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Early Science Literacy: Fostering Scientific Thinking Through Play-Based Learning in Early Childhood Education

Maria Fatima Mardina Angkur[1]
[1]Universitas Katolik Indonesia Santu Paulus Ruteng, Indonesia

ABSTRACT

Background. The development of science literacy in early childhood lays the foundation for critical thinking, inquiry skills, and lifelong learning. Traditional approaches to science education often overlook the unique cognitive and developmental needs of young learners. Recent pedagogical shifts suggest that play-based learning may offer an effective pathway to foster scientific thinking in early childhood education.

Purpose. This study investigates how play-based strategies support the development of early science literacy among preschool-aged children. The research employed a qualitative case study design involving three early childhood education centers that integrated science themes into daily play activities.

Method. Data were collected through classroom observations, educator interviews, and children's learning artifacts, then analyzed thematically to identify patterns of inquiry and conceptual understanding.

Results. Findings revealed that play-based environments encouraged curiosity, hypothesis generation, experimentation, and early evidence-based reasoning. Children demonstrated an emerging understanding of scientific concepts such as cause and effect, classification, and environmental awareness through guided exploratory play.

Conclusion. The study concludes that play-based learning serves as a powerful pedagogical approach for nurturing early science literacy. It recommends intentional integration of scientific exploration into play curricula to promote cognitive engagement and scientific habits of mind in early learners.

KEYWORDS

Early Childhood Education, Science Literacy, Play-Based Learning, Inquiry Skills, Cognitive Development

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Correspondence:

Maria Fatima Mardina Angkur,
mariafatimamardinaangkur@gmail.com

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INTRODUCTION

Science literacy is a foundational skill in the 21st century, vital for equipping individuals with the ability to inquire, analyze, and make evidence-based decisions in everyday life. The cultivation of scientific habits of mind should ideally begin during early childhood, a critical period in human development when cognitive and socio-emotional capacities are rapidly forming. Early exposure to scientific thinking not only builds conceptual understanding but also strengthens metacognitive and problem-solving abilities, which are essential for lifelong learning and adaptability.

Educational research has long recognized the value of early intervention in literacy and numeracy, yet science as a core domain in early childhood education often remains underemphasized. This neglect is partly due to a misconception that young children are not cognitively ready for science, and partly because of curricular and policy limitations that prioritize language and mathematics over integrated inquiry-based exploration. However, children as young as three are capable of observing, questioning, experimenting, and drawing conclusions from their interactions with the environment.

Play-based learning, grounded in constructivist and socio-cultural theories, has gained increasing attention as an effective pedagogical strategy in early childhood education. Within this context, play becomes not merely recreational but a central mode of learning that reflects and reinforces cognitive development (Mayourian et al., 2025; Nasution et al., 2025; Teherán et al., 2025). When infused with scientific themes and guided facilitation, play allows children to engage in processes analogous to scientific inquiry, such as observation, prediction, hypothesis testing, and explanation, thereby laying the groundwork for early science literacy.

Despite growing consensus on the importance of fostering science literacy from an early age, implementation at the preschool level remains fragmented and inconsistent. Many early childhood programs lack structured approaches to integrate science into everyday classroom activities, often due to a scarcity of resources, inadequate teacher preparation, or the absence of supportive frameworks for inquiry-based learning (Molloy et al., 2025; Wolf et al., 2025; Zamora et al., 2025). As a result, opportunities to nurture children's innate curiosity about the natural world are frequently missed or left to chance.

Teachers frequently face challenges in translating scientific content into developmentally appropriate, engaging activities. While they may recognize the value of science exploration, many early childhood educators report low confidence in their own science knowledge or instructional strategies (Bhochhibhoya et al., 2025; Fikadu et al., 2025; Løkken et al., 2025). Without intentional planning, science in early childhood settings often becomes superficial-limited to occasional themed activities rather than embedded, sustained experiences that support deeper conceptual development.

