectively to foster coherent scientific thinking (Aydoğdu, 2014).

Bell et al. (2012) proposed a process-skills-based approach to NOS instruction, emphasising that connecting abstract epistemic ideas to familiar procedural practices can help students internalise how science works. For example, the tentativeness of scientific knowledge reflects the ability to revise conclusions in light of new evidence, while the interplay between observation and inference mirrors how scientists construct explanations. In this sense, explicit-reflective NOS instruction integrated with process-skill practice allows learners to connect conceptual understanding with scientific reasoning and inquiry performance (Witucki et al., 2024).

Recent empirical studies have increasingly examined this intersection. Wesnawati et al. (2022) demonstrated that NOS-oriented instructional materials can lead to measurable gains in students' process skills, supporting the view that epistemic reflection and inquiry practice reinforce one another. Similarly, Khishfe and Abd-El-Khalick (2002) and Can and Şahin-Pekmez (2010) investigated NOS-based activities in middle school contexts and observed improvements in inquiry-related abilities. Despite these contributions, although numerous studies have explored the Nature of Science as a concept, empirical research directly linking NOS instruction to measurable SPS outcomes remains limited (Erduran & Dagher, 2014; Wesnawati et al., 2022). Consequently, this limited focus indicates an important gap in the literature and highlights the need for research that empirically examines how NOS-based instruction supports students' process-oriented competencies.

Moreover, the majority of previous studies have focused on students in grades six to eight or higher (Arıcı, 2025; Khishfe & Lederman, 2006; Mesci & Kartal, 2021), whereas fifth graders—representing a critical stage in which foundational process skills such as observation, prediction, and measurement are systematically developed—have received comparatively little research attention. Investigating NOS-SPS relationships at this level can provide early insights into how epistemic understanding and procedural competence co-evolve. Additionally, many previous interventions have been short—typically one to three weeks—limiting the sustainability and depth of observed outcomes (Fontes, 2025; Khishfe & Abd-El-Khalick, 2002). In response, the present study implements a long-term, eight-week intervention that enables students to repeatedly engage in explicit-reflective NOS activities and apply these concepts across multiple inquiry contexts.

Furthermore, prior research has typically treated SPS as a single composite construct, providing a limited understanding of how individual subskills respond to instruction (Arıcı, 2025). Few studies have examined specific SPS subdimensions—such as observation, inference, prediction, measurement, variable control, and data interpretation—within the context of NOS learning (Aydoğdu, 2014). Consequently, little is known about which process skills are most responsive to explicit-reflective NOS activities. By analysing each subdimension separately, this study offers a detailed understanding of how NOS instruction influences both lower-order and higher-order process skills.

Taken together, the current research fills several interrelated gaps in the literature. Although a substantial body of research has examined the effects of NOS instruction, prior studies have largely focused on students' understanding of NOS concepts rather than its direct impact on scientific process skills (Lederman, 2007; Lederman et al., 2014). Moreover, existing research has predominantly been conducted at secondary and higher education levels, with relatively limited attention given to elementary students. This limitation is particularly important given that scientific process skills develop progressively, with foundational (lower-order) skills such as observing and classifying emerging in early years, while higher-order skills such as hypothesising, interpreting data, and drawing conclusions begin to develop during the transition to middle school (Ergin et al., 2005; Rambuda & Fraser, 2004; Rubin & Norman, 1992). In this respect, fifth grade represents a critical transitional stage in which students are expected to build upon their foundational skills while beginning to develop more complex forms of scientific reasoning (Çepni & Çil, 2009). In addition, while scientific process skills are often treated as a unified construct, few studies have systematically examined how NOS instruction differentially influences lower-order and higher-order skills. While comprehensive reviews have explored SPS development and instructional strategies, they largely address SPS in isolation without integrating the epistemic dimension of NOS, thereby leaving an important gap in understanding the mechanisms through which students develop scientific thinking (Gizaw & Sota, 2023).

Therefore, the purpose of this study is to investigate the effects of explicit-reflective NOS activities on fifth-grade students' scientific process skills. Specifically, it aims to determine whether such activities lead to measurable improvements in students' ability to observe, hypothesise, and interpret data.

