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Deep Learning-Based STEM Learning Model To Improve Early Childhood Science Literacy

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Abstract

This study developed and tested a STEM learning model based on deep learning principles to improve science literacy in young children. Three problems observed in the field prompted the work: children had a weak grasp of basic science concepts, kindergartens gave them few chances to explore, and most teaching was still teacher-centered, which left little room for active learning or critical thinking. In the model, children move through observation, questioning, experimentation, discussion, and reflection, and build their own understanding of what they see. The study used a qualitative Research and Development (R&D) design involving teachers, children aged five to six, and the school principal. Data were collected through classroom observation, field notes, interviews, and documentation, and analyzed thematically. After the model was introduced, children asked more questions, made predictions, explained what they observed, and began to recognize simple cause-and-effect relationships. They were also more curious, more willing to try experiments, and more confident when presenting their findings. Teachers became better at facilitating inquiry and experiment-based activities, and a well-prepared learning environment helped sustain these experiences. The findings indicate that the model is feasible, practical, and effective for strengthening science literacy in early childhood settings and can be used as an alternative to conventional instruction.

Keywords: *STEM; Deep Learning; Science Literacy;Early Childhood.*

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INTRODUCTION

Early childhood education shapes a child's character, ways of thinking, and the basic competencies needed for lifelong learning. The early years are often called the golden age because cognitive, social-emotional, and motor abilities develop very quickly during this period, so interventions at this stage should be planned carefully and based on evidence. Science literacy is one skill worth developing early. It is the ability to understand natural phenomena by observing, asking questions, exploring, and drawing simple conclusions. Besides knowing facts, it involves a scientific way of thinking that combines curiosity, problem solving, and critical thought.

Rapid social and technological change in the twenty-first century has made science literacy more important. A bibliometric study found that research on STEM education has grown sharply worldwide over the past five years (Li & Xiao, 2022). Studies of kindergarten leadership describe scientific literacy as necessary for preparing children for a world shaped by technology, though many institutions still find it hard to turn this into daily classroom practice (Wu & Huang, 2023). Children therefore need learning opportunities that let a scientific mindset develop from an early age. Recent studies in Indonesia and elsewhere, however, report that science literacy among young children remains low, mainly because learning is still conventional and teacher-centered and leaves little room for exploration (Movahedazarhouligh et al., 2023; Ramulumo, 2023).

Many early childhood institutions still see science as difficult and unsuitable for young children. Teachers often reduce it to demonstrations, and the children never go through the scientific process themselves. Children learn science best when they investigate phenomena directly through hands-on and loose-parts play, yet preschool directors and teachers commonly view STEM as too abstract or too demanding in resources for this age group (Cankaya et al., 2023; Wu & Huang, 2023). Science activities should therefore let children carry out the scientific process directly.

Preliminary observations identified three problems. First, children had a weak understanding of basic science concepts. Many could not recognize or explain everyday events such as changes in the weather, water changing form, or plants growing. Second, their scientific thinking skills were underdeveloped. Faced with a new object or an unusual event, most children stayed passive and rarely asked "why" or "how." Third, they had little sense of how science relates to their own lives. What they learned at school seldom went beyond memorization, and they did not know how to use it to solve problems around them.

STEM (Science, Technology, Engineering, and Mathematics) learning has received growing attention as a way to build science literacy in PAUD (Indonesian early childhood education). STEM combines several disciplines around real-world problems through exploratory, creative, and collaborative activities. Recent work on STEM-integrated curricula shows that the approach helps children think, design, and test solutions by combining science concepts with hands-on engineering, provided teachers hold suitable pedagogical beliefs and are well prepared (Movahedazarhouligh et al., 2023). It also suits the way young children learn, through play, exploration, and direct experimentation, as studies of hands-on learning and children's attention and reasoning confirm (Rani & Suvidha, 2022).

