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Teachers' Strategies in Developing Scientific Literacy for Children with Special Needs in Inclusive Early Childhood Education

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Abstract

The phenomenon of low scientific literacy among early childhood learners, particularly in inclusive educational institutions, indicates a gap between policy and classroom practice. Children with special needs often experience limited access to adaptive science learning, even though scientific literacy skills are essential for developing reasoning and problem-solving abilities in daily life. This study aims to analyze teachers' strategies for developing scientific literacy among children with special needs in inclusive early childhood education and to identify the challenges and solutions implemented by teachers at Ibnu Sina Islamic Kindergarten in Bandung Regency. The study employed a qualitative case study design, using in-depth interviews, participatory observations, and analysis of learning documents. Data were analyzed using Miles and Huberman's interactive model, with validity ensured through triangulation and member checking. The findings reveal that teachers applied differentiated instruction, interpersonal communication, and the use of visual media, simple technology, and the surrounding environment as a natural laboratory. Collaboration among classroom teachers, special education teachers, parents, and the principal emerged as a key factor for success. The main challenges included limited resources, pedagogical competence, and the lack of specialized training in scientific literacy for children with special needs. The implications of this study emphasize the importance of enhancing teacher training, strengthening systemic support, and fostering school–family partnerships to achieve sustainable, inclusive science education.

Keywords: Scientific literacy, Children with Special Needs, Teachers' Strategies, Inclusive Education.

INTRODUCTION

Scientific literacy has become a central competency in 21st-century early childhood education, as it equips children with essential skills such as reasoning, problem-solving, and inquiry-based thinking needed in everyday life (Risna et al., 2023; Rahmawati et al., 2025). However, despite the growing emphasis on scientific literacy worldwide, many educational institutions still struggle to ensure that young learners receive meaningful and developmentally appropriate science experiences. The challenge is even greater in inclusive early childhood education settings, where Children with Special Needs (CwSN) require adaptive, multisensory, and flexible learning approaches.

In Indonesia, inclusive early childhood education has been promoted to ensure equal access to quality learning for all children, including those with disabilities (Iman et al., 2025). Yet the implementation of inclusive science learning remains uneven. While policies encourage inclusion, classroom realities often reveal gaps between expectations and practice. Teachers face the dual responsibility of mastering scientific concepts while simultaneously designing pedagogical strategies that respond to diverse cognitive, sensory, and developmental needs (Mallillin, 2021). This complexity underscores the urgency of understanding how teachers operationalize inclusivity within science learning.

Previous research on scientific literacy in early childhood has largely focused on mainstream classroom settings. For example, studies have shown that play-based inquiry, hands-on exploration, and teacher-guided investigations effectively support young children's early scientific reasoning (Roy et al., 2025; Zeng & Ng, 2025). However, these studies seldom examine how such instructional approaches operate within inclusive learning environments where Children with Special Needs (CwSN) learn alongside typically developing peers. As highlighted in recent reviews, research addressing the adaptation of science-learning pedagogies for diverse learners in inclusive early childhood contexts remains limited, leaving a gap in understanding how existing models can be effectively modified to support all children's participation and scientific literacy development (Lundqvist, 2025; Balık & Ozgun, 2024).

Research on inclusive education highlights several key factors that shape learning outcomes. Collaboration between general teachers and special education teachers is consistently cited as a determining factor for successful inclusion (Alhossyan, 2023). Meanwhile, Lin et al. (2025) emphasize the importance of differentiated instruction and individualized scaffolding to promote equitable participation in learning. Yet, empirical evidence on how these principles are applied specifically in early childhood science learning remains scarce. Furthermore, many teachers still lack the confidence, training, and resources needed to deliver adaptive science instruction to CwSN.

Contextual and environmental-based learning has emerged as a promising approach for fostering scientific literacy, particularly in early childhood settings (Vitiello & Williford, 2021; Ardoin & Heimlich, 2021). By engaging children with natural phenomena, hands-on experiences, and everyday materials, contextual learning enhances curiosity and supports conceptual understanding. However, studies rarely explore how contextual learning can be integrated with inclusive pedagogy, particularly in settings where environmental facilities may vary and teachers must improvise with limited resources.