In line with this aim, the central research question guiding the study is: "What is the effect of nature of science activities on fifth-grade students' scientific process skills?" To provide a more nuanced understanding, the study also addresses the following sub-question: "How do explicit-reflective NOS activities influence students' lower-order (e.g., observing, classifying) and emerging higher-order (e.g., hypothesising, interpreting data) scientific process skills?"

Method

Research Model

This study adopted a single-group pretest-posttest quasi-experimental design, in which the effect of the intervention was evaluated by comparing the group's pretest and posttest scores.

Study Group

This study was conducted with fifth-grade students (n = 18), consisting of 13 girls (72.2%) and 5 boys (27.7%), all attending a public school in Denizli province during the 2022-2023 academic year. The study group was selected using convenience sampling, a non-probability sampling technique in which participants are chosen based on their accessibility and willingness to participate (Sönmez, 2005).

In this context, the researcher included the only fifth-grade class available at the school where the study was carried out. Since this was the only class at that grade level at the institution, it was selected for its accessibility, appropriateness, and voluntary participation. This approach also provided practical advantages in time management and implementation feasibility.

Individuals can acquire basic skills during the preschool period, while high-level skills can be developed starting in the 5th grade of primary education (Aydoğdu & Karakuş, 2015). From this perspective, the study has acted as a bridge for 5th-grade students transitioning from basic to advanced skills.

Research Instruments

Basic Skills Scale for Primary School Students

Since the study group included 5th-grade students, the *Basic Skills Scale for Primary School Students*, developed by Padilla et al. (1985) and adapted into Turkish by Aydoğdu and Karakuş (2015), was administered as a pretest before implementation and a posttest after implementation. The study titled "*Adaptation of the Basic Skills Scale for Primary School Students into Turkish*" was conducted with 3rd-, 4th-, and 5th-grade students (n = 447). The dimensions and number of items of the Basic Skills Scale are presented in Table 1.

Table 1. Dimensions, Number of Items and Item Number of the Basic Skills Scale

Basic Skills	Number of Items	Item
Measurement	5	1-10-19-25-31
Observation	5	2-11-12-26-28
Prediction	6	3-7-9-13-21-27
Classification	5	4-6-8-14-30
Making Inferences	5	5-20-22-24-29
Communicating	5	15-16-17-18-23

Scientific Process Skills Evaluation Form (SPSEF)

The qualitative dimension of the research was assessed using worksheets collected from students who participated in NOS activities. This study aimed to measure scientific process skills; therefore, the 'Scientific Process Skills Evaluation Form (SPSEF)' developed by Şahin-Pekmez et al. (2010) was employed. The SPSEF, which was utilised to score the activity sheets, is presented in the appendix and is compared with the Basic Skills Scale data. Detailed descriptions of the activities and the specific skills they assessed are provided in the experimental procedures section.

In their study, Aktamış and Şahin-Pekmez (2011) developed a Scientific Process Skills Scale for the Science and Technology course, aiming to construct a valid and reliable measurement tool to assess the scientific process skills embedded in the curriculum through a combination of question types. They emphasised the importance of using both closed-ended (test-based) and open-ended questions to enable a more comprehensive and detailed evaluation of students' scientific process skills. Similarly, the literature highlights the necessity of employing diverse question formats when assessing these skills (Monica, 2005; Okey et al., 1985). In addition, the use of multiple question types allows for the identification of the formats in which students demonstrate stronger or weaker performance (Aktamış & Şahin-Pekmez, 2011). Building on this methodological perspective, the present study analysed scientific process skills by distinguishing between basic (lower-order) and higher-order skills, thereby enabling a more nuanced evaluation of students' performance across different levels of cognitive demand and question types, as well as identifying the areas in which students perform more effectively.

Scientific process skills are understood to develop progressively as students advance to higher grade levels (Çepni & Çil, 2009). The study group falls within a developmental stage in which students begin to transition from basic to more advanced skills. In this context, higher-order skills such as controlling variables, formulating hypotheses, interpreting data, and conducting experiments become measurable at this level. Furthermore, these skills should not be viewed merely as sequential steps but rather as an integrated set of competencies that collectively form a scientific mindset (Ergin et al., 2005). The structure of the SPSEF also indicates that it can be applied to individuals from middle school onwards.