STEM activities in early childhood have been linked to better critical thinking, creativity, and problem solving, and children who take part in them tend to participate more, show more curiosity, and understand basic science concepts better. Bringing STEM into early childhood

classrooms is still difficult. Teachers often think of STEM as complicated and dependent on advanced technology, although it can be done with cheap, natural, or recycled materials (Leung, 2023; Nurhayati, 2021). Studies of preservice and in-service teacher preparation also find that many teachers lack the pedagogical competence and self-efficacy to design developmentally appropriate STEM activities, so targeted professional development is still needed (Chen et al., 2021; Weinberg et al., 2021).

Learning theory has also moved toward deeper and more reflective approaches, and deep learning is one of them. Children are encouraged to understand meaning, link ideas, and use higher-order thinking instead of only remembering facts. Research on meaningful learning in early childhood shows that young children's thinking skills grow when they actively look for meaning, connect concepts, and use evidence to support their reasoning (Nugroho & Amalia, 2022). Because science depends on conceptual understanding, analysis, and reasoning, these principles are central to developing science literacy.

With young children, deep learning can happen through activities in which they take part in the whole scientific process: noticing phenomena, asking questions, setting up simple experiments, and thinking about what they found. Combined with STEM, this lets children build science concepts in a meaningful way. Research using constructivist methods with children aged 4 to 6 found that active interaction with the environment, reflection, and discovery produced meaningful learning and measurable gains in cognitive ability (Mulyasa & Hernawati, 2023). Work on scaffolding in the zone of proximal development adds that conceptual progress depends on guided, responsive support from teachers, and that unstructured play alone is not enough (Kurniawan et al., 2022).

This study, "Deep Learning-Based STEM Learning Model to Improve Early Childhood Science Literacy," differs from earlier work in using deep learning principles as the main basis for designing STEM learning for young children. Existing STEM models generally integrate the four disciplines through exploration, problem solving, experimentation, design, and product making. They give children active and contextual experiences, but the learning process is not always planned to make children aware of how they learn, to give them meaningful experiences, and to keep learning enjoyable while developing deeper scientific thinking.

The first contribution is a STEM learning syntax rebuilt around deep learning principles, which emphasize learning that is mindful, meaningful, and joyful. At each stage of the model, children observe phenomena, ask questions, make predictions, explore, run experiments, examine simple results, find cause-and-effect relationships, draw conclusions, reflect, and share what they discovered. The focus of STEM learning thus moves from producing a finished product to building understanding through direct experience and scientific thinking suited to young children's development.

The second contribution is that scientific literacy is targeted in every phase of learning instead of being measured only after the STEM activity ends. Each activity is linked to indicators of early childhood scientific literacy: observing, recognizing, classifying, predicting, carrying out simple experiments, explaining cause and effect, drawing conclusions, and communicating observations. In this way the STEM process helps children gain knowledge, science process skills, critical thinking, and the ability to apply what they know in real situations.

The study is new in three respects. Conceptually, it brings deep learning principles into STEM education. Pedagogically, it develops a STEM syntax that fits the characteristics and

learning needs of young children. Empirically, it produces a model designed specifically to strengthen early childhood science literacy. The aim is a STEM framework in which children complete science and engineering tasks, experience mindful, meaningful, and joyful learning, and develop scientific literacy from an early age.

Deep learning and STEM both center on exploration, problem solving, and making meaning, which is why a model combining them is promising for early science literacy. Each experiment is followed by reflection and analysis. Besides following the teacher's instructions, children are expected to understand what they are doing and why something happens. This is consistent with recent findings on preschoolers at the preoperational stage, who build knowledge gradually by handling concrete objects and events and learn best from instruction designed with this stage in mind (Maharani et al., 2023).

In practice, children might build a bridge from ice cream sticks, make a simple windmill, watch plants grow, or put together a rain gauge. During each activity the teacher asks questions such as "what happened?", "why did this happen?", and "how can we make it better?" These questions encourage higher-order thinking and help children connect science concepts to daily life. Problem-based learning research shows that this kind of open, evidence-seeking questioning has a consistent positive effect on critical thinking across levels of education (Liu & Pásztor, 2022).