There is a critical need to understand how pedagogical methods-specifically play-based learning-can be leveraged to create meaningful science learning experiences for young children. This research addresses that need by examining how guided play can be used as a medium for developing scientific thinking and fostering foundational science literacy (Amjad et al., 2025; Deniz et al., 2025; Ekawati et al., 2025). The study focuses on identifying observable indicators of scientific inquiry within naturalistic play and understanding how teacher facilitation influences learning outcomes.

The primary aim of this study is to explore the role of play-based learning in promoting early science literacy among preschool-aged children. The research seeks to investigate how scientific concepts, inquiry behaviors, and reasoning skills emerge in play environments that are intentionally designed to support scientific exploration (Cadima et al., 2025; Nelson et al., 2025; Pacca et al., 2025; Soukaina et al., 2025). A secondary objective is to examine how educators facilitate and scaffold children's scientific thinking during play.

This study aims to contribute a framework for identifying and interpreting science-related behaviors in young children, offering educators practical tools to observe, assess, and enrich learning. The investigation will also explore how children's engagement in scientific inquiry during play relates to broader developmental outcomes, such as language use, social interaction, and executive function.

Through systematic observation, documentation, and thematic analysis, the research intends to uncover the pedagogical conditions that best support the integration of science into play-based settings. The goal is to bridge the gap between developmental theory and classroom practice, offering insights that can inform curriculum design, teacher training, and educational policy in early childhood science education.

A review of existing literature reveals that while the importance of science education in early childhood is increasingly acknowledged, few empirical studies have investigated the mechanisms through which scientific thinking develops in young learners through play (Bartoskova Polcrova et al., 2025; Fermín-González et al., 2025). Most research either focuses on cognitive development broadly or evaluates the impact of structured science instruction, without considering the informal, dynamic learning processes that occur during child-initiated play.

Previous studies on play-based learning have extensively examined social, linguistic, and emotional outcomes, but rarely frame play as a vehicle for cultivating domain-specific literacies such as science (Mudalige et al., 2025; Speldewinde, 2025). Furthermore, available literature tends to conceptualize science learning as content acquisition rather than a process of inquiry, leaving a gap in understanding how early learners engage in scientific practices before formal schooling begins.

This study addresses a critical void by focusing on the intersection between play pedagogy and science literacy development. It builds on the theoretical premise that young children are natural scientists and extends it by offering empirical evidence of how this potential can be realized through play-based environments. The research also contributes to closing the methodological gap by applying qualitative, observational approaches to capture authentic, context-rich data on learning as it naturally unfolds in early childhood classrooms.

This study presents a novel perspective by re-framing play not merely as a developmental necessity but as a legitimate medium for scientific inquiry in early childhood education. While much discourse emphasizes play's role in social or emotional growth, this research elevates its cognitive dimension-particularly its capacity to stimulate curiosity, hypothesis testing, and conceptual understanding. The study uniquely contributes to the field by defining specific indicators of science literacy observable during child-led, play-based activities.

The conceptual contribution lies in establishing a model of science-rich play that integrates inquiry-based learning with developmentally appropriate pedagogy. This model emphasizes the educator's role not as a knowledge transmitter, but as a co-inquirer who scaffolds children's thinking while respecting the integrity of their play. Such an approach offers a promising alternative to didactic methods and aligns with contemporary views on learner-centered education.

The significance of this research extends beyond academic inquiry. Findings from this study have practical implications for curriculum developers, teacher educators, and early childhood policymakers seeking to strengthen science education from the ground up. By demonstrating that scientific thinking can be fostered through play, the research challenges the traditional separation between "academic" and "developmental" learning, advocating instead for integrated, holistic approaches that prepare young children for future scientific engagement.

RESEARCH METHODOLOGY

This study employed a qualitative case study design to explore how play-based learning fosters early science literacy and scientific thinking in preschool-aged children. The case study approach was selected to capture the complexity and authenticity of children's inquiry behaviors within naturalistic classroom settings (Hagan-Haynes et al., 2025; Hargrave & Cain, 2025; Scalise et al., 2025). This design allowed the researchers to observe and analyze phenomena in context, emphasizing the interactions between learners, materials, and educators that contribute to the development of early scientific competencies.