When the experiment reports evaluation form (Scientific Process Skills Evaluation Form; SPSEF) is examined (Appendix 1), the boxes marked "2" and "3" represent the highest possible scores for each section. For instance, in the "What's in the Tube?" activity, if students explain how the mechanism works based on external observations, they receive full points for identifying dependent, independent, and control variables. Correctly inferring and illustrating the internal mechanism with a justified explanation yields full points for the hypothesis/preliminary idea section. Designing and illustrating an appropriate setup based on the problem and hypothesis earns full marks for experiment design and presentation. If the presented mechanism functions correctly or aligns with the data, full points are given in the results section. Finally, students receive full marks in the comments section if they accurately interpret the relationships, compare them with the original mechanism, and discuss the outcomes clearly. Each activity's implementation and evaluation were designed to be distinct and independent. The scoring criteria for all activities are detailed in the Experimental Procedures section, as outlined in the SPSEF. The SPSEF scores range from 0 to 24. Scores below 8 indicate low, 8-16 moderate, and 16-24 high levels of scientific process skills. In addition, classroom discussions were held periodically to explore and deepen students' understanding of the nature of science.

Experimental Process

In the study involving fifth-grade students, seven activities that featured Lederman's Nature of Science outcomes, as outlined in the book 'Teaching the Nature of Science' by Doğan et al. (2014), were conducted. These activities were carefully selected and organised according to the principles of teaching NOS, with some being completed in groups and others individually. At the conclusion of each activity, students' worksheets, which served as implementation data, were collected. Details about the implementation process and the activities are presented in Table 2.

Table 2. The Experimental Process of Research

Pretest	Implementation	Posttest
Basic Skills Scale	Nature of Science Activities 1. What's inside the tube? (Scientific knowledge requires evidence obtained from experiments and observations.) /18 students 2. Scientific or not? (characteristics of scientific knowledge) /16 students 3. Footprints (observations, inferences and theoretical topics in science) /16 students 4. Fossils (creative nature of scientific knowledge) / 17 students 5. Mysterious cubes (changeable nature of scientific knowledge) / 5 groups / 18 students 6. Young-Old (subjectivity) / 3 groups / 18 students 7. Card exchange (characteristics of scientific knowledge) /5 groups/ 16 students	Basic Skills Scale

First week

During the first week of implementation, the Basic Skills Scale was administered as a pretest, followed by the initiation of activities.

Activity 1: What's Inside the Tube? This activity simulates the processes scientists use in research, enabling students to ***distinguish between observation and inference,*** recognise that scientific knowledge relies on experimental and observational data, and understand that scientific models can evolve. Using toilet paper rolls as invisible systems, students observe that pulling one string (A) causes the other (B) to retract into the tube. They are then asked to hypothesise about the internal mechanism and illustrate their ideas. Each student formulates an individual hypothesis and drawing, then compares it with the teacher's model in the following lesson. The activity helps students grasp the role of prediction in science and that models may not always reflect reality. Evaluation includes identifying the problem, forming hypotheses through initial and revised drawings, depicting variables, designing and presenting a model, and interpreting predictions and results.

Second week

Activity 2: Scientific or not? (I) This activity is designed to help students learn how to distinguish scientific information from non-scientific information. Students are asked to consider ***what characteristics make information scientific*** and then to discuss and share their ideas with each other (Scharmann et al., 2005). They are given various statements that may or may not have scientific value and are tasked with ordering them from most to least scientific. Following this, students must categorise each statement in a table as 'Scientific' or 'Non-Scientific' and provide explanations for their choices. The completion and quality of this table are considered in the scoring, along with the thoroughness of the students' results and commentary.

Third Week

Activity 3: Footprints (I): The aim of this activity is to engage students in working like paleontologists—using data and creativity while grounding their predictions in scientific knowledge to generate new insights. The activity emphasises that ***scientific knowledge arises from human inference and creativity, evolves with new evidence, and relies on collaboration*** (Abd-El-Khalick et al., 1998). Students also learn that fossils are not limited to dinosaurs or animal remains but can include plants, shells, rocks, or resin (Doğan et al., 2014).

In this task, students examined two crab fossils and made predictions based on their observations, supporting their hypotheses with scientific reasoning. The evaluation focused on the hypothesis, results, and interpretation sections and applied the same scoring criteria used in the *Footprints* activity.