When children build boats from scrap materials, for example, they learn about shapes and materials and also begin to understand density, buoyancy, and thrust. Testing the boats in water requires them to observe, predict, and evaluate, which are core parts of science literacy. Deep learning follows when the teacher asks them to think about what they found. Studies of exploration-based learning models also report measurable gains in cognitive development and creativity among children aged 4 to 5 who regularly get reflective opportunities to experiment (Nurjannah, 2023).

Implementing such a model requires specific teaching skills. Teachers have to design activities that lead to meaningful learning while keeping play as the main method, and they have to guide children with open-ended questions as facilitators. Evidence from ICT-assisted guided inquiry shows that teachers can learn curiosity-driven questioning (Irdalisa et al., 2021), and training studies show that structured STEAM workshops for science teachers measurably improve this facilitation capacity (Irdalisa et al., 2022). Even so, several studies indicate that many PAUD teachers in Indonesia struggle to integrate STEM, and combining it with deep learning is harder still. Teachers therefore need a systematic learning model that is easy to use.

A model like this would also benefit teachers and schools. Teachers would gain skill in designing new kinds of lessons, and schools would have an approach that matches the national curriculum. The Kurikulum Merdeka (Freedom Curriculum) makes project-based learning and exploration key priorities. Recent studies of its rollout in PAUD institutions show that project-based learning has become a main channel for STEAM and inquiry-oriented experiences, although quality varies between schools and depends heavily on teacher readiness (Munawar, 2022; Nursalam et al., 2023; Rasmani et al., 2023). Evaluations of curriculum implementation find that the policy direction is sound but that differentiated learning, project management, and teacher mentoring are still uneven across regions (Fitrianingtyas et al., 2025; Lestari, 2024; Nofitasari et al., 2023; Noer Ashfarina & Tri Wijayati, 2023; Rasmani et al., 2024; Retnaningsih & Khairiyah, 2022; Zakso, 2022). Analyses of the curriculum's differentiated and individualized principles suggest that the reasoning behind the reform at higher levels of

education applies directly to PAUD (Anggraini et al., 2022; Aslina & Hidayah, 2025; Komari & Aslan, 2025). How well parents understand this holistic, project-based curriculum also affects how well these initiatives work at home and at school (Ramadhani, 2022).

Based on the needs analysis and previous research, the researcher designed the framework for the Deep Learning-Based STEM Learning Model to Improve Early Childhood Science Literacy shown in Figure 1.