In Indonesia, the effectiveness of inclusive education is shaped not only by classroom instructional practices but also by larger systemic factors, such as school leadership, parental involvement, and community engagement (Musendo et al., 2023; Symeonidou et al., 2025). These interdependent components align with Bronfenbrenner's ecological systems theory, which positions child development as the outcome of interactions across multiple environments. Yet, little research has examined how these ecological factors specifically influence the development of scientific literacy for CwSN.

Responding to these gaps, this study investigates teachers' strategies in developing scientific literacy for CwSN in an inclusive early childhood context. Ibnu Sina Islamic Kindergarten in Bandung Regency presents a unique case because it integrates nature-based learning with inclusive principles. Although nature-based learning has been widely associated with environmental awareness and sensory engagement (King et al., 2024; Arsyad et al., 2024), limited empirical research explores how it can be tailored to support scientific literacy among CwSN.

Therefore, this study aims to provide a comprehensive understanding of how teachers design, adapt, and implement science learning for CwSN within an inclusive, nature-based early childhood environment. It also examines the challenges teachers face including resource limitations, pedagogical readiness, and varying levels of parental involvement and the adaptive solutions developed through collaboration and contextual innovation. By grounding the analysis in both empirical findings and theoretical frameworks, this study contributes to the existing literature by linking inclusive pedagogy, contextual learning, and scientific literacy development in early childhood education.

Therefore, this research offers both conceptual and practical insights. Academically, it addresses an underexplored intersection in the literature, the development of scientific literacy within inclusive early childhood settings. Practically, it provides evidence-based guidance for teachers, school leaders, and policymakers seeking to enhance inclusive science education. The novelty of this study lies in its focus on adaptive teacher strategies that integrate nature-based learning with inclusive pedagogy an approach rarely documented yet urgently needed to strengthen equitable science learning opportunities for all young children.

METHOD

This study employed a qualitative approach with a case study design, which is considered appropriate for exploring teachers' strategies in developing scientific literacy for CwSN within the real-life context of inclusive education. According to Yin (2019), case studies are particularly suitable for addressing "how" and "why" questions, thereby offering an in-depth understanding of teachers' practices in early childhood settings. This approach also enables the researcher to capture teachers' experiences, challenges, and adaptive strategies through close interaction with participants (Leko et al., 2021). Overall, the method section of this study is well structured, as it clearly outlines the research design, data collection techniques, analytical procedures, and the trustworthiness strategies adopted to ensure the credibility and reliability of the findings.

The research was conducted at Ibnu Sina Islamic Kindergarten, Bandung Regency, an early childhood institution that integrates nature-based learning with inclusive principles. The school has a total of 32 students, including 6 CwSN with diverse categories such as autism spectrum disorder, speech delay, and mild intellectual disability. Learning is organized into three classes consisting of mixed-ability groups. Participants in this study included five classroom teachers who directly worked with CwSN, one special education teacher, and the school principal. Additionally, four parents of CwSN were involved as supporting informants to provide complementary perspectives. The selection of participants followed purposive sampling based on specific criteria, namely: (1) having direct teaching responsibility for CwSN, (2) having at least one year of teaching experience at the school, (3) being actively involved in planning or implementing science-related learning activities, and (4) for parents, having a child with special needs enrolled in the school. These criteria ensured that all informants possessed relevant knowledge and experiences aligned with the objectives of the study (Solarino & Aguinis, 2021).

Data were collected using three complementary techniques: (1) in-depth, semi-structured interviews to explore teachers' strategies, challenges, and problem-solving approaches, which directly support the objective of understanding their lived experiences in fostering scientific literacy; (2) participant observation of classroom and outdoor learning activities to document how scientific literacy practices were enacted in authentic instructional contexts; and (3) document analysis of daily lesson plans, developmental records, and visual learning materials to verify the alignment between instructional planning and classroom implementation. Together, these techniques ensured strong alignment with the research objectives and provided triangulated evidence necessary for generating rich and comprehensive insights (Vivek, 2023).

The data were analysed using the interactive model of Miles et al. (2014), which involves three iterative stages: data reduction, data display, and conclusion drawing/verification. This recursive process aligns with Ahmed (2024), who emphasizes that qualitative analysis requires ongoing interpretation to ensure the credibility and depth of findings.

To ensure trustworthiness, multiple strategies were implemented, including triangulation of data collection techniques and informant sources, member checking with key participants to validate emerging interpretations, and data saturation to ensure that no new themes appeared during later stages of analysis (Mckim & Mckim, 2023). Ethical procedures followed in this study were aligned with widely accepted research ethics guidelines in studies involving young children, including obtaining informed consent from parents or guardians, ensuring confidentiality and anonymity of participants, and safeguarding the rights and well-being of child participants (Alderson & Morrow, 2024).