Fourth week

Activity 4: Fossils (I)The aim of this activity is for students to work like paleontologists, using their data and creativity while grounding their predictions in scientific knowledge to generate new insights. Accordingly, they are expected to understand that ***scientific knowledge is derived from human inferences and creativity***, evolves with new data, and necessitates collaboration (Abd-El-Khalick et al., 1998). It is well understood that fossils are not limited to dinosaur or other animal remains; they can also include various organisms, such as trees, oyster shells, rocks, and resin (Doğan et al., 2014). In this activity, students were presented with two crab fossils. They were tasked with making predictions based on the remains they observed and grounding their hypotheses in scientific data. The evaluation of the activity involved scoring the hypothesis, results, and interpretation sections, following the same procedure used in the footprints activity.

Fifth Week

Activity 5: Mysterious Cubes (G): This activity was designed to enable students to make observations and inferences, interpret the data, and formulate predictions based on the available mathematical data. Through this process, students are expected to understand that scientists filter the data they collect through a theoretical lens and also ***make inferences influenced by their social environments*** (Abd-El-Khalick et al., 1998). The features of scientific models are emphasised during discussions. In groups, students participated in a game-style activity by rotating cubes they had prepared and numbered according to specific rules, as instructed. They attempted to base their predictions on documented information. In evaluating the activity, the sections on problem identification, experimental design, hypotheses, results, and comments were scored.

Sixth Week

Activity 6: Young-Old (G): In this activity, ***the subjectivity of scientific knowledge*** is highlighted. Through this exercise, students will come to understand how scientists' beliefs, expectations, and perspectives influence their observations and interpretations of data (Abd-El-Khalick et al., 1998). The students were shown two very similar images, yet they could be interpreted differently based on one's perspective. They expressed their thoughts about the images and discussed them in groups. The evaluation of this activity involved scoring the hypotheses, results, and comments sections.

Seventh Week

Activity 7: Card Exchange (G): This activity was designed to clarify students' perceptions of science. Cards containing statements representing different viewpoints were used to ***explore the characteristics of scientific knowledge through discussion*** (Cobern & Loving, 1998). Students were divided into groups, examined the information on the cards, recorded individual opinions, explained their reasoning, and supported their ideas with scientific evidence. This activity, a continuation of week 2's practice, became easier as students grew more familiar with the card-exchange method. The same evaluation procedure used in the *"Scientific or Not"* activity was applied.

Because students initially had difficulty independently linking NOS elements, additional explanations and guiding questions were provided. Each week, attention was directed to the NOS elements targeted by the activity, and students were encouraged to discuss these both in groups and as a whole class.

Data Analysis

In the study examining the effect of NOS activities on students' science process skills, the Basic Skills Scale and the SPSEF were used to assess basic and higher-level- process skills. The data were collected from students' responses to both scales. KR-21 reliability analysis was conducted to examine students' test performance. The levels of knowledge of the basic skills assessed in the study were evaluated based on the test results. Nonparametric tests were preferred since the study group consisted of 18 people. A Wilcoxon signed-rank test was performed to examine differences between pre and post-test levels. In the study, a significance level of 0.05 was set as the threshold for decision-making squared (Γ^2) magnitude calculations were calculated for significant p values and interpreted at the 0.01-0.06-0.14 levels.

Qualitative analysis, an important dimension of the research, was evaluated in accordance with the *SPSEF* using the worksheets collected from students' NOS activities, as stated in the data collection tools section. The appearance and content validity of the SPSEF scale were reviewed by two expert academics within the university. The statements on the working papers were matched with the items on the scale. The first and second authors re-examined these opinions and reached a consensus based on the correlation.

Validity and Reliability

On a 31-item scale, the pretest's internal consistency was calculated as KR-21 = 0.73. This generally indicates that the measurement tool is consistent in assessing participants' skill levels. For the post-test, the KR-21 was 0.76. This also suggests that the measurement tool, which consists of statements from questions based on participants' skill levels, is a reliable instrument (KR-21 > 0.70). In summary, the 'Basic Skills Scale for Primary School Students' can be considered a successful tool for measuring students' skill levels (Karakoç & Dönmez, 2014).

'Basic Skills Scale for Primary School Students' is a knowledge scale that measures student achievement. Scoring is based on the correct and incorrect options assigned to each question, based on the scale's sub-dimensions and general knowledge level. This scale is coded as true or false before analysis, initially for reliability (KR-21), and then included in the analysis based on the scoring values (correct answer = 1 point, incorrect answer = 0 points).