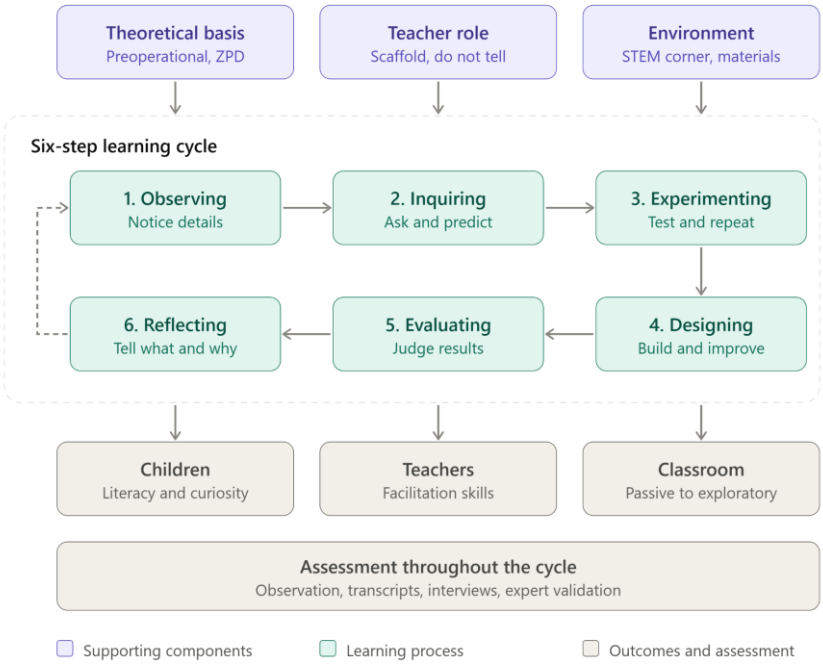


Figure 1. Learning Model Framework

Figure 1 shows the framework of the model, which rests on three supports: a learning environment with a STEM corner and materials for exploration, a teacher who acts as a facilitator and provides scaffolding, and a theoretical basis in the preoperational stage and the zone of proximal development (ZPD). Learning proceeds in six steps: observing, questioning, experimenting, designing, assessing, and reflecting. Assessment takes place throughout the cycle through observations, transcripts, interviews, and expert validation. The intended outcomes are stronger scientific literacy and curiosity in children, better facilitation skills in teachers, and a more exploratory learning environment.

METHODS

This study used the ADDIE development model, which consists of analysis, design, development, implementation, and evaluation, to build a deep learning-based STEM learning model for young children aimed at improving their scientific literacy. In the analysis stage, the researcher identified learning needs, the characteristics of young children, current STEM practice in early childhood education (PAUD) units, children's initial scientific literacy, teacher competencies, and the media and learning resources available. This stage also examined why children's scientific literacy was low, for example because they had few opportunities to experiment, solve problems, explore, and reason from observation. The results of the analysis determined the features of the model.

The design stage produced the conceptual blueprint of the model: learning objectives, model characteristics, learning syntax, the roles of teachers and children, materials, media,

STEM activities, and instruments for assessing scientific literacy. Deep learning principles were built in through mindful, meaningful, and joyful learning, so that during the activities children would observe, ask, explore, experiment, discover cause and effect, share results, and reflect in simple ways. The design also relied on play and concrete experiences to suit the development of five- and six-year-olds.

In the development stage, the design became a learning product made up of the model syntax, teacher guidelines, learning resources, STEM media, child-friendly activities, and scientific literacy instruments. Experts in early childhood education, STEM education, deep learning, and scientific literacy validated the product. Their feedback was used to revise it so that the final model was feasible, had a clear syntax and sound content, and was appropriate for young children.

In the implementation stage, the model was used with young children in real classrooms. While children worked on STEM tasks, the teacher acted as a facilitator who encouraged them, asked questions that made them think, gave them room to inquire, and helped when needed. Children observed events, identified simple problems, tried out options, worked with concrete objects and materials, tested ideas, and shared their results. Implementation could involve limited trials and field trials to assess the model's practicality and effectiveness.

Evaluation was both formative and summative. Formative evaluation took place at each development stage to find and fix weaknesses in the model. Summative evaluation followed implementation and assessed how far the model improved children's scientific literacy. The aspects observed were the ability to observe, identify, classify, predict, carry out simple experiments, explain cause and effect, solve simple problems, draw simple conclusions, and communicate observations. The evaluation results were used to finalize a feasible, practical, and effective model.

The subjects were children aged 5 to 6 in PAUD units. At this age, children's cognitive development and exploratory skills allow them to observe, ask questions, experiment, compare, classify, solve simple problems, and share observations, which fits the deep learning principles and STEM activities designed for the study.

PAUD teachers also took part, first as informants in the needs analysis and later as users of the model during implementation. The children, however, were the main subjects for assessing the model's feasibility and its effect on scientific literacy. PAUD units were selected purposively based on the children's characteristics, the availability of activities that support STEM, support from teachers and the school, and the school's willingness to participate.

Data were analyzed qualitatively and quantitatively according to the ADDIE stages. Observations, field notes, documentation, interviews, and validators' comments and suggestions were analyzed qualitatively through data reduction, classification, display, interpretation, and conclusion drawing. Expert validation data, practicality data, and effectiveness data were analyzed quantitatively. Validation and practicality data were converted to percentage scores to judge the feasibility and practicality of the product.

Effectiveness was assessed by comparing children's scientific literacy before and after implementation, with gains calculated using the N-Gain score. Pretest and posttest scores were compared with a paired-sample t-test if the data were normally distributed and with the Wilcoxon signed-rank test if they were not. The quantitative results were interpreted together with the qualitative findings to describe the model's validity, practicality, implementation, and

effectiveness. The product was considered final once it met the criteria of being valid, practical, and effective in improving early childhood science literacy.