As this study employed a fully qualitative approach, no quantitative data or numerical frequencies were generated or analysed. All interpretations were derived from narrative accounts obtained through interviews, observations, and document reviews. The analysis therefore focused on understanding patterns of teacher practices and experiences rather than quantifying participation levels, ensuring that the findings remained aligned with the qualitative purpose and emphasis on depth over measurement.

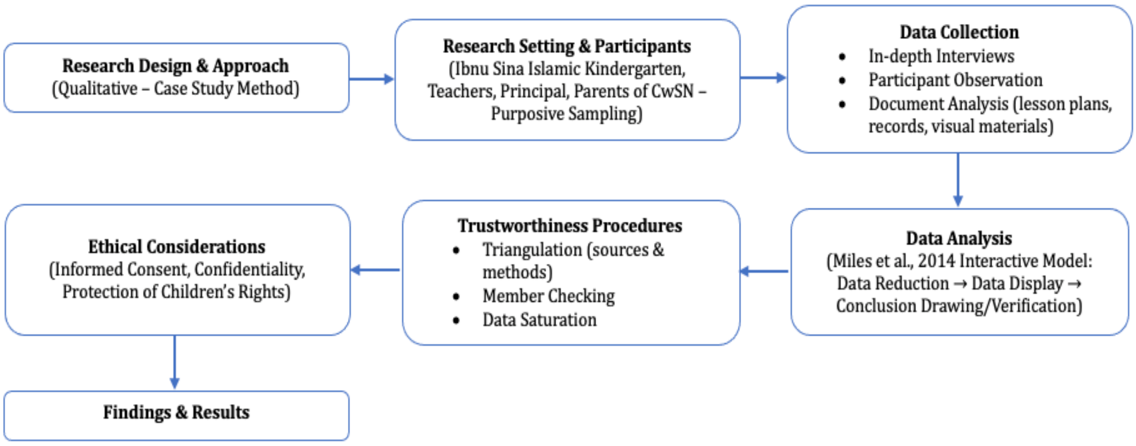

Figure 1. Research Procedures
Source: Authors' (2025)

RESULTS AND DISCUSSION

Findings

This study was conducted at Ibnu Sina Islamic Kindergarten, Bandung Regency, an early childhood education institution that integrates nature-based learning with inclusive principles. The research aimed to analyse teachers' strategies in developing scientific literacy for CwSN, identify the challenges they encountered, and explore the solutions they implemented. Data were obtained through interviews, classroom observations, and document analysis.

To provide analytical clarity, this study adopts a definition of scientific literacy grounded in early childhood science education literature. In this framework, scientific literacy encompasses four interrelated dimensions: scientific knowledge, which involves children's ability to recognise and understand basic science concepts; scientific practices, which include the skills of observing, predicting, and experimenting through direct engagement with phenomena; scientific reasoning, reflected in children's capacity to connect simple cause–effect relationships and identify emerging patterns; and scientific attitudes, which refer to the development of curiosity, persistence, and a sense of care toward the environment. These dimensions serve as the analytical lens for interpreting how each learning activity contributes to the scientific literacy development of CwSN in the inclusive early childhood context.

This framework is used to interpret how each classroom activity contributes to the scientific literacy development of CwSN. For example, gardening and seed-planting activities support scientific knowledge (understanding plant growth) and scientific practices (observing daily changes, watering plants). Rainfall observation and water play strengthen scientific reasoning, such as identifying why puddles form or which objects float or sink. Meanwhile, the hands-on and multisensory nature of these activities promotes scientific attitudes, including curiosity, willingness to explore, and enjoyment in learning.

Through this framework, the findings demonstrate that the activities implemented by teachers do not merely represent general science exposure, but are intentionally structured to target specific indicators of scientific literacy adapted to the developmental profiles of CwSN.

Teachers' Strategies in Developing Scientific Literacy for Children with Special Needs

The findings indicate that teachers employed multiple, complementary strategies to foster scientific literacy among CwSN. These strategies emerged from interviews, classroom observations, and supporting documents such as lesson plans, daily learning records, and photographic documentation. To clarify patterns in the data, Table 1 summarizes the key strategies and their alignment with the four dimensions of scientific literacy used in this study.