The evaluation criteria identified in SPSEF were prepared by examining students' worksheets. As part of the reliability study for these criteria, 18 worksheets were scored independently by two researchers to assess inter-rater reliability. The Pearson correlation analysis yielded a correlation of .89 between the two researchers, indicating consensus. In preparing the scale, Şahin-Pekmez et al. (2010) ensured the form's appearance and content validity by consulting six experts and implementing the necessary adjustments.

Findings

The findings from the analysis were discussed and interpreted in response to the question, "What is the effect of NOS activities on the science process skills of 5th-grade students?"

Basic Skills Scale Analysis Results

In the study, because of the small sample size (n<30), the distributions of pretest and posttest achievement scores are unlikely to be normally distributed. For this reason, it was determined that nonparametric tests, which do not assume normality, were necessary.

In the study, participants' test success was coded as 1 for each correct answer and 0 for each incorrect answer. A paired Wilcoxon signed-rank test was applied as a dependent-measures nonparametric test for both scores. The results of the study are given in Table 3.

Table 3. Examination of pretest and posttest scores

Measurement	X±SD	z	p	r^2
Pretest score	23,50±2,25	-8,33	.01*	.09*
Posttest score	27,33±1,32			

**Wilcoxon sign test, *significant difference at 0.05 level

The data in the table clearly show a significant increase in participants' post-test scores compared to their pretest levels (z = -8.33, p = .01, p < .05). Initially, the pretest scores averaged 23.50 ± 2.25, which notably rose to an average of 27.33 ± 1.32 following NOS activities. It was observed that the effect size of the significant difference obtained in the pretest-posttest comparison was medium (R2 = 0.09).

In the pretest, the item most frequently answered incorrectly was item 31, which pertained to measurement. By contrast, in the final test, only one student answered this item incorrectly. Additionally, items number 7 (prediction), 14 (classification), 18 (communication), and 20 (inference), which had posed challenges in the pretest, were answered correctly by all students in the post-test.

Table 4. Examination of Pretest and Posttest Scores of the Sub-Dimensions of the Basic Skills Scale

Measurement	X±SD	z	p	r^2
Pre-Measurement	3,17±0,71	-9,46	.01*	.11
Post-Measurement	4,39±0,61			
Pre-Observation	4,22±0,94	-2,7	.02*	.05
Post-Observation	4,72±0,57			
Pre-Prediction	4,94±0,87	-4,53	.01*	.07
Post-Prediction	5,83±0,38			
Pre-Classification	3,89±0,58	-2,36	.03*	.04
Post-Classification	4,28±0,75			
Pre-Making Inferences	3,22±0,94	-3,43	.01*	.06
Post-Making Inferences	3,72±0,75			
Pre-Communicating	4,06±0,94	-1,68	.11	-
Post-Communicating	4,39±0,70			

**Wilcoxon sign test, *significant difference at .05 level

Based on the provided data, there was a noteworthy improvement in participants' post-test scores relative to their pretest scores across various skills (Table 4). Specifically, a considerable increase was observed in the posttest scores for Measurement (z=-9.46, p=.01, p<.05), Observation (z=-2.70, p=.02, p<.05), Prediction (z=-4.53, p=.02, p<.05), and Making Inferences (z=-3.43, p=.02, p<.05) in comparison to their respective pretest levels.

However, it is worth noting that there was no statistically significant difference in the pretest and posttest scores regarding Communicating ($p=.11$, $p>.05$). Hence, while there was a notable improvement in the skills relating to Measurement, Observation, Prediction, and Making Inferences post-assessment, there was no significant change in Communication skill.

The significant differences obtained for the Measurement, Prediction, and Making Inferences sub-dimensions were found to have a moderate effect (ƞ2=0.06-0.14). The significant differences obtained for the Observation and Classification sub-dimensions were found to have a low effect (ƞ2=0.01-0.06). Since the pretest and posttests of the Communication skills dimension were not significantly different, no effect size was calculated.

Qualitative Analysis Results

Table 5 presents the score evaluations for 18 students. Students absent for some weeks are marked with an (a).

