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Enhancing Scientific Process Skills through Clay-Based Learning Media: An Early Childhood Science Learning Strategy on the Thematic Unit "The Universe"

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Abstract

This study examined the development and implementation of clay-based experimental media to support early childhood science learning on the theme of the universe. Although early science education has received increasing attention, young children often struggle to understand abstract astronomical concepts because they lack access to tangible, developmentally appropriate learning materials. This study addressed this issue through the integration of art-based, hands-on inquiry activities that emphasize sensory exploration as a basis for conceptual understanding. A descriptive qualitative design was conducted in an early childhood education setting in Makassar, Indonesia, involving seventeen informants consisting of two early childhood teachers, ten children aged five to six years, and five parents. Data were collected through classroom observations, semi-structured interviews, and document analysis. The research focused on the process of designing and applying clay-based models of the sun, Earth, moon, and stars to simulate day and night through guided experimentation in a play-based learning environment. The findings indicate that children engaged with concrete representations of astronomical phenomena, demonstrated sustained participation in learning activities, and expressed emerging explanations of light, darkness, and Earth's rotation. The learning process was also characterized by increased teacher–child interaction during inquiry-oriented discussions. Supporting factors included teacher creativity, the accessibility of low-cost materials, and children's interest in manipulative activities, while constraining factors involved limited instructional time and variation in teachers' prior experience with arts-integrated science learning. This study contributes to broader debates on early childhood science education by illustrating how low-cost, tactile learning materials mediate children's engagement with abstract scientific concepts across early learning contexts in resource-limited educational settings.

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Introduction

Science learning in early childhood is widely recognized as a foundational element in developing children's scientific thinking, curiosity, and inquiry skills. Rather than serving merely as an introduction to factual knowledge, early science learning supports cognitive development by strengthening memory, reasoning, and analytical abilities that underlie logical thinking (Churiyah & Ruqoyyah, 2024; Izzuddin, 2023). At the same time, science activities that emphasize direct engagement enable children to develop motor skills through hands-on, exploratory experiences (Andari et al., 2022). Interaction with natural objects and phenomena allows children to construct meaning through experience, making learning more concrete and relevant to their everyday lives. Furthermore, the orientation of early science learning toward higher-order thinking skills, such as problem-solving, reasoning, and innovation, aligns with the competencies required in the 21st century (Hartono et al., 2022; Setyawarno & Kurniawati, 2022).

In early childhood education, science learning not only enhances logical and observational skills but also nurtures curiosity through play-based and inquiry-oriented approaches. These approaches position children as active learners who explore, question, and reflect on their experiences rather than passively receiving information (Andari et al., 2022; Wiguna et al., 2023). Play-based science activities have been shown to create joyful learning environments while maintaining conceptual depth and meaning (Kasmiati, 2024). The integration of STEAM further expands children's learning experiences by connecting science, technology, engineering, the arts, and mathematics holistically (Wiguna et al., 2023). Topics related to earth and space science are particularly relevant because they are closely linked to children's daily observations and contribute significantly to the development of early science literacy (Anawaty & Iftitah, 2023; Choiriyah et al., 2021).

Despite its potential, the implementation of science learning in early childhood education is influenced by both supporting and inhibiting factors. Research highlights that rich learning environments, parental involvement, and teachers' roles as facilitators of exploration are key supporting elements in effective science learning (Bjerknes et al., 2024; Fragkiadaki, 2023; Goulart et al., 2022). In contrast, premature academic demands often shift the focus of science learning away from exploration toward rote instruction. Limited teacher training in developmentally appropriate science methods and the scarcity of engaging learning media further constrain meaningful learning experiences (Guarrella et al., 2023; Hirst-Bernhardt & Almasi, 2022; Tin, 2023). These challenges are particularly pronounced in resource-limited early education settings, where access to affordable, safe, and child-friendly learning materials remains restricted (Dominguez & Stephens, 2022).