The population of the study included early childhood education centers located in urban areas of West Java, Indonesia, that implemented play-based curricula. Three centers were purposively selected based on their commitment to integrated thematic instruction and teacher willingness to participate. The sample consisted of 45 children aged 4 to 6 years and 6 early childhood educators, all of whom were actively engaged in daily play-based learning activities. The diversity in institutional profiles and classroom practices ensured variation in the data while maintaining a shared pedagogical foundation relevant to the study objectives.

Data collection instruments included structured observation sheets, audio and video recordings, teacher interview protocols, and child learning artifacts such as drawings, science journals, and construction projects. The observation sheets were designed to capture specific indicators of scientific inquiry, including questioning behavior, use of evidence, prediction-making, and engagement with cause-and-effect relationships. Interview protocols explored educators' perceptions of science learning through play, instructional strategies, and challenges encountered in practice. Triangulation of these instruments enhanced data validity by allowing for cross-verification of findings across multiple sources.

The procedures began with a preliminary visit to each center to build rapport, obtain consent, and familiarize educators and children with the presence of the researchers. Data collection was conducted over a six-week period during regular classroom hours to ensure ecological validity. Observations were carried out during free play, guided exploration sessions, and outdoor activities where science-related themes (e.g., water cycles, plants, motion) were naturally integrated. Educators were not instructed to alter their typical teaching styles, allowing the study to capture authentic pedagogical practices. Interviews with teachers were conducted at the end of the observation period, and data were transcribed, coded, and analyzed thematically using NVivo software to identify patterns related to the emergence of science literacy through play.

RESULT AND DISCUSSION

Quantitative data were collected from three early childhood education centers (Center A, Center B, and Center C) to observe key indicators of early scientific thinking. These included behaviors such as questioning, predicting, observing, explaining, and experimenting, rated on a scale from 1 (never) to 4 (frequently). Observations were conducted over a period of six weeks with 45 children (15 per center), yielding a comparative dataset across institutions.

Table 1.
Mean Scores of Science-Related Behaviors by Center

Behavior	Center A	Center B	Center C
Questioning	2.60	2.27	2.47
Predicting	2.33	2.80	2.67
Observing	2.93	3.20	3.07
Explaining	2.00	1.53	2.13
Experimenting	2.40	2.80	2.93

Children in all three centers demonstrated moderate to high frequencies of science-related behaviors during play, with observing and experimenting emerging as the most dominant activities. Center B showed the highest mean in predicting ($M = 2.80$) and observing ($M = 3.20$), suggesting an enriched play environment for hypothesis formation and attention to detail. Center C led in experimenting ($M = 2.93$), while Center A showed a relatively higher frequency of questioning ($M = 2.60$), indicating active verbal inquiry among its learners.

These variations may reflect differences in teacher facilitation strategies, availability of materials, or thematic foci across centers. Higher scores in observing and experimenting are consistent with play contexts that offer open-ended, sensory-rich materials, allowing children to explore cause-effect relationships. The lower mean in explaining, particularly in Center B ($M = 1.53$), may suggest the need for more adult scaffolding to help children articulate their observations and findings.

Across the centers, children engaged in a range of scientific thinking behaviors naturally embedded in their play. Observing was the most consistently high-scoring behavior, with all centers averaging above 2.9. This trend supports the idea that sensory exploration forms a core component of science learning at the preschool level. Predicting and experimenting also appeared frequently, reinforcing the developmental capacity of young children to engage in basic inquiry cycles.

Questioning and explaining were less frequent, which may reflect the linguistic demands of these behaviors. Questioning requires not only curiosity but also confidence in verbal expression, while explaining calls for cognitive synthesis and appropriate vocabulary. These results underscore the importance of teacher support in helping children externalize and structure their emerging ideas during play.

Due to the qualitative orientation of the study and small sample size, inferential statistics were not applied to test for significance. However, descriptive analysis was sufficient to establish observable trends in behavior and inform the thematic coding of qualitative data. Patterns revealed through the quantitative data guided further interpretation of teacher strategies and child interactions.

Non-parametric cross-checks supported the descriptive findings. Centers with higher average scores in predicting and experimenting also showed stronger alignment with inquiry-oriented teacher behaviors during classroom observations. These patterns provide contextual support for the idea that intentional facilitation enhances children’s engagement in scientific thought.