Table 5. Nature of Science Activities SPSEF Scores

	Activities/SPSEF Points						
Student No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	13	12	15	16	17	17	18
2	11	14	16	18	18	17	19
3	12	13	16	18	18	17	19
4	15	14	17	17	19	18	22
5	10	12	16	17	18	19	20
6	11	14	15	17	18	18	21
7	8	10	14	16	16	19	18
8	11	12	14	17	18	19	21
9	14	15	15	18	19	20	21
10	16	16	15	17	18	20	21
11	7	8	11	14	17	15	16
12	9	(a)	(a)	12	15	16	17
13	9	10	11	14	18	20	20
14	12	14	15	17	19	18	20
15	15	16	(a)	(a)	19	21	(a)
16	12	14	16	18	17	19	21
17	9	13	16	15	18	20	21
18	8	(a)	10	12	17	18	(a)

Upon reviewing Table 5, it is apparent that the students' SPSEF scores generally improved as the activities progressed. Initially, the impact of just starting the program was evident in the scores. For instance, in the first activity, Student Number 11 scored fewer than 8 points, indicating low performance, whereas the others achieved medium performance, with scores ranging from 8 to 16 points. As the weeks progressed, there was a consistent improvement in performance; by the final week, all students demonstrated high-level scientific process skills, with scores ranging from 16 to 22 points. Notably, Student Number 4 excelled by scoring the maximum of 22 points in the last activity.

Therefore, performances can be distinctly categorised as low, medium, or high based on this data. To illustrate, students' performance levels in the first activity can serve as a benchmark for these categories.

- Students performing at a low level (7-8 points): 7, 11 and 18,0
- Students performing at an intermediate level (10-11 points): 2, 5, 6 and 8,
- Students who performed at a high level (14-16 points): 4, 9, 10 and 15.

A student from each level was sampled to analyse which skills were implicated in the questions they answered incorrectly during the pretest and posttest of the basic skills scale. Accordingly, the data for student number 11 at the low level, student number 8 at the medium level, and student number 4 at the high level are given in Table 6.

Table 6. Basic Skills Scale (Pretest and Posttest) Question Analysis

	Low Level (student number 11)	Intermediate (student number 8)	High level (student number 4)
Basic skills scale (Pretest) question numbers answered incorrectly/skills included	3, 7 and 13 (prediction) 4 and 30 (classification) 10 (measurement) 11, 12 and 28 (observation) 23 (communicating) 29 (making an inference	2 and 12 (observation) 3 (guess) 29 (making an inference) 30 (classification) 31 (measurement)	4 (classification) 5 (making inferences) 9 (guess) 31 (measurement)
Basic skills scale (posttest) corrected questions/skills included	3 and 13 (prediction) 4 (classification) 10 (measurement)	2 (observation) 3 (guess) 30 (classification) 31 (measurement)	5th question (making an inference) 31 (measurement)

When combining the open-ended responses given by Student Number 11 with the tests in activities (Table 6), the following statements were used in the "Footprints" activity: *"In the first picture, there is a squirrel, then a beaver comes and they become friends", "In the second picture, the two might be fighting because their tracks are intertwined.", "In the third picture, as far as I understand, one is running away from the fight while the other stays, but this is just a guess; scientists make predictions too."* From these statements, it can be inferred that the student utilised their observational skills and made inferences based on previous experiences. Student Number 11, who initially answered some questions related to these skills incorrectly, answered them correctly on the final test (questions 11, 12, 28, and 29).

Similarly, the student made predictions and inferences by drawing two separate models in the "What's inside the tube?" activity. The scores show that applying prediction and inference skills in initial activities benefits the process.

When the changes observed in Student Number 8 (Table 6) are combined with the open-ended responses, significant developments in ***measurement*** skills are evident. In the "What's inside the Tube?" activity, the student stated, *"I tied four ropes together, but when I pulled on rope D, I realised it was short, so I made it longer to fix it."* This response may indicate improved measurement capabilities. In the "Fossils" activity conducted during the fourth week, the student described, *"I see a crab fossil. Crabs live by the sea and have hard shells. Their soft parts have rotted away, mixed with the sand, and dried up."* This observation shows the student's ability to ***classify*** organisms based on their physical and environmental traits.

Additionally, in the "Mysterious Cubes" activity in the fifth week, the student explained, *"Looking at the covered part of the cube in front of me, I think there is a '5' because the numbers I can see are 1, 2, 3, 4. Someone else might see a '5' or '6', so I guessed it was '5'."* This statement demonstrates the student's use of ***observation*** to support and ***justify their predictions***. These responses showcase the student's growth in observational, predictive, and classification skills through engaging and sequential learning activities.

