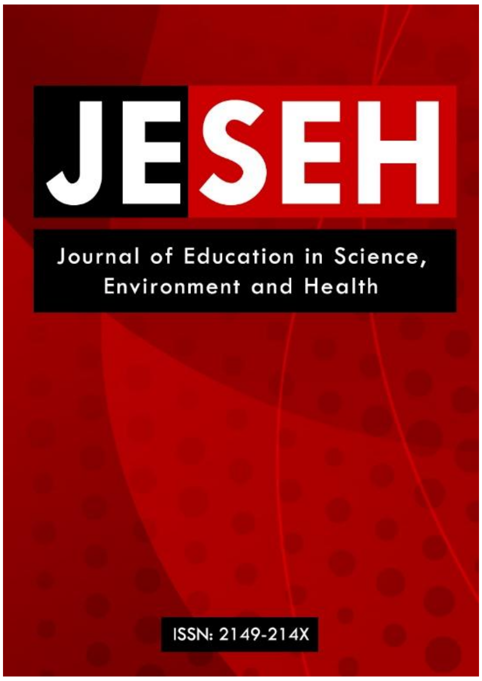

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Abstract

This study examines the baseline scientific process skill profiles of 4–5-year-old children participating in a nature-based science program developed through a Turkish–U.S. partnership funded by TÜBİTAK. The intervention was aligned with both the Next Generation Science Standards (NGSS) for K–2 and the United Nations Sustainable Development Goals (SDGs), integrating early science learning with global sustainability competencies. Using a mixed-methods embedded case study design, pre-test data were collected from experimental ($n = 14$) and control ($n = 13$) groups attending a public preschool in Bloomington, Indiana. The Science Observation Form (Kuru & Akman, 2017) showed strong internal consistency (Cronbach's $\alpha = .896$–$.961$). Mann-Whitney U tests revealed significantly higher baseline scores for the experimental group on Scientific Process Skills ($U = 140.0$, $p = .017$) and total scores ($U = 132.5$, $p = .046$), with no differences on Problem Solving or Scientific Attitudes. Qualitative observations documented emergent inquiry behaviors, including prediction-testing cycles, explanatory language, variable awareness, and peer collaboration. The teacher reported strong curricular compatibility, indicating high ecological validity. These findings underscore the need for baseline-adjusted models in subsequent effect estimation and strengthen the evidence base for nature-based early science education within globally relevant sustainability frameworks.

Introduction

Early childhood represents a uniquely sensitive period for the development of scientific thinking, as young children naturally engage with their environment through observation, exploration, and questioning (Greenfield et al., 2024). The innate curiosity of preschool-aged children, when intentionally supported through developmentally appropriate pedagogical design, can be channeled into foundational scientific process skills—observing, classifying, predicting, measuring, inferring, and communicating—that serve as precursors to formal scientific reasoning (Speldewinde & Campbell, 2025). However, translating these natural behaviors into structured scientific competencies requires learning environments that provide rich, authentic opportunities for inquiry while respecting the play-based, experiential nature of early childhood learning (Trina et al., 2024).

In recent years, nature-based learning (NBL) has emerged as a particularly promising pedagogical approach for early science education. By situating learning in outdoor and nature-rich environments, NBL offers children direct, hands-on experiences with natural phenomena, fostering not only environmental awareness but also the core practices of scientific inquiry: asking questions, planning investigations, collecting data, and constructing explanations (Ardoin & Bowers, 2020; Brussoni et al., 2015; Chawla, 2015). The affordances of natural environments—soil that invites classification, wind that invites prediction, shadows that invite causal reasoning—provide unique opportunities for scientific thinking that are often absent in traditional classroom settings (Gibson, 1979; Mifflin, 2023). Nevertheless, despite growing enthusiasm for nature-based early childhood education, there remains a limited evidence base documenting precisely how such interventions influence young children's scientific process skills, particularly in cross-cultural and collaborative research contexts (Kavak, 2024; Sarı, 2022).

This study addresses this gap by presenting baseline findings from a nature-based science activity program implemented in a public preschool in Bloomington, Indiana, through a collaborative partnership between Turkish and U.S. researchers. The intervention was designed with a dual-alignment framework, integrating the Next Generation Science Standards (NGSS) for K–2 with the United Nations Sustainable Development Goals (SDGs). This dual alignment ensures that the program is not only pedagogically robust and internationally recognized but also positions early science education within a broader global framework of sustainability, equity, and responsible citizenship—a critical consideration given the urgent environmental challenges facing the next generation (UNESCO, 2017; Somerville & Williams, 2015).