A strong co-occurrence was noted between observing and experimenting behaviors. Children who frequently manipulated objects, materials, or environments also tended to exhibit higher engagement in making predictions or drawing conclusions. This relationship suggests a developmental pathway from hands-on exploration to more abstract reasoning, consistent with Piagetian theory and other constructivist frameworks.

Low explaining scores appeared in contexts with minimal adult interaction, implying that children’s capacity to verbalize scientific thinking is closely tied to the presence of guided dialogue. Teachers who actively prompted reflection or encouraged children to describe their actions saw higher rates of verbal explanation, supporting the importance of scaffolding in verbalizing inquiry.

In Center C, a group of four children was observed building a water channel using plastic tubing, containers, and natural materials. They repeatedly adjusted the angle and flow direction to “make the water go faster,” verbalizing hypotheses such as “It works better if it’s high” and “Too many rocks make it slow.” One child suggested testing two designs side by side to compare outcomes. This behavior demonstrated early forms of controlled experimentation and causal reasoning.

In Center A, a teacher facilitated a planting activity where children placed seeds in differently lit locations. The children revisited the plants daily and recorded their growth through drawings. One child asked, “Why is mine not growing?” prompting a peer to respond, “Yours is in the dark.” These exchanges reflect peer-to-peer hypothesis building and evidence-based explanation, supported by teacher prompting and observational journaling.

These case studies illustrate how science-related behaviors emerge organically within play when environments and adult facilitation are aligned with inquiry-based principles. The water channel activity, although unstructured, allowed children to cycle through prediction, testing, and reflection in a way consistent with early scientific investigation (Bennetsen et al., 2025; Elsenburg et al., 2025; Hobbs et al., 2025; Joner, 2025). The planting activity exemplified how repeated observation and discussion can scaffold complex concepts such as light dependency in plant growth.

Children’s capacity to engage in prediction and explanation was most apparent when teachers modeled language or asked open-ended questions. This emphasizes the role of educators as co-investigators who enrich children’s thinking without dominating the play narrative (Halls & Sakr, 2025; Hossain et al., 2025; Utami et al., 2025; Yamamoto et al., 2025). When adults act as reflective partners, children are more likely to externalize their cognitive processes and make connections across experiences.

Play-based learning environments can serve as fertile ground for early science literacy when intentionally designed and facilitated. Observational data from this study confirm that young children are capable of engaging in inquiry behaviors typically associated with formal science, including observing, experimenting, predicting, and to a lesser extent, explaining. These behaviors emerge most strongly in contexts that provide open-ended materials and adult scaffolding.

While verbal reasoning remains a developing skill among preschoolers, early forms of scientific thinking are clearly present and can be nurtured through play. The findings support the integration of science-focused exploration in early childhood curricula, with emphasis on guided play and teacher engagement to unlock children’s potential for scientific inquiry.

The study revealed that children in play-based early childhood settings regularly engaged in behaviors indicative of early scientific thinking, including observation, experimentation, questioning, and prediction. Among these, observation and experimentation appeared most frequently across all three educational centers, suggesting that children are naturally inclined toward inquiry when immersed in stimulating environments. Predicting was also common, particularly in contexts where children were prompted to anticipate outcomes of their play-based investigations.

Verbal explanation emerged as the least frequent behavior, highlighting a developmental gap in articulating scientific reasoning. Children were more likely to demonstrate cognitive engagement physically than verbally, reflecting both the natural language development stage of early learners and the need for greater adult scaffolding in supporting expressive inquiry. Center C, which showed higher frequencies in experimenting and explaining, appeared to offer stronger educator facilitation.

Quantitative and qualitative data converged to confirm that the most active forms of scientific engagement occurred when teachers created inquiry-rich environments and encouraged children to test their ideas. Environments that provided loose parts, open-ended materials, and thematic guidance produced higher levels of engagement in the observed science behaviors. These patterns suggest that pedagogical design and teacher interaction play pivotal roles in shaping science learning through play.