Table 1. Teachers' Strategies and Their Alignment with Scientific Literacy Dimensions

Teacher Strategy	Description Based on Findings	Related Scientific Literacy Dimensions
Experiential learning	Gardening, observing rainfall, water play, simple experiments (bubbles, colour mixing). Children directly manipulate materials and observe changes.	Knowledge, Practices, Reasoning, Attitudes
Differentiated instruction	Step-by-step scaffolding, assistive tools (large spoons, funnels), visual supports.	Practices, Reasoning
Interpersonal communication	Simple language, repetition, emotional support, praise, one-on-one encouragement for CwSN.	Attitudes, Practices
Use of visual & multisensory media	Pictures, posters, short videos, concrete objects and props.	Knowledge, Attitudes
Home–school collaboration	Guidance for parents, communication about science activities, continuity of stimulation at home.	Attitudes, Knowledge

Classroom observations revealed that teachers frequently engaged children—including CwSN in experiential learning activities, such as gardening, observing rainfall, and playing with water. These hands-on practices allowed children to directly interact with natural phenomena, which strengthened their scientific practices (e.g., observing changes, predicting outcomes) and scientific attitudes (e.g., curiosity, persistence). Documentary evidence from lesson plans and learning photos confirmed that experiential tasks were consistently implemented as part of weekly thematic units. For example, lesson plan documentation for Week 3 included an activity indicator stating: "Children are able to observe simple changes in the plants they plant.."

Figure 2 below shows one experiential learning activity documented during observations, where children learned about gardening and interacted directly with plants.

Figure 2. Children engaging in gardening activities as part of experiential science learning. (Observation, 2025)

One teacher highlighted in an interview:

"Children understand better when they practice directly. If we only explain, especially to CwSN, they quickly lose focus. So, we invite them to plant, watch the rain, or blow soap bubbles. We must patiently repeat instructions until they are willing to participate." (Interview, February 2025)

Another prominent strategy was differentiated instruction, which teachers used to adjust task difficulty and provide individualized support. Observations showed that children with attention difficulties received step-by-step guidance, while those with motor challenges used assistive tools such as larger spoons for planting or funnels for pouring water. This was supported by documentary triangulation: lesson plan checklists showed flexible success criteria that did not require accuracy or speed, particularly for CwSN.

As one teacher explained:

"Not all children can do the same thing in the same way. Some need assistive tools, while others use pictures. We adjust so everyone can participate." (Interview, February 2025)

Teachers also relied heavily on interpersonal communication to create an emotionally supportive learning environment. They used simple, clear language, repeated instructions, offered praise, and provided one-on-one encouragement for children who were reluctant to participate. Observation notes documented a case where a child with autism initially refused to engage in planting but eventually joined after receiving calm and consistent verbal reassurance from the teacher.

In addition, teachers integrated visual and multisensory media, including pictures, posters, and short science videos. These tools helped simplify abstract concepts such as colour mixing and water absorption. Simple experiments documented in classroom photos such as mixing coloured water and blowing soap bubbles were used to strengthen children's scientific reasoning and attitudes. "*If we only talk, children quickly lose focus. But with pictures, props, or hands-on tools, they understand more easily.*" (Interview, March 2025).

Support from school leadership also played a pivotal role. The principal encouraged teachers to utilize the natural environment and low-cost materials to overcome limitations in science facilities. Documentary evidence in meeting notes showed that the principal regularly emphasized the importance of science exposure and inclusivity during staff meetings.

Parents' perspectives further reinforced the effectiveness of teachers' strategies. Some parents reported that children replicated school activities at home for example, watering plants after participating in gardening at school. However, variations in parental confidence and ability to extend scientific literacy at home were also noted. "*Sometimes we are unsure how to explain the concepts at home, especially when they are more difficult. So, we usually wait for the teacher's guidance*." (Interview, March 2025).

Overall, these findings demonstrate that strategies for developing scientific literacy in inclusive early childhood education involve interconnected efforts across teachers, parents, and school leadership. The triangulation of interviews, observations, and documentation confirms that experiential learning, differentiation, and visual–multisensory supports are central strategies used by teachers to make scientific concepts accessible and meaningful for CwSN.