The present study reports on the first phase of a larger embedded case study (Yin, 2003), focusing on pre-test data collected using the Science Observation Form (Kuru & Akman, 2017) and qualitative classroom observations. The research was guided by the following questions:
1. What are the baseline scientific process skill profiles of experimental and control groups before the intervention?
2. How do the groups compare in terms of total scores and sub-dimensions (scientific process skills, problem solving, scientific attitudes)?
3. What qualitative patterns of engagement and inquiry behavior emerge during the initial implementation of nature-based activities?
4. What methodological implications arise from baseline group differences for subsequent intervention effect analyses?

By integrating quantitative reliability and group comparison analyses with rich qualitative observations, this study contributes to the growing literature on nature-based early science education by offering a nuanced, context-sensitive understanding of how play in natural environments can serve as a fertile ground for the emergence of scientific reasoning in early childhood, while simultaneously advancing global sustainability competencies.

Theoretical Framework

The theoretical foundation of this study integrates three interconnected perspectives: (1) affordance theory (Gibson, 1979), which explains how environmental features invite specific learning behaviors; (2) experiential learning theory (Dewey, 1938; Kolb, 1984), which emphasizes learning through direct experience and reflection; and (3) sociocultural theories of play and learning (Vygotsky, 1978), which highlight the role of social interaction and guided participation in cognitive development. Together, these perspectives frame nature-based play as a unique pedagogical context in which children can actively construct scientific knowledge through exploration, experimentation, and communication.

Affordance Theory and Nature-Based Learning

Affordance theory posits that environments offer specific opportunities for action and learning that are perceived and taken up by individuals based on their capabilities and intentions (Gibson, 1979). In natural environments, affordances for scientific inquiry are abundant: soil offers opportunities for observation and classification; moving water offers opportunities for prediction and measurement; shadows offer opportunities for causal reasoning about light and position. Mifflin (2023) found that nature preschools afford STEM-related skills primarily through water features, climbable structures, and manipulable objects such as leaves, sticks, and stones. Similarly, Speldewinde and Campbell (2025) demonstrated that children in bush kindergarten settings spontaneously apply five interconnected science skills—observing, comparing, classifying, measuring, and communicating—when engaged in unstructured nature play. The present study extends this work by demonstrating how intentionally designed activities can amplify these natural affordances, guiding children's exploration toward specific scientific process skills without sacrificing the open-ended, play-based character of the experience.

Experiential Learning and Scientific Inquiry

Experiential learning theory (Dewey, 1938; Kolb, 1984) emphasizes that meaningful learning occurs through cycles of concrete experience, reflective observation, abstract conceptualization, and active experimentation. In nature-based settings, children naturally engage in these cycles: planting a seed (concrete experience), observing its growth over time (reflective observation), inferring that plants need water and sunlight (abstract conceptualization), and testing this inference by varying conditions (active experimentation). These cycles mirror the science and engineering practices outlined in the NGSS, including asking questions, planning and carrying out investigations, analyzing and interpreting data, and constructing explanations (NGSS Lead States, 2013). Research has consistently shown that experiential, inquiry-based approaches to early science education enhance children's ability to engage in these practices, supporting both cognitive development and scientific reasoning (Worth & Grollman, 2003; Greenfield et al., 2024).

Sociocultural Theory and Guided Participation

Vygotsky's (1978) sociocultural theory highlights the role of social interaction and adult guidance in moving children from what they can do independently to what they can achieve with support—the zone of proximal development. In the context of nature-based play, teachers act as facilitators who model scientific language, prompt predictions, encourage evidence-based reasoning, and scaffold children's emerging understanding. As noted in the teacher reflection document from this study, the classroom teacher integrated the nature-based activities into the existing curriculum with minimal disruption, preserving teacher agency while ensuring that children received appropriate guidance during inquiry activities. This alignment between theoretical principles and classroom practice is critical for the effectiveness of nature-based interventions (Ardoin & Bowers, 2020; Barrable & Barrable, 2024).