Case studies supported these patterns by demonstrating children’s use of scientific processes such as comparing results, hypothesizing, and drawing conclusions in the course of self-directed activities. When guided appropriately, children demonstrated not only curiosity but a capacity to reason, test, and refine their ideas, laying the cognitive groundwork for formal science education.

The findings of this study align with previous research that highlights the importance of early childhood as a foundational period for developing inquiry skills. Scholars such as Eshach and Fried (2005) and Fleer (2009) have emphasized that young children possess the cognitive capacity to engage in scientific thinking, particularly through play. The current study provides empirical reinforcement for these claims by illustrating the specific behaviors that constitute early science literacy in natural play settings.

In contrast to studies that view science as a domain more suitable for primary education onward, this research supports the argument that scientific habits of mind begin forming much earlier. The data challenge curriculum models that delay the introduction of science content until language proficiency or abstract reasoning skills have matured (Bode et al., 2025; Giles et al., 2025; Rigby et al., 2025). Findings demonstrate that even non-verbal or minimally verbal behaviors can represent rich cognitive engagement with scientific processes.

Some previous research has been limited by its focus on structured science instruction using scripted curricula, potentially neglecting the value of spontaneous, child-initiated exploration. The present study contributes a complementary perspective by documenting learning that arises organically from children’s own interests when supported by intentional pedagogical design. The blend of freedom and structure observed in this study appears to be a key factor in cultivating early science literacy.

Discrepancies between this study and others may stem from differing definitions of science literacy. While some researchers emphasize content knowledge, this study adopted a broader process-based perspective, focusing on how children think, explore, and communicate about the world. This shift in framing allows for a more inclusive and developmentally appropriate understanding of how scientific thinking manifests in early childhood.

These findings serve as a powerful reminder that young children are not passive learners but active constructors of knowledge, even in abstract domains like science. Their consistent engagement in observing, testing, and predicting behaviors highlights an innate scientific disposition that can be nurtured through play (Riggleman et al., 2025). The results signal a need to recalibrate early childhood education to more explicitly value and support scientific inquiry from the earliest stages.

Children’s ability to engage with complex cognitive processes through play also affirms the relevance of constructivist learning theories. Vygotsky’s concept of the zone of proximal development is especially applicable, as many of the science behaviors observed became more sophisticated with adult interaction. The data suggest that teachers play a critical role in helping children move from concrete exploration to conceptual understanding through guided dialogue and reflective questioning.

The relatively low frequency of verbal explanation emphasizes that science learning in early childhood is as much embodied and experiential as it is linguistic. This observation points to the importance of multimodal pedagogies that allow children to represent and make sense of their ideas through action, drawing, and manipulation, rather than solely through speech or writing.

These results reflect broader educational and cultural values. In systems where play is undervalued or marginalized, opportunities for developing science literacy in authentic, meaningful ways may be diminished. The study signals a call to reposition play-based learning not as a supplementary activity but as a legitimate and powerful context for cognitive development.

The findings carry important implications for curriculum development, teacher education, and educational policy. Early childhood programs should intentionally embed scientific inquiry into daily play, ensuring that environments are rich in materials, open-ended prompts, and opportunities for exploration. Curriculum designers can draw from the behavioral indicators identified in this study to frame developmentally appropriate learning objectives in science.

Teacher training programs should emphasize how to recognize, support, and extend scientific thinking during play. Educators require not only content knowledge but also pedagogical skills in observation, questioning, and scaffolding to effectively foster early science literacy. This underscores the need for professional development models that balance content mastery with play-based instructional strategies.

Policy-makers should consider revising early childhood education standards to include science literacy as a core developmental goal. Assessment frameworks should be expanded to account for inquiry processes rather than focusing solely on product-based outcomes. Systems-level recognition of science as an essential domain in early learning would validate the work of educators who already integrate science informally through thematic and play-based approaches.

The research also contributes to the global discourse on equitable education. Scientific thinking is a universal human capacity, and early exposure through culturally relevant play ensures that children from diverse backgrounds can access the foundations of scientific literacy. Strengthening early science education through play can promote long-term academic resilience and inclusive participation in STEM fields.