Challenges Faced by Teachers

Findings from Ibnu Sina Islamic Kindergarten reveal that the challenges faced by teachers in fostering scientific literacy for CwSN are closely related to the four scientific literacy indicators used in this study, namely (1) observing, (2) predicting, (3) classifying, and (4) communicating findings. Limited pedagogical competence, high teacher–student ratios, inadequate learning resources, and inconsistent parental support directly constrained teachers' efforts to help children achieve each indicator. Interviews with teachers in February 2025 showed that most had never received formal training on scientific literacy for CwSN, which made it difficult for them to guide children in conducting structured observations. One teacher admitted that instructional decisions were often based on intuition rather than evidence-based strategies, affecting children's ability to develop systematic observation skills a foundational component of scientific literacy. As she stated, "Most children with special needs need step-by-step guidance when observing plants. If the instructions are lengthy, they'll get confused and simply glance without knowing what to observe." (Interview, February 2025). This constraint was evident during plant growth observations, where CwSN often engaged in superficial looking rather than focused observing because the scaffolding required for deeper engagement was not sufficiently provided.

The high teacher–student ratio further limited the capacity to support children in making predictions or hypotheses, the second indicator of scientific literacy. A teacher explained that when a CwSN required extended one-on-one guidance during simple experiments such as mixing coloured water, the teacher simultaneously had to manage the rest of the class. She noted, "When asked to guess what happens when mixing colours, children with special needs often take a long time. While one child needs intensive supervision, I also have to manage the rest of the class, so the prediction part often suffers." (Interview, February 2025). Under such conditions, children rarely received the individualized prompting needed to meaningfully practice prediction skills for example, hypothesizing whether a seed would sprout faster in sunlight or shade. Teachers acknowledged that limited time and competing responsibilities made it difficult to sustain meaningful scaffolding during inquiry-based learning tasks.

Resource limitations also directly impacted the third indicator classifying objects or phenomena based on simple attributes. Observations and lesson plan documents revealed the absence of basic science kits, such as magnifying glasses, sorting trays, or simple measurement tools that would normally support structured comparison. As a result, classification activities were often improvised using recycled materials, which, although creative, did not always align well with the intended literacy indicators. One teacher explained in March 2025, "We rely on second-hand materials, but kids really need tools like magnifying glasses or sorting trays. Without them, classifying becomes just another game." This limitation caused CwSN to engage primarily in sensory play without progressing to classification tasks that build foundational conceptual understanding.

Variations in parental involvement also influenced children's ability to achieve the fourth indicator communicating scientific findings. Interviews in March 2025 revealed that while some parents encouraged children to share their observations or retell science activities at home, others delegated all responsibility to the school. A teacher described, "Children who don't continue their activities at home often have difficulty recounting what they did at school. We need parents' help to get their children used to telling stories." (Interview, March 2025). When communication practice was not reinforced at home, children's progress in expressing findings verbally or through drawings became slower, and many quickly forgot concepts introduced during class activities. This disrupted learning continuity between school-based observations and the communication of results an essential component of scientific literacy development.

Overall, the challenges faced by teachers are therefore not merely general obstacles, but are specifically linked to the difficulty of supporting CwSN in achieving each scientific literacy indicator. Limited pedagogical knowledge affects guided observation; time constraints hinder prediction skills; inadequate resources limit classification practices; and inconsistent family involvement disrupts children's ability to communicate scientific ideas. These interconnected barriers underscore that implementing scientific literacy in inclusive early childhood settings requires not only teacher creativity, but also systemic support and coordinated efforts between school and home, as reflected in the evidence collected through interviews, observations, and document analysis.

To strengthen this linkage, the following table provides a clear mapping of how each challenge corresponds to specific scientific literacy indicators and the associated field evidence.

Table 2. Mapping of Teacher Challenges to Scientific Literacy Indicators and Field Evidence

Teacher Challenges	Scientific Literacy Indicator Affected	Nature of Impact	Supporting Field Evidence
Limited pedagogical competence; lack of training	Observing	Teachers were unable to scaffold observation tasks into step-by-step guidance; CwSN tended to "see" rather than truly "observe."	"Instructions are often based on intuition… the children only glance without understanding what they are supposed to observe." (Interview, Feb 2025)
High teacher–student ratios; time constraints	Predicting	Individualized prompting was limited; prediction activities were minimally supported.	"When one child needs prolonged support, the prediction activity becomes less optimal because I still have to manage the whole

			class." (Interview, Feb 2025)
Inadequate learning resources	Classifying	Improvised materials constrained structured sorting and comparison activities.	"Without magnifying glasses or sorting trays, classification activities end up becoming simple play." (Interview, Mar 2025)
Inconsistent parental involvement	Communicating Findings	Lack of reinforcement at home weakened children's ability to describe their observations.	"Children struggle to retell their activities when parents do not continue the stimulation at home." (Interview, Mar 2025)