RESULTS AND DISCUSSION

Results

The model was trialed for four weeks with Group B (ages 5–6) at an early childhood education center in Sukabumi, West Java, with 23 children, two teachers, and the principal taking part. It has six steps: observing, asking questions, experimenting, designing, assessing, and reflecting. Data came from direct observation, children's work, recordings of experiments, discussion transcripts, and interviews with teachers, the principal, and parents. Children's science literacy improved in observation, questioning, experimentation and problem solving, reflection, and collaboration.

Table 1. Development of Core Science Literacy Indicators

Indicator	Pre-implementation	Post-implementation
Observation (naming ≥2 characteristics)	30% (7/23)	78% (18/23)
Questioning (questions per session)	11	34–38
Experimentation and problem-solving	26% (6/23)	74% (17/23)
Scientific reflection	22% (5/23)	83% (19/23)
Explaining cause–effect relationships	17%	61%

Before the intervention, most children looked at phenomena only briefly. After it, they noticed changes in shape, direction, movement, texture, and size. During the "Flowing Water" activity, one child said, "If the path is very sloppy, the water goes down quickly. It is slow if it is somewhat flat." In "Mini Windmill," another child compared two windmills: "The one made of thick paper rotates slower than the one made of thin paper." No comparisons like these appeared in the pretest. In the "Water and Motion" session, 8 of the 23 children could identify why the water flowed downward, while 15 reasoned that "the water came down because gravity was strong."

At the start, each session produced only about 11 questions, mostly factual ones such as "what is this for?" or "can I take it?" By the end of the trial, children asked 34–38 questions per session, many of them predictive or exploratory: "If I blow it harder, will the fan go faster?", "Why did the straw bridge collapse but the ice cream stick one?", and "If the balloon is two, can the car go farther?" Teacher A said: "The kids usually wait for me to give them instructions. They now genuinely inquire first. Occasionally, the question even causes me to reconsider." (December 13).

Experimentation and problem solving showed the largest gains. In the "Balloon Car" activity, children built cars from straws, cardboard, and balloons and tried different wheel designs and balloon positions over several rounds. One transcript recorded this exchange:

Child: "Mom, the cardboard wheel is not straight, it is shaking."

Teacher: "Why do you think so?"

Child: "Because the shape is not round. The bottle cap is rounder." (Observation Transcript, December 16)

Teacher B: *" They seek for ways to thicken the straw bridge right away if it is weak. They have begun experimenting without waiting for my guidance."* (December 18).

Each session closed with a reflection. After the "Windmill" activity, one child said: "I was blowing tightly, so it was playing fast. If it's slow, it's slow. So the strong winds make him go faster." (December 17). By the end of the cycle, 19 children (83%) could say what they had done, what happened, and why.

In the "Balloon Rocket" activity, 95% of the children recognized the link between air escaping and the balloon moving, and 60% could explain it in their own words. According to the field notes, one child said, "Because the wind is coming out fast, then the balloon is moving forward!" and another added, "If the wind is little, the road is short, ma'am." In "Plants and Light," six-year-old Child F compared seedlings grown in light and in darkness: "The one in the light grows tall." The child went on to explain that the seedlings kept in the dark did not grow because they received no sunlight, and that plants need light to survive. Table 2 shows gains on all explanatory indicators.

Table 2. Development of Explanatory and Argumentative Skills

Indicator	Pre (%)	Post (%)
Explaining differences	35	88
Stating causes	22	79
Summing up results	18	72

Non-cognitive indicators also rose (Table 3), and children started taking the initiative. Child S (age 5), for instance, asked, "Mom, if the rope is tilted, can the balloon turn?" and a classmate replied, "Just try it, let's test!" Collaboration improved too. Children who used to work alone and did not want to share tools began talking with each other, dividing roles, and commenting on each other's work: "Having Dinda is stronger because two sticks are installed. I only have one." (Observation, December 19).