Dual Alignment: NGSS and Sustainable Development Goals

A distinctive feature of the present intervention is its dual alignment with both the NGSS for K–2 and the United Nations SDGs. The NGSS provide a coherent set of performance expectations organized around three dimensions: science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs) (NGSS Lead States, 2013). For early childhood, these standards are appropriately scaffolded, with simplified vocabulary and concrete materials while maintaining the core practices of scientific inquiry. The SDGs, adopted by all United Nations member states in 2015, provide a shared blueprint for peace and prosperity for people and the planet, now and into the future (United Nations, 2015). Integrating the SDGs into early childhood science education positions young children as active contributors to sustainable futures, fostering not only scientific literacy but also environmental stewardship, social responsibility, and global citizenship (UNESCO, 2017; Somerville & Williams, 2015). The present intervention explicitly mapped each activity to relevant SDGs (see Table 1), ensuring that sustainability competencies are embedded within the science learning experience rather than treated as an add-on.

Method

In the sections below we describe the design of the research, the participants and context, and the intervention. We further describe the instrumentation and data analysis.

Research Design

This study employs an embedded case study design (Yin, 2003) with a mixed-methods approach, integrating quantitative data from the Science Observation Form (Kuru & Akman, 2017) and qualitative data from classroom observations and teacher reflections. The embedded design allows for multiple units of analysis (children, teachers, classrooms) within a single case (the nature-based play intervention), facilitating a holistic understanding of how the program influences children's scientific process skills. The study was conducted in two phases: (1) pre-test data collection and baseline analysis (reported here), and (2) intervention implementation and post-test assessment (ongoing).

Participants and Context

The study was conducted in a public preschool in Bloomington, Indiana USA serving children aged 4–5 years from diverse socioeconomic backgrounds. A stratified random sampling method was used to assign participants to experimental ($n = 14$) and control ($n = 13$) groups, ensuring comparability in age (all 4–5 years) and classroom environment. Parental consent was obtained for all participants, and the study was approved by the relevant institutional review board. All children were typically developing and attended the preschool on a full-time basis.

The experimental group received the nature-based play intervention, consisting of eight activity modules implemented over an 8-week period (see Table 1 for detailed activity descriptions). The control group continued with their regular science curriculum, which included some nature-based elements (e.g., occasional outdoor observation) but not the structured sequence of eight activities with explicit NGSS and SDG alignment. Pre-test data were collected by classroom teachers using the Science Observation Form, and additional qualitative observations were conducted by the researcher during the initial implementation week.

The Nature-Based Play Intervention: Dual Alignment with NGSS and SDGs

The intervention program comprised eight nature-based science activities, each designed to target specific scientific process skills while aligning with both NGSS performance expectations (for K–2) and relevant SDGs. Table 1 provides a comprehensive overview of the activity sequence, objectives, NGSS alignment, and SDG contributions.

Table 1. Nature-based science activity program: NGSS and SDG alignment

Activity	Core Scientific Focus	NGSS Alignment (K–2)	SDG Alignment	Key Scientific Process Skills
1. The Secret Life Beneath the Soil	Soil as habitat; living vs. non-living components	K-LS1-1 (basic needs of living things); K-ESS3-1 (organism-environment relationships)	SDG 15 (Life on Land)	Observation, classification, description, inference
2. Water Cycle Wonders	Evaporation, condensation, precipitation	K-ESS2-1 (weather observations); 2-ESS2-3 (water's distribution and forms)	SDG 6 (Clean Water); SDG 13 (Climate Action)	Prediction, observation, sequencing, cause-effect reasoning
3. Seeds of Change – From Seed to Plant	Plant growth stages; needs of living things	K-LS1-1 (basic needs of plants/animals)	SDG 2 (Zero Hunger); SDG 15 (Life on Land)	Prediction, longitudinal observation, data recording, responsibility
4. Wind Detectives – Exploring the Invisible	Wind as invisible force; effects on motion	K-ESS2-1 (weather patterns); K-PS2-1 (effects of pushes/pulls)	SDG 7 (Clean Energy); SDG 13 (Climate Action)	Prediction, experimentation, variable testing, explanation
5. Animal Architects – Homes in Nature	Animal habitats; adaptation and design	K-ESS3-1 (habitat needs); 1-LS1-1 (design solutions based on structures)	SDG 15 (Life on Land)	Observation, classification, model-building, design reasoning
6. Little Recycling Detectives	Waste sorting; reduce-reuse-recycle	K-ESS3-3 (solutions to reduce human impact)	SDG 11 (Sustainable Cities); SDG 12 (Responsible Consumption); SDG 13 (Climate Action)	Classification, problem solving, environmental reasoning, civic responsibility
7. Weather Watchers	Daily weather observation and recording	K-ESS2-1 (weather observations and patterns)	SDG 13 (Climate Action)	Observation, data representation, pattern recognition, descriptive language
8. Shadows and Light Explorers	Light as necessary for shadows; shadow variation	1-PS4-2 (visibility requires light); K-PS3-1 (sunlight as energy)	SDG 7 (Clean Energy)	Prediction, experimentation, measurement, causal reasoning, creative expression

(NGSS = Next Generation Science Standards; SDG = Sustainable Development Goal. NGSS performance expectations are structured for K–2; for ages 4–5, tasks are scaffolded with simplified vocabulary and concrete materials while maintaining science and engineering practices and crosscutting concepts.)