Solutions Implemented by Teachers

Although many of the strategies previously described represent the teachers' regular instructional practices, the findings also show several adaptive solutions that specifically emerged in response to the challenges identified earlier. These solutions are not merely extensions of routine teaching approaches, but rather intentional adaptations developed to address limitations in school resources, teachers' pedagogical competence, and the inconsistency of parental involvement.

A key solution relates to teachers' efforts to maximize the use of the surrounding environment. Given the school's limited science-related equipment and the absence of laboratory facilities, teachers deliberately transformed the garden, mini farm, and fish pond into alternative "natural laboratories." While contextual learning was already part of routine instruction, this intensified reliance on environmental resources functioned as a strategic response to material constraints. By engaging children directly in planting, watering, and observing natural changes, teachers operationalized the principles of experiential learning, which emphasize concrete sensory experiences as foundational for conceptual understanding particularly crucial for CwSN whose learning depends heavily on hands-on engagement. As one teacher noted, "We try to use the school environment as a learning medium… children are directly involved in planting, watering, and observing." (Interview, February 2025)

Another prominent solution was the strengthening of collaboration between classroom teachers and the special education teacher. This practice emerged as a response to teachers' limited specialized training in scientific literacy for CwSN and the challenge of managing large, mixed-ability classes. Through shared roles and coordinated planning, teachers were able to distribute responsibilities more effectively, ensuring that individualized assistance was provided during science activities. This collaborative approach aligns with inclusive pedagogy theory, which highlights the importance of collective professional expertise rather than individual teacher capacity in meeting diverse learner needs. As described by a teacher, "We always share roles… the special teacher provides one-on-one assistance for children who need extra guidance." (Interview, March 2025)

Teachers also adopted simple technological tools as a deliberate solution to the challenge of explaining scientific concepts that could not be demonstrated directly due to the lack of equipment. Short science videos were used to visualize abstract processes such as evaporation, enabling children to form mental representations before engaging in simple follow-up experiments. This practice is consistent with multimodal learning theory, which emphasizes the integration of visual and experiential modalities to support comprehension, particularly for young learners with developmental differences.

In addition, the inconsistency of parental involvement prompted teachers to intensify home–school communication. Parents who lacked confidence or knowledge to support scientific literacy at home required more structured guidance, leading teachers to provide regular reminders, suggestions for simple home-based activities, and individualized feedback. This solution reflects ecological systems theory, which underscores the importance of synchronization between the home and school environments to sustain children's learning progress. One teacher emphasized this need, stating, "We always remind parents to continue the stimulation at home… parents can invite them to plant chilies or tomatoes." (Interview, March 2025)

Collectively, these adaptive solutions illustrate how teachers negotiated structural constraints through context-based innovation, collaboration, multimodal instruction, and strengthened home–school partnerships. Rather than functioning as routine teaching strategies, these practices emerged specifically to mitigate the challenges of limited resources, insufficient training, and uneven family support, thereby demonstrating the dynamic and responsive nature of inclusive science pedagogy in early childhood settings.

Table 3. Summary of Key Findings

Category	Important Findings
Challenges	
1. Insufficient teacher competence in scientific literacy for Children with Special Needs (CwSN) 2. Large teacher–student ratios, making individualized support difficult 3. Inconsistent parental involvement in continuing science activities at home	Limited science resources and the absence of laboratory facilities
Adaptive Solutions	
1. Strengthening collaboration between classroom teachers and the special education teacher to address competence gaps and provide individualized support 2. Employing simple technology (e.g., short science videos) to explain abstract concepts 3. Intensifying home–school communication to ensure continued stimulation for CwSN outside school	Using the school garden, mini farm, and fish pond as natural laboratories to compensate for the lack of science equipment
Teaching Strategies	
1. Differentiated instruction based on children's developmental needs 2. Use of visual media and multisensory learning tools 3. Interpersonal communication strategies such as simplified language, repeated instructions, and positive reinforcement	Contextual learning involving observation and hands-on activities