It was determined that student number 4 answered only the 4th and 9th items incorrectly in the post-test (Table 6). Integrating the changes observed in the student with the open-ended responses from the activities, notably from the 'What's in the Tube?' activity conducted in the first week, it is evident that she/he developed a cause-and-effect relationship through their predictive models. She/he stated, *'In my first prediction, it did not comply with the instructions; in the other, I felt the need to add a ring because when we pulled a string, according to the instructions, not all should go inside.'* This demonstrates that she/he tested and revised her hypothesis based on the instructions.

In the 'Scientific or Not?' activity conducted during the second week, student number 4 effectively ranked various statements from most scientific to least scientific. During the exercise, he/she evaluated statements from an article about vitamin C, including*: 'We get vitamin C from citrus fruits, and we become more energetic,' 'Last year and this year, we learned at school that the shape of the world is a sphere,'* and *'There is no such thing as an evil eye, even if it exists, it has nothing to do with eye color.'* Her/his responses indicate a clear understanding of the characteristics of scientific knowledge.

At the 'What's Inside the Tube?' event, all students displayed their models using their own rolls. When tested, 14 students found that their initial models did not function as expected and had to revise their designs. However, four students successfully identified the correct mechanism from the start. Reviewing the worksheets of students 1, 2, 4, 9, 10, 14, 15, and 17 revealed their initial predictions, corrections of any inaccuracies, and the reasoning behind their successful or erroneous mechanisms. Some students, lacking a clear understanding of the mechanism, resorted to making random guesses. Evaluations were conducted to ascertain whether the students' hypotheses and their understanding of dependent, independent, and control variables were correctly applied and grounded in scientific knowledge.

In summary, there was a significant increase in scores from the pretest to the posttest. Almost all students who made fewer errors on the Basic Skills Scale in the post-test also achieved higher SPSEF scores (Table 5). Both qualitative and quantitative findings indicate that as students engage in NOS-based activities, their fundamental skills—such as sorting, classifying, predicting, observing, and inferring—improve substantially. At the same time, their higher-order skills, including hypothesis formulation, variable identification, and analytical reasoning, also develop. This overall progression is consistently reflected in the improvements observed on the Basic Skills Scale (Table 4).

Discussion, Conclusion and Recommendations

The nature of science (NOS) and scientific process skills (SPS) are at the heart of science education, serving as key elements that foster students' critical thinking, evidence-based reasoning, and understanding of the epistemic foundations of science (Abd-El-Khalick & Lederman, 2023; Erduran & Kaya, 2018). This study examined the impact of structured NOS activities on fifth-grade students' SPS, including their sub-dimensions. After an eight-week implementation, significant improvements were observed in measurement, observation, prediction, and inference skills. These findings indicate that NOS-based learning environments not only enhance procedural competence but also deepen students' awareness of how scientific knowledge is generated and justified.

Previous studies have shown that explicit-reflective NOS instruction strengthens students' conceptual understanding and inquiry-related attitudes (Namakula & Akerson, 2024). However, most of this research has focused on students in grades 6-8 and secondary education. By providing empirical evidence that NOS-based teaching can also support advanced SPS development at earlier grade levels, the present study helps fill an important gap in the literature. The results align with the findings of Khishfe (2021), who emphasised that inquiry- and argumentation-based activities enhance both NOS awareness and procedural competencies among younger learners.

The multidimensional pattern of improvement observed in this study is consistent with literature grounded in epistemic inquiry. Erduran and Dagher (2014) have noted that engaging students in hypothesis generation, testing ideas, and justification fosters both cognitive and epistemic awareness. The "What's in the Tube?" activity in this study encouraged students to propose multiple explanations for an unseen mechanism and to test them through evidence-based reasoning. Similarly, Koumara, et al. (2022) demonstrated in their "black box" activity that imagination plays a key role in problem-solving and that identical observations may lead to different inferences. In both contexts, students directly experienced the tentative, creative, and evidence-based nature of scientific knowledge.