Each activity was designed to be implemented over 45–60 minutes, with some activities (e.g., Seeds of Change, Weather Watchers) extended across multiple days to support longitudinal observation and data collection. Activities followed a consistent pedagogical structure: (1) an introductory circle discussion to activate prior knowledge and generate questions; (2) hands-on exploration with natural or naturalistic materials; (3) structured data collection or classification; and (4) reflection and sharing to consolidate learning and develop scientific language. This structure aligns with recommended practices for inquiry-based early science education (Worth & Grollman, 2003; NSTA, 2014).

Instrumentation

This study employed a combination of quantitative and qualitative data collection instruments to provide a comprehensive assessment of children's scientific process skills. Quantitative data were obtained through a structured observation form designed to measure preschool children's science process skills, problem-solving tendencies, and attitudes toward science. Qualitative data were gathered through researcher-conducted classroom observations, teacher reflection journals, and informal debriefing conversations following the implementation sessions. Each data collection instrument is described in detail below.

Science Observation Form

The Science Observation Form (Kuru & Akman, 2017) is a 22-item observation-based instrument designed to assess preschool children's scientific process skills across three sub-dimensions: (1) Scientific Process Skills (14 items, e.g., "Makes detailed observations," "Makes inferences," "Classifies objects/events," "States predictions," "Identifies variables," "Interprets data"), (2) Problem Solving (3 items, e.g., "Solves problems multiple ways," "States problem"), and (3) Scientific Attitudes (5 items, e.g., "Confidence in science," "Perseverance," "Flexibility," "Recognizes learning"). Each item is rated on a three-point scale (1 = never, 2 = sometimes, 3 = always). The instrument has demonstrated acceptable validity and reliability in previous studies with Turkish preschool populations (Kuru & Akman, 2017) and was adapted for use in the U.S. context with minor wording modifications to ensure cultural appropriateness.

Qualitative Data Sources

Qualitative data were collected through three sources: (a) classroom observation notes recorded by the researcher during the initial implementation week, focusing on children's engagement, questioning, explanation behaviors, and peer interactions; (b) a teacher reflection document completed by the classroom teacher at the end of the implementation phase, documenting her perceptions of curricular fit, student engagement, observed cognitive shifts, and any challenges encountered; and (c) informal debriefing conversations between the researcher and the teacher following each activity session. These multiple sources were used to triangulate the quantitative findings and provide a richer, contextualized understanding of how the intervention was enacted in practice.

Data Analysis

The analysis of the collected data proceeded in two parallel yet integrated strands corresponding to the quantitative and qualitative components of the mixed-methods design. Quantitative analyses focused on descriptive statistics, internal consistency, and baseline group comparisons using nonparametric tests. Qualitative analyses employed thematic analysis to identify patterns and themes in the observation notes and teacher reflection documents. Each analytic approach is described in detail below.

Quantitative Analysis

Descriptive statistics (means, standard deviations) were calculated for total and sub-dimension scores for both groups. Internal consistency was assessed using Cronbach's alpha for the total scale and each sub-dimension, with acceptable thresholds set at $\alpha \geq .70$. Given the small sample size and non-normal distribution of some sub-dimensions as indicated by Shapiro-Wilk tests, Mann-Whitney U tests were used to compare groups at baseline, with Holm's adjustment for multiple comparisons to control Type I error. Effect sizes ($r = Z/\sqrt{N}$) were calculated for significant comparisons. All analyses were conducted using SPSS version 21.

Qualitative Analysis

Observation notes and the teacher reflection document were analyzed using thematic analysis following the six-phase approach outlined by Braun and Clarke (2006): (1) familiarization with the data, (2) generating initial codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) producing the report. The researcher first read all documents multiple times to achieve familiarity, then generated initial codes (e.g., "curiosity about invisible forces," "prediction language," "peer discussion," "explanation attempts," "variable awareness"). These codes were subsequently grouped into broader themes through an iterative process of comparison and refinement. Themes were reviewed and refined in consultation with a second researcher to ensure credibility and dependability. Representative quotes were selected to illustrate each theme, with pseudonyms used to protect participant confidentiality.