Discussion

The findings reveal that teachers' strategies in developing scientific literacy for CwSN align strongly with contextual and inclusive learning principles. Activities such as gardening, observing natural phenomena, and conducting simple experiments reflect contextual learning theory, which emphasizes that children learn best through direct and meaningful experiences connected to their daily lives (Ardoin & Heimlich, 2021; Vitiello & Williford, 2021). For CwSN, sensory engagement provides the foundation for cognitive development, enabling them to interact with soil, rainfall, and water play. These concrete experiences develop core scientific literacy indicators observing, predicting, and reasoning by helping children notice changes in plants, anticipate outcomes of water or colour mixing, and connect cause–effect relations. This aligns with Rahmian et al. (2024), who argue that learning embedded in authentic contexts strengthens motivation and curiosity.

Differentiation also plays a central role in supporting scientific literacy. Inclusive pedagogy stresses that educators must adapt content, processes, and learning environments to accommodate diverse learner needs (Starkey, 2020; Florian, 2022). Teachers at Ibnu Sina Islamic Kindergarten employed differentiation through adjusted instructions, assistive tools, and individualized support. These adaptations help CwSN engage in prediction tasks such as guessing experimental outcomes and develop reasoning through step-by-step scaffolding. Lin et al. (2025) emphasize that individualized scaffolding and interpersonal sensitivity are essential for the development of scientific literacy in CwSN, reinforcing that equity rather than uniformity is key for meaningful participation in science learning.

Interpersonal communication also emerged as a crucial strategy. Teachers used simple language, repeated instructions, and positive reinforcement to create emotionally secure learning environments. This resonates with Fuertes et al. (2022), who found that emotional attunement enhances engagement in CwSN, and Dare & Nowicki (2023), who argue that adaptive communication improves comprehension and motivation for children with learning differences. Importantly, such communication directly supports the scientific communication indicator, enabling CwSN to articulate observations and retell their findings more confidently. This demonstrates that empathy and patience are not only ethical but pedagogically important in inclusive science learning.

Visual and multisensory media further reinforced children's scientific literacy development. Pictures, videos, and manipulatives correspond with the multimodal learning perspective (Bezemer & Kress, 2020). These tools transform abstract concepts such as evaporation, plant growth, or colour mixing into concrete and accessible representations. In practice, these media strengthen children's observing abilities (e.g., comparing plant growth images), prediction skills (e.g., anticipating colour changes), and reasoning (linking visual representations to real-world outcomes). The creativity of teachers in using such media aligns with the inclusive principle of accessibility, ensuring that all students, regardless of ability, can engage with scientific concepts (Arsyad et al., 2024; Mrayhi et al., 2024).

Institutional and parental support also serve as important ecological factors. The principal's encouragement of teacher innovation reflects inclusive leadership, which fosters autonomy, collaboration, and alignment between school policies and inclusive goals (Sharma, 2022). Meanwhile, parental involvement reinforces scientific literacy outside school. Volodina et al. (2024) highlight that early literacy scientific or otherwise develops more robustly when home and school environments provide continuous stimulation. When parents extend school activities at home such as assisting with watering plants or prompting children to retell their observations they contribute directly to the communication and observation indicators. Hart et al. (2024) describe this as a home–school partnership model, where parents function as co-educators rather than passive supporters.

Despite these strengths, the study identifies systemic challenges that affect the development of scientific literacy for CwSN. Limited access to training, high teacher–student ratios, and inadequate facilities are recurring issues in inclusive education (Totini et al., 2025; Taghap & Pabalan, 2025). However, teachers' adaptive use of environmental resources and recycled materials demonstrates pedagogical resilience. Rahmian et al. (2024) In experiential learning theory emphasizes learning through cycles of experience, reflection, and experimentation, and this study shows that school gardens, fish ponds, and mini-farms serve as accessible "natural laboratories." These contexts support observation and reasoning by allowing CwSN to notice real-time changes in natural elements, even without specialized equipment.

Variations in parental involvement also influence scientific literacy development. Some parents reinforce learning at home, while others rely heavily on school-based initiatives (Musendo et al., 2023; Drew et al., 2024). Teachers address this challenge through communication books and regular meetings, which strengthen parental understanding and engagement. García-Crespo et al. (2021) found that structured communication improves family–school collaboration. In this study, such collaboration helps children practice scientific communication, particularly when they retell observations or describe experimental results at home. This demonstrates that inclusivity extends beyond the classroom into coordinated home–school support systems.