Conversely, no significant improvement was observed in communication skills. This suggests that while students could perform procedural reasoning individually, opportunities for reflective and dialogic engagement were limited. The literature highlights that scientific communication skills and reasoning are best advanced through environments that promote argumentation and dialogic interaction (Akerson et al., 2019; Jiménez-Aleixandre & Crujeiras, 2017). Future implementations should therefore integrate structured peer discussions, collaborative inquiry tasks, and reflective writing activities to strengthen this dimension. The initial challenges observed in measurement and inference skills may be attributed to students' limited familiarity with test formats, as prior research has shown that exposure to multiple question types can enhance performance and measurement reliability (Aktamış & Şahin-Pekmez, 2011; Monica, 2005; Okey et al., 1985).

Unlike previous studies that focused solely on students' conceptions of NOS (Cofré et al., 2019; Gören, 2021), this research operationalised NOS principles through practical, inquiry-based activities, thereby building a tangible bridge between epistemic cognition and measurable skills. The marked progress among students from lower- to middle-socioeconomic backgrounds further demonstrates that well-designed NOS activities can mitigate resource limitations. The finding that science textbooks insufficiently address epistemic and cognitive categories (Okan & Kaya, 2023) underscores the compensatory role of experiential classroom NOS instruction in closing this curricular gap.

The teacher dimension is also critical for ensuring sustainability. Teachers often learn about NOS in contexts disconnected from their classroom practices, making it difficult for them to perceive how NOS aligns with their existing instruction. Stadermann and Goedhart (2021) argued that this contextual misalignment can be alleviated by teaching NOS through a process-skills-based approach—one that explicitly links NOS concepts to inquiry practices teachers are already accustomed to implementing. Such an approach employs engaging, critical-thinking activities that make NOS ideas concrete and pedagogically relevant, thereby increasing coherence between how teachers learn about NOS and how they later teach it. This integration ultimately strengthens both teachers' and students' meaningful engagement in scientific reasoning (Bell, 2008).

Methodologically, the single-group pretest-posttest quasi-experimental design limits causal inference. Future studies should adopt control-group designs, longitudinal tracking, and mixed methods to examine causal relationships more rigorously (Deehan et al., 2024). Although epistemic thinking was not directly assessed in this study, the interactive NOS activities engaged students in reasoning, evidence evaluation, and reflection—processes that are associated with the development and durability of epistemic awareness over time. Considering contextual and cultural diversity, incorporating perspectives that emphasise epistemic practices can also enhance inclusivity and strengthen the long-term impact of NOS instruction in diverse classrooms (Agustian, 2024; Zetterqvist & Bach, 2023).

In conclusion, the findings provide strong evidence that explicit-reflective NOS activities can significantly enhance SPS -particularly measurement, observation, prediction, and inference- at early grade levels. Integrating NOS and SPS as complementary pillars of science education, supported by evidence evaluation, hypothesis formulation, and activities that reveal the human and creative dimensions of scientific knowledge, can foster students' ability to connect scientific reasoning with real-life contexts. Such integration helps nurture reflective, evidence-oriented citizens capable of critically engaging with the complex scientific and societal challenges of the twenty-first century.

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Appendix 1. Experiment Reports Evaluation Form. (Scientific Process Skills Evaluation Form/SPSEF)

Problem	**Not suitable (0)**	**Suitable (1)**	
Dependent variable	Not Specified (0)	Not Suitable for the Problem (1)	Suitable for the Problem, incorrectly expressed (2) Correctly Expressed (3)
Independent variable	Not Specified (0)	Not Suitable for the Problem (1)	Suitable for the Problem, incorrectly expressed (2) Correctly Expressed (3)
Control variable	Not Specified (0)	Not Suitable for the Problem (1)	Suitable for the Problem, incorrectly expressed (2) Correctly Expressed (3)
Hypothesis/Preliminary idea	not based on information (0)	Knowledge-based (1)	Not suitable for the problem (0) Suitable for the Problem (1)
Experiment Design	Suitable for the problem (0)	Suitable for the Problem (1)	Not Suitable for Hypothesis (0) Suitable for Hypothesis (1)
Presentation	Table	Unused (0) All data exactly processed (2)	only dependent variable defined (1) only independent variable defined (1)
	Graphic	Unused (0) All data exactly processed (2)	only dependent variable defined (1) only independent variable defined (1)
	Other	Unused (0)	Not Suitable (1) /Suitable (2)
Conclusion	Not Specified or Not related to the Problem (0)	Not expressed according to data (1)	Expressed according to the data (2)
Comment	Not done or not related to the problem (0)	Not properly expressed (1)	Associated with the data obtained (2)