Validity and Reliability

Several strategies were employed to ensure the trustworthiness of the findings. For the quantitative component, internal consistency (Cronbach's alpha) was calculated for the total scale and sub-dimensions in both groups, with all values exceeding the conventional .70 threshold (see Findings). For the qualitative component, triangulation was achieved by comparing multiple data sources (observation notes, teacher reflection, debriefing conversations). Additionally, member checking was conducted by sharing preliminary qualitative findings with the classroom teacher to confirm accuracy and interpretation. The researcher also maintained a reflexive journal throughout data collection and analysis to bracket personal biases and assumptions, documenting decision points and alternative interpretations. Prolonged engagement in the classroom setting (the researcher was present for the full 8-week implementation period) further supported the credibility of the qualitative observations.

Results and Discussion

This section presents the baseline results from the pre-test phase of the study, organized according to the mixed-methods design. Quantitative findings include descriptive statistics, internal consistency estimates, and group comparisons derived from the Science Observation Form. Qualitative findings are drawn from classroom observation notes and the teacher reflection document, providing a contextualized understanding of children's engagement and inquiry behaviors during the initial implementation. The section concludes with an integration of quantitative and qualitative patterns to inform subsequent intervention analyses. Below, the quantitative baseline profiles are reported first.

Quantitative Baseline Profile

Internal Consistency of the Science Observation Form

The Science Observation Form demonstrated strong internal consistency at baseline for both groups. As shown in Table 2, Cronbach's alpha values for the total scale were .896 for the control group and .961 for the experimental group, indicating excellent reliability. Sub-dimension alphas ranged from .786 to .939, all exceeding conventional acceptability thresholds. These coefficients support the reliability of the instrument within this classroom-based sample and justify its use for subsequent comparative analyses.

Table 2. Internal consistency (Cronbach's Alpha) of the science observation form at baseline

Scale/Sub-dimension	Control Group (n = 13)	Experimental Group (n = 14)
Total Scale (22 items)	.896	.961
Scientific Process Skills (14 items)	.844	.928
Problem Solving (3 items)	.786	.842
Scientific Attitudes (5 items)	.828	.939

Descriptive Statistics and Group Comparisons

Table 3 presents descriptive statistics for total and sub-dimension scores for both groups. For the total score (maximum possible = 66), the control group had a mean of 36.08 (SD = 5.51), while the experimental group had a mean of 40.86 (SD = 8.19). For Scientific Process Skills (maximum = 42), the control group scored 20.46 (SD = 3.67), compared to the experimental group's 24.71 (SD = 4.92). Problem Solving (maximum = 6) showed a smaller difference: control group M = 3.77 (SD = 0.60), experimental group M = 3.93 (SD = 1.07). Similarly, for Scientific Attitudes (maximum = 18), the control group scored 11.85 (SD = 2.03), while the experimental group scored 12.21 (SD = 2.64).

Table 3. Baseline descriptive statistics and group comparisons

Variable	Control (n = 13) M (SD)	Experimental (n = 14) M (SD)	Mann-Whitney U	p	Effect Size (r)
Total Score	36.08 (5.51)	40.86 (8.19)	132.5	.046*	.38
Scientific Process Skills	20.46 (3.67)	24.71 (4.92)	140.0	.017*	.45
Problem Solving	3.77 (0.60)	3.93 (1.07)	88.0	.547	.12
Scientific Attitudes	11.85 (2.03)	12.21 (2.64)	86.5	.530	.04

*p < .05 (two-tailed). Effect size r calculated as Z/√N, with N = 27.

Mann-Whitney U tests indicated that the experimental group had significantly higher scores than the control group for the total score (U = 132.5, p = .046, r = .38) and for Scientific Process Skills (U = 140.0, p = .017, r = .45). No significant differences were found for Problem Solving (p = .547) or Scientific Attitudes (p = .530). Item-level analyses after Holm adjustment showed that the experimental group scored significantly higher on two items from the Scientific Process Skills sub-dimension: "Identifies variables" (U = 138.5, p = .008) and "Interprets data" (U = 135.0, p = .012). Interestingly, the control group scored significantly higher on "Measures objects" (U = 52.5, p = .023), suggesting that the two groups had different patterns of relative strength at baseline.