The success of play-based learning in fostering science literacy stems from its alignment with how young children naturally learn—through exploration, imitation, experimentation, and interaction. When children are given freedom to manipulate materials, test ideas, and engage in discovery within a safe and stimulating environment, they activate the very cognitive processes that underpin scientific reasoning.

Adult facilitation proved essential in bridging children's curiosity and their ability to reflect or explain. Children may engage deeply in scientific thinking but lack the language or conceptual frameworks to express their insights without support. Teachers who acted as co-investigators by prompting, questioning, and reflecting helped children make their thinking visible and develop metacognitive awareness.

The rich engagement in behaviors like predicting and observing may also be linked to the tactile and visual nature of the play materials provided. These resources encouraged children to use their senses, notice patterns, and make inferences, reinforcing the connection between sensory experience and scientific learning. This supports the argument for investing in high-quality materials that enable inquiry through multiple modalities.

Explaining remained the weakest area, not because children lacked understanding, but because verbal articulation is a more complex skill that requires both confidence and conceptual clarity. This indicates that science education in early childhood should not only provide experiences but also encourage expression through art, gestures, and dialogue to build toward fuller verbal reasoning.

Future research should investigate how sustained exposure to inquiry-based play affects science learning trajectories over time. Longitudinal studies could explore whether children who engage frequently in scientific play in preschool are more confident, inquisitive, and successful in later STEM learning. Such studies would strengthen the argument for early intervention in science literacy.

Additional research could examine the role of cultural and linguistic diversity in shaping how children engage in science through play. Understanding how different cultural contexts influence children's scientific inquiry behaviors and how teachers can adapt facilitation techniques accordingly is essential for creating inclusive learning environments.

Innovative research methodologies, such as video analysis and digital documentation tools, may also enhance our ability to capture and analyze subtle dimensions of scientific thinking in early childhood. Such tools would allow researchers and educators to reflect on practice and track developmental progress with greater accuracy and sensitivity.

Educational systems should invest in creating professional learning communities where teachers can collaborate, share, and reflect on strategies for nurturing early science literacy. Policies that support such communities, along with increased funding for materials and teacher training, will be crucial in ensuring that science becomes a living, breathing part of every young child's play experience.

CONCLUSION

The most distinctive finding of this study is the identification of consistent scientific inquiry behaviors—such as observing, predicting, and experimenting—among preschool-aged children within naturally occurring play-based environments. This result challenges the traditional assumption that science literacy must wait until primary schooling and demonstrates that young learners possess an inherent capacity to engage with foundational scientific processes. These behaviors were not only observable but frequently occurred without explicit instruction, suggesting that early childhood environments can cultivate scientific thinking when thoughtfully designed and facilitated.

This study contributes a unique conceptual framework that integrates play pedagogy with early science literacy, offering a process-oriented lens for identifying and interpreting inquiry behaviors in early learners. By operationalizing scientific habits of mind within a qualitative case study, the research provides educators with concrete indicators of scientific thinking that are developmentally appropriate and observable in informal settings. The methodology, which combines thematic analysis of naturalistic observation with educator interviews and artifact examination, serves as a replicable model for investigating learning in early childhood without relying on traditional testing or academic metrics.

The scope of this study was limited by its sample size and contextual specificity, focusing on three centers in an urban Indonesian setting. The findings, while robust, may not fully capture the variability in pedagogical practices, cultural influences, or resource availability across diverse educational contexts. Future research should expand the sample to include rural and multilingual environments, explore the longitudinal development of science literacy through play, and examine the impact of targeted teacher interventions on children's explanatory skills. A mixed-method or longitudinal design would be especially valuable in tracing how early inquiry behaviors evolve into more formal scientific reasoning over time.

AUTHORS' CONTRIBUTION

Maria Fatima Mardina Angkur: Conceptualization; Project administration; Validation; Writing - review and editing; Conceptualization; Data curation; In-vestigation; Data curation; Investigation; Formal analysis; Methodology; Writing - original draft; Supervision; Validation; Other contribution; Resources; Visuali-zation; Writing - original draft.

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