Table 3. Indicators of Scientific Behavior

Indicator	Pre (%)	Post (%)
Curiosity	41	89
Willingness to try	48	87
Repeating experiments	32	79
Asking questions	25	68

Teacher A noted that the children were "more courageous to express their opinions" and sometimes came up with ideas "more creative than I thought" (December 13). Teacher B had

once doubted that young children could grasp ideas like motion or air pressure. After seeing that "they can learn through real experiments" (December 18), this teacher moved from explaining concepts to letting children work them out: "now the child finds it first, I just guide." Teacher C said: "I have become accustomed to asking 'why do you think so?' instead of telling them directly." Teachers A and B agreed that the model made learning more meaningful, spontaneous, and contextual. The principal saw it as consistent with the Kurikulum Merdeka's emphasis on project-based learning and exploration, and noted that it fostered "cooperation, perseverance, and independence" (December 21). Most parents said their children had become more curious and critical at home. One parent said: "Now if it rains, my son says he wants to see why the water is coming into the sewer." (Parent B, December 22).

The teachers set up a STEM corner, used simple materials (pipettes, water, balloons, glasses, cardboard, leaves), and documented activities with photos and recordings. Teacher A explained: "When the children saw photos of the experiment last week, they immediately remembered what they found. It makes reflective discussions more lively."

The trial also had difficulties. Preparing equipment and materials took a long time. Not every child was used to reflecting, so teachers had to model it at first, and the exploratory activities meant more movement around the classroom, which required tighter classroom management. Expert validation gave an average score of 89.7%, which puts the model in the "very feasible" category. One validator who teaches early childhood science commented: "This model is good because it not only invites children to experiment, but also to think about what they are doing." (Validator 2).

DISCUSSION

The results show improvements in children's science literacy, in teaching practice, and in the learning process. They are discussed below in relation to deep learning theory, STEM education, and early childhood education.

Deep Learning-Based STEM Creates More Meaningful Learning Experiences

Besides handling materials, the children were thinking, predicting, testing, and explaining. This is consistent with research showing that hands-on activities sharpen young children's attention to and reasoning about observable phenomena (Rani & Suvidha, 2022), and that learning becomes meaningful when children connect ideas, weigh evidence, and apply what they understand in new situations (Nugroho & Amalia, 2022). Teacher A's remark that children now ask "why is the water fast?" instead of just playing with the water shows the kind of curiosity that science literacy depends on. Well-designed learning resources can also help children engage mentally with everyday phenomena (Martinez & Chen, 2022). The model appears to help children understand concepts and not only remember them.

Structured Exploration Supports Conceptual Understanding

The cycle of observing, asking, trying, analyzing, and concluding resembles inquiry frameworks for preschool science, which treat observation, questioning, experimenting, and reflection as the recurring elements of inquiry at this age (Ramanathan et al., 2022). In the "Balloon Rocket" discussion, children reached the idea of thrust by reflecting on what they had seen, without being given a definition. A similar pattern has been found in home science activities where parents scaffold learning and use causal, explanatory talk (Karnani et al., 2023;

Lin et al., 2023). The finding also agrees with preoperational-stage theory, according to which children build knowledge by interacting with concrete objects (Maharani et al., 2023), and with research on the zone of proximal development showing that well-calibrated support from teachers and peers speeds up the internalization of concepts (Kurniawan et al., 2022). Compared with demonstration-based teaching, the approach seems to support conceptual development better.

Growth in Questioning, Experimentation, Reflection, and Explanation

The rise in spontaneous, predictive questions agrees with findings that structured questioning routines in guided inquiry build curiosity-driven inquiry over time (Irdalisa et al., 2021). The children kept going through trial and error despite their age, which echoes problem-based learning research linking repeated, evidence-seeking experimentation to stronger critical thinking (Liu & Pásztor, 2022; Mardhani et al., 2022). Reflective experimentation has also been shown to benefit cognitive development and creativity in children aged 4 to 5 (Nurjannah, 2023). The children's reflections show early signs of deep learning in the form of meaning making and reflection. In the "Plants and Light" explanation, for example, a child linked direct experience to a scientific principle, which is how cognitivist accounts describe children connecting observation with cause (Basyir et al., 2022). The gains in Table 2 are also consistent with studies linking curiosity, creativity, and motivation to better explanatory ability (Mahama et al., 2023). By the end of the trial, children had started to connect causes with effects, evaluate their findings, and offer simple scientific arguments, which form the basis of twenty-first-century science literacy.