These baseline differences, particularly in the Scientific Process Skills domain, have important implications for subsequent analyses of intervention effects. Simple post-test comparisons would be confounded by initial group disparities; therefore, baseline-adjusted models (e.g., ANCOVA with pre-test scores as covariates) will be used to evaluate the intervention's true impact in the post-test phase. The finding that the experimental group began with higher scores on core scientific process skills also suggests that the intervention may be particularly well-suited to children who already have some emerging competencies in this area, a hypothesis that will be examined in future analyses.

Qualitative Observations: Patterns of Engagement and Inquiry

During the initial implementation of the nature-based activities, the researcher observed consistently high levels of engagement across all eight modules, with notable peaks during the wind (Activity 4), water (Activity 2), and shadow (Activity 8) activities. Children demonstrated several emergent inquiry behaviors that aligned closely with the items comprising the Scientific Process Skills sub-dimension of the quantitative instrument.

Theme 1: From Description to Explanation

A consistent pattern observed across multiple activities was children's gradual shift from simply describing what they saw to attempting causal explanations. During the water cycle activity (Activity 2), children initially produced descriptive statements about observable phenomena. After the demonstration with warm water and ice, however, their language shifted noticeably. One child remarked, "The water is going up because the sun makes it hot. Then it gets cold and makes rain." Another child added, "It's like a circle—it goes up and down and up again." The teacher reflected on this pattern in her post-implementation reflection: "By the third week, I noticed children using 'because' and 'so' much more often. They weren't just telling me what they saw—they were trying to explain why it happened. One child said, 'The shadow got bigger because I moved the light closer.' That's a real shift from how they talked at the beginning.". This movement from description to explanation is a core scientific practice and was observed most strongly in activities that involved observable but non-obvious mechanisms (water cycle, shadows, wind).

Theme 2: Prediction-Testing-Explanation Cycles

During the wind activity (Activity 4), children were asked to predict which objects (feathers, toy cars, scarves) would move most easily when placed in front of a fan. Many children spontaneously tested their predictions multiple times, adjusting their explanations based on the outcomes. The researcher's observation notes captured one such episode: "A child initially predicted that the toy car would move the most because 'it's big and strong.' After observing that the feather moved more easily, he revised his explanation: 'The feather is light, so the wind pushes it more. The car is heavy, so the wind can't push it as much.' He then tested the scarf, noting, 'The scarf is kind of light, so it moves a lot but not as much as the feather.' This spontaneous revision of explanation based on evidence was unprompted."

This type of prediction-testing-revision cycle—a simplified version of scientific methods—was observed across multiple activities and was particularly evident when the outcomes were somewhat surprising (e.g., a light object moving more than a heavy object, a shadow changing size when the light was moved).

Theme 3: Emerging Variable Awareness

The shadow activity (Activity 8) provided particularly clear evidence of children's emerging awareness of variables. Using flashlights, children explored how the size and direction of shadows change when the light source is moved. Several children spontaneously noted relationships that demonstrated variable awareness. One child stated, "If I put the light down low, the shadow gets big." Another child added, "If I move the light to the side, the shadow goes the other way." A third child experimented systematically, announcing, "See? When the light is close, the shadow is big. When I move it far away, the shadow gets small." This emerging understanding that changing one variable (light position) affects another (shadow size/direction) is a foundational skill for experimental design and was explicitly targeted in the activity design.

Theme 4: Peer Collaboration and Scientific Discourse

Throughout the activities, children frequently discussed their observations with peers, often spontaneously comparing results and building on each other's ideas. In the soil activity (Activity 1), two children examined their soil trays together:

*Child A: "I found a worm. It's alive because it's moving."**
*Child B: "I found a rock. It's not alive. Rocks don't move."**
*Child A: "Worms need dirt to live. The rock doesn't need anything."**
Child B: "So the worm is living, and the rock is non-living. We should put the worm in the living column."

This peer interaction was not directed by the teacher but emerged naturally from the shared exploratory context. The teacher noted in her reflection that such collaborative discussions became more frequent as the intervention progressed, suggesting that the nature-based activities supported not only individual scientific thinking but also the social construction of scientific knowledge.

Theme 5: Teacher-Perceived Cognitive Shifts

In the reflection document, the teacher identified three qualitative shifts she observed in her students over the 8-week intervention period: "First, they moved from passive observation to active testing. They stopped just watching and started trying things out—'What happens if I do this?' Second, they developed a greater tolerance for uncertainty. They didn't get frustrated when things didn't work the first time; they just tried again. And third, I heard more 'What if…?' questions. They were starting to think about variables before they even tested them." She also noted that the activities "fit naturally into our daily routine" and that she only needed to "swap a few lessons to better match ongoing classroom themes," indicating strong ecological validity. This finding is particularly important for scalability, as interventions that are perceived as compatible with existing classroom practices are more likely to be sustained.