The adaptive solutions developed by teachers environmental utilization, team teaching, simple technology, and intensified communication represent effective models of inclusive pedagogy. Team teaching between classroom teachers and special education teachers enhances collective capacity (Alsudairy, 2024). This collaborative model provides targeted scaffolding that strengthens both prediction and reasoning indicators, especially when CwSN require one-on-one guidance. Fernandez (2021) also argues that such collaboration reflects a shared institutional commitment to inclusion. Meanwhile, simple technological tools, such as short science videos, help visualize abstract processes. Höttecke & Allchin (2020) highlight the role of digital media in simplifying science concepts. Meanwhile, Mehto et al. (2020) note that even basic technological interventions improve comprehension for CwSN. These tools therefore support the observation and reasoning indicators by offering concrete visualizations.

The interaction among teachers, parents, and school leadership can be explained using Bronfenbrenner's ecological systems theory (El Zaatari & Maalouf, 2022). Children's development is shaped by reciprocal interactions across the microsystem, mesosystem, and broader systems. When these systems are aligned and mutually reinforcing, scientific literacy across all four indicators develops more holistically. Conversely, fragmentation in any subsystem leads to uneven learning experiences.

At the national level, the findings contribute to the discourse on inclusive education reform in Indonesia. The experience of Ibnu Sina Islamic Kindergarten shows that inclusion is not merely a mandate but a lived pedagogical practice. Creative adaptations and sustained collaboration at the school level represent grassroots innovation that can inform policy, particularly regarding teacher training, parental engagement, and resource provision. The integration of environmental and digital literacy aligns with national priorities for sustainability and technological advancement. Moreover, this study demonstrates that developing scientific literacy especially observation and reasoning does not require sophisticated tools but depends on thoughtful pedagogical design.

In summary, the development of scientific literacy among CwSN in inclusive early childhood settings is a multidimensional process shaped by adaptive pedagogy, inclusive leadership, strong parental collaboration, and context-based resources. These interconnected elements illustrate that inclusive science literacy is both a pedagogical and social endeavour. As Symeonidou et al. (2025) argue, inclusive education succeeds not only through teacher competence but through collaborative ecosystems. The experience of Ibnu Sina Islamic Kindergarten shows that when teachers, families, and institutions work synergistically, even systemic limitations can become opportunities for transforming learning particularly in strengthening the scientific literacy indicators of observation, prediction, reasoning, and communication.

CONCLUSION

This study found that the teachers' strategies in developing scientific literacy for CwSN including the use of environmental resources, visual and multisensory media, differentiated instruction, teamwork with special education teachers, and communication with parents had a stronger impact than previously assumed. These strategies not only supported inclusion but directly strengthened core scientific literacy indicators such as observing, predicting, reasoning, and scientific communication. The findings also reveal significant challenges, including limited teacher training, scarce resources, and varying levels of parental involvement. Nevertheless, teachers demonstrated high creativity and resilience by adapting environments, implementing simple technologies, and collaborating across roles. These results challenge traditional assumptions that CwSN require highly specialized tools to learn science, showing instead that contextualized, inclusive, and collaborative strategies can effectively support their scientific literacy development.

Scientifically, this study reinforces previous arguments about the role of contextual learning, multimodal instruction, and inclusive pedagogy in supporting young learners, while also questioning the assumption that CwSN cannot meaningfully engage in early scientific reasoning. The study introduces a more explicit linkage between inclusive teaching strategies and specific scientific literacy indicators, thus enriching theoretical discussions on how scientific literacy develops in inclusive early childhood settings. Practically, the findings highlight the necessity of strengthening teacher competencies, enhancing school–parent partnerships, and ensuring institutional support from school leadership. The evidence demonstrates that simple, accessible, and context-based pedagogical designs can serve as effective alternatives where specialized facilities are limited, offering a replicable model for other inclusive early childhood institutions.

This study is limited by its small sample size, single-site focus, and the specific characteristics of one inclusive kindergarten, which limit the generalizability of the findings. Additional limitations include the variations in children's developmental levels, gender, and ages, which were beyond the analytical scope of this research. Future studies should include larger and more diverse samples, incorporate longitudinal designs to track scientific literacy development over time, and explore additional variables such as socio-emotional factors or parental educational background that may influence scientific literacy outcomes. Expanding research across different types of inclusive settings will provide a more comprehensive understanding of how inclusive strategies can best support scientific literacy among CwSN.

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