Curiosity, Courage to Experiment, and Independence

The behavioral gains in Table 3 suggest that the model shapes a scientific mindset as well as scientific knowledge. Children's self-initiated tests fit the evidence on hands-on learning (Rani & Suvidha, 2022) and exploration-based models (Nurjannah, 2023). Parents' reports of curiosity at home match findings that a supportive home science environment predicts later scientific literacy (Bae et al., 2023) and that responsive parenting nurtures epistemic curiosity (Iwasaki et al., 2023), which suggests that science literacy keeps growing outside school. This mindset also develops across the different cognitive profiles found at this age (Lestari et al., 2023; Permata & Wibowo, 2022). The improved collaboration indicates that group-based STEM work strengthens social skills along with scientific ones.

Teachers Become Better Facilitators

Teachers moved from explaining concepts to guiding discovery. They asked "why do you think so?" and supported learning with lighter questions, facilitated discussion, gentle direction, and prompts for reflection. Similar shifts toward facilitation have been reported among teachers with sustained exposure to inquiry-based STEM models (Movahedazarhouligh et al., 2023), and structured support has been found to make kindergarten STEM teaching more consistent and confident (Wu & Huang, 2023). Well-timed scaffolding closes the gap between what children can do alone and what they can do with guidance (Kurniawan et al., 2022). Teachers develop this capacity over time through training and communities of practice (Chen et al., 2021; Weinberg et al., 2021), as Indonesian studies of project-based learning (Ringotama et al., 2022) and work on the challenges of early-years STEM pedagogy (Leung, 2023) also show. The model therefore supports the professional growth of PAUD teachers in addition to children's

science literacy. The difficulties reported earlier (preparation time, modeling reflection, and classroom management) are practical demands of this shift and did not reduce the model's effectiveness.

The Learning Environment Sustains Deep Learning

Simple materials, a STEM corner, and photo documentation made reflection more engaging and kept children involved in the scientific process. Research shows that inexpensive natural and recycled materials can enrich PAUD science environments without costly equipment (Nurhayati, 2021), and that well-designed digital or interactive tools can further support reflection when used properly (Campos & Muñoz, 2023; Canbeldek & Isikoglu, 2022; Dewi et al., 2021).

Feasibility, Effectiveness, and Alignment with Kurikulum Merdeka

The expert validation score of 89.7% supports the model's theoretical soundness, since STEM, inquiry, and deep learning fit young children's needs. Teachers also found experiment-based learning easier to carry out, which points to practicality, and the gains in science literacy point to effectiveness. The model's combination of inquiry and critical thinking follows the project-based, exploration-oriented direction the Kurikulum Merdeka sets for PAUD (Fitrianingtyas et al., 2025; Munawar, 2022; Nursalam et al., 2023; Rasmani et al., 2023). Implementation studies show that such practices are adopted more easily when parents understand them, planning is individualized, and mentoring is consistent (Afif et al., 2022; Anggraini et al., 2022; Aslina & Hidayah, 2025; Komari & Aslan, 2025; Lestari, 2024; Nofitasari et al., 2023; Noer Ashfarina & Tri Wijayati, 2023; Ramadhani, 2022; Retnaningsih & Khairiyah, 2022; Zakso, 2022). Classroom STEAM studies in Indonesian PAUD also show that project-based science and creativity activities are feasible and well received (Ayuningsih et al., 2022; Azizah et al., 2023; Fitri & Suryana, 2022).

CONCLUSION

The deep learning-based STEM learning model improved early childhood science literacy in observation, questioning, experimentation and problem solving, reflection, and collaboration and scientific communication. Classroom learning also became more active and exploratory, with less direct instruction. The model can be recommended as a more scientific, in-depth, and contextual option for early childhood learning.

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