Integration of Quantitative and Qualitative Findings

The qualitative observations provide a rich complement to the quantitative baseline data. While the experimental group began the study with higher scores on Scientific Process Skills, the observational data suggest that this advantage may not be solely a function of initial differences but also reflects the intervention's capacity to structure and amplify existing competencies. The high internal consistency of the instrument in both groups (.896–.961) supports its reliability for capturing these competencies, while the qualitative themes—prediction, testing, explanation, collaboration, variable awareness—map directly onto the items in the Scientific Process Skills sub-dimension (e.g., "Makes predictions," "Tests predictions," "Explains observations," "Cooperates with others," "Identifies variables"). Together, these findings suggest that nature-based play can serve as a fertile context for the emergence of early scientific reasoning, but that baseline-adjusted analyses will be essential to isolate the true intervention effect from pre-existing group differences.

Discussion

This study aimed to describe the baseline scientific process skill profiles of 4–5-year-old children in a nature-based play intervention and to examine qualitative patterns of engagement and inquiry during initial implementation. The findings contribute to the growing literature on nature-based early childhood science education in several important ways.

First, the study provides empirical support for the application of affordance theory (Gibson, 1979) to early science learning. The nature-based activities were intentionally designed to offer specific affordances for scientific inquiry: soil trays afforded observation and classification; fans and objects afforded prediction and testing; flashlights afforded variable manipulation. Children spontaneously took up these affordances, engaging in behaviors that mirror the science and engineering practices outlined in NGSS (NGSS Lead States, 2013). This aligns with recent work by Mifflin (2023) and Speldewinde and Campbell (2025), who found that nature-based settings afford STEM-related skills through both fixed features (e.g., water, climbable structures) and manipulable objects (e.g., leaves, rocks). However, the present study extends these findings by demonstrating that intentional activity design can amplify these affordances, guiding children's exploration toward specific scientific process skills without sacrificing the open-ended, play-based nature of the experience.

Second, the dual alignment of the intervention with both NGSS and the SDGs represents a novel contribution to the literature. While previous studies have examined nature-based early childhood education through either a science standards lens (e.g., NGSS alignment) or a sustainability lens (e.g., environmental education), few have explicitly integrated both frameworks within a single intervention design. By mapping each activity to relevant SDGs (see Table 1), the present study demonstrates how early science education can simultaneously foster scientific literacy and global sustainability competencies—an integration that is increasingly urgent given the environmental challenges facing the next generation (UNESCO, 2017; Somerville & Williams, 2015).

Third, the study highlights the importance of baseline-adjusted analyses in intervention research. The finding that the experimental group began the study with significantly higher Scientific Process Skills scores—despite random assignment—underscores the need for rigorous statistical controls when evaluating intervention effects. As noted in the baseline analysis, ANCOVA with pre-test scores as covariates will be used in the post-test phase to isolate the true effect of the nature-based play program. This is a methodological strength of the study, as many early childhood intervention studies fail to account for baseline differences, leading to inflated or biased effect estimates (What Works Clearinghouse, 2020). The strong internal consistency of the instrument in both groups (.896–.961) further supports its use in such adjusted models.

Fourth, the mixed-methods design, integrating quantitative reliability and group comparison analyses with rich qualitative observations, provides a more complete picture of the intervention's functioning than either method alone could offer. The qualitative findings not only corroborate the quantitative results but also illuminate the mechanisms underlying those results—for example, showing *how* children's prediction skills were activated during the wind activity, not merely that they scored higher on a prediction item. This integration of methods enhances both the internal validity and the ecological validity of the study (Creswell & Plano Clark, 2018).

Fifth, the qualitative findings have practical implications for early childhood educators seeking to integrate nature-based play into their curricula. The teacher's reflection that the activities "fit naturally into our daily routine" and that she only needed to "swap a few lessons" suggests that nature-based interventions can be implemented with high ecological validity—that is, without disrupting the existing classroom ecology. This is critical for scalability, as interventions that are perceived as "add-ons" or "extra work" are less likely to be sustained (Durlak & DuPre, 2008). Moreover, the observed shifts in children's language (from description to explanation), behavior (from passive watching to active testing), and social interaction (from individual play to collaborative discussion) provide concrete examples of how nature-based play can support the development of scientific reasoning in age-appropriate ways. These examples can be used in teacher professional development to illustrate what scientific process skills look like in practice and how they can be elicited through intentional activity design.

Limitations

This study has several limitations that should be acknowledged. First, the sample size is small (N = 27), which limits the generalizability of the findings and the statistical power of the group comparisons. The observed baseline differences, while statistically significant, should be interpreted with caution given the small sample. Second, the baseline non-equivalence between groups, while methodologically manageable, may reflect unmeasured confounding variables (e.g., prior science exposure at home, parental education, previous preschool experience) that were not assessed in this study. Third, the qualitative observations were conducted primarily during the initial implementation week, and it is possible that engagement patterns changed over time as children became more familiar with the activities. Fourth, the study is situated in a specific cultural and institutional context (a public preschool in the Midwestern United States), and the findings may not transfer directly to other settings, particularly those with different curricular standards, teacher training, or access to natural spaces. Fifth, the Science Observation Form, while validated in a Turkish context, has not been extensively validated in U.S. preschool settings; however, the high internal consistency observed in this study provides preliminary evidence of its reliability in this new context.

Conclusion

This baseline study of a nature-based play intervention for 4–5-year-old children provides evidence that (a) the Science Observation Form (Kuru & Akman, 2017) is a reliable instrument for assessing scientific process skills in this age group, with high internal consistency across both experimental and control groups; (b) the experimental group began the study with significantly higher Scientific Process Skills and total scores than the control group, necessitating baseline-adjusted analyses for subsequent intervention effect estimation; (c) the intervention was designed with a dual alignment to both NGSS for K–2 and the UN Sustainable Development Goals, providing a framework that integrates early science learning with global sustainability competencies; and (d) qualitative observations reveal that nature-based play activities elicit rich inquiry behaviors—including prediction-testing cycles, explanatory language development, variable awareness, and peer collaboration—that align with the core practices of scientific reasoning. The teacher's reflection further indicates that the intervention was perceived as compatible with the existing curriculum, suggesting strong ecological validity.

The dual alignment of the intervention with both NGSS and the SDGs represents a distinctive contribution to the field, demonstrating how early science education can simultaneously advance scientific literacy and sustainability competencies. As the world faces unprecedented environmental challenges, fostering these competencies from the earliest years of schooling is not merely desirable but essential. This study provides a foundation for future research examining the effectiveness of nature-based play interventions in promoting early scientific reasoning within a globally relevant sustainability framework.

Recommendations

For researchers, the findings underscore the importance of rigorous baseline measurement and adjusted analyses in intervention studies, as well as the value of integrating qualitative observations to understand the mechanisms underlying quantitative effects. Future research should (a) complete the post-test phase of this study using baseline-adjusted models to estimate the true intervention effect; (b) extend the study to a larger, more diverse sample to examine moderation by socioeconomic status, prior science exposure, or teacher experience; (c) conduct longitudinal follow-ups to assess the durability of any observed gains; and (d) explore cross-cultural comparisons, as the Turkish–U.S. collaboration that underpins this study offers a unique opportunity to examine how different curricular standards, teacher training, and cultural values shape the implementation and outcomes of nature-based science education.

For practitioners, the study provides concrete examples of how nature-based activities can be designed and implemented to foster specific scientific process skills, along with evidence that such activities can be integrated into existing classroom routines without disruption. The dual alignment with NGSS and SDGs offers a framework that teachers can use to justify nature-based play as a legitimate approach to meeting both science standards and sustainability education goals.

For policymakers, the study supports the growing call for nature-based early childhood education as a legitimate and effective approach to promoting early STEM learning, particularly in contexts where access to formal science instruction is limited. The alignment with internationally recognized frameworks (NGSS and SDGs) provides a rationale for investing in nature-based early childhood programs as a strategy for advancing both scientific literacy and global sustainability competencies.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors. This study was conducted in accordance with ethical standards for research involving human participants. Ethical approval was obtained from the Indiana University Human Research Protection Program (HRPP) on December 9, 2025 (Protocol #28497; Enhancing Science Education Through Nature-Based Play in Early Childhood). Participation was voluntary, and all procedures ensured the confidentiality and anonymity of participants. No identifying information was collected or reported. The study adhered to all relevant institutional and international ethical guidelines for research with young children.

Conflict of Interest

* The authors declare that they have no conflicts of interest.

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