To address these challenges, various learning media have been developed to support early childhood science education, ranging from simple experiments using ice and balloons to natural indicators such as butterfly pea flower extract (Azra & Sankari, 2022; Harahap et al., 2022; Hasan & Anwar, 2022). More recently, thematic media such as *Galaxy Gifts* have been introduced to help children understand concepts related to the universe (Syarfina et al., 2024). These media have demonstrated effectiveness in enhancing children's understanding of scientific concepts. However, their implementation often depends on the availability of specialized materials and teachers' technical expertise. This dependency limits the scalability and accessibility of such media, particularly in early childhood education settings with limited resources.

In this context, the use of readily available materials, such as clay, offers considerable potential for early childhood science learning. Clay is a relatively low-cost, flexible medium that can be adapted to various learning objectives and contexts (Nirwana et al., 2019; Riska, 2019). Through clay-based activities, children actively engage in shaping, modifying, and representing objects, making abstract concepts more tangible. This form of engagement supports experiential learning while accommodating diverse learning styles. As such, clay emerges as a practical alternative for addressing the limitations teachers commonly face when implementing science learning media in early childhood classrooms.

Clay-based media provide tactile, creative, and constructivist learning experiences that align with STEAM and early childhood science education principles. Clay can be produced from locally available materials such as flour, starch, and natural colorants, enabling its use across diverse early childhood education settings (Ulfa et al., 2021). Through modeling activities, children can visualize and manipulate representations of natural phenomena, fostering both conceptual understanding and fine motor development. These processes support learning through active construction rather than passive reception. Nevertheless, empirical studies that specifically examine the use of clay as a medium for teaching earth and space science concepts, particularly the day–night phenomenon, remain limited. Previous research has focused mainly on thematic experimentation, with insufficient attention to material accessibility and adaptability (Syarfina et al., 2024).

In response to these gaps, the present study introduces clay-based media as a simple, accessible, and developmentally appropriate alternative for early childhood science learning. The approach integrates constructivist, experiential, and STEAM-based principles to support children's exploration of the day-night phenomenon through modeling and simple experimentation. Specifically, this study aims to describe the process of preparing clay experimental materials representing the sun, earth, moon, and stars. It also examines how simple experimental methods are applied to explain the day–night phenomenon to young children. Additionally, the study seeks to identify the supporting and inhibiting factors influencing the implementation of clay-based science learning. The findings are expected to contribute to the development of contextual, engaging, and low-cost science learning media and to enrich the early childhood science education literature with a pedagogical model that bridges theoretical understanding and classroom practice.

Methods

Research Design and Paradigm

This study employed a descriptive qualitative research design grounded in a constructivist–interpretivist paradigm, which emphasizes understanding the meanings and experiences participants construct within their natural contexts. This paradigm was selected to explore how teachers, children, and parents experience and interpret science learning activities using clay-based media. The approach enabled the researchers to capture the contextual realities of early childhood education as they unfold in authentic learning environments. A qualitative design was considered appropriate because it allows for an in-depth examination of interactions, perceptions, and learning processes rather than focusing on numerical measurement of outcomes (Clarke-Midura, 2021; Creswell & Creswell, 2018).

Research Setting and Participants

The research was conducted in a kindergarten located in Makassar, South Sulawesi, Indonesia, during the second semester of the 2024/2025 academic year. This setting was selected due to its active implementation of play-based science learning approaches in daily classroom practices. Participants included two early childhood teachers, ten children aged 5–6 years (five boys and five girls), and five parents involved in classroom-based or home-supported science activities. The inclusion of multiple participant groups enabled a more comprehensive understanding of the learning process from pedagogical, experiential, and familial perspectives.

Sampling Technique and Criteria

A purposive sampling technique was used to select participants based on predefined inclusion criteria relevant to the study objectives. The criteria included teachers with at least 3 years of experience in early childhood education, children who regularly participated in science-related learning activities, and parents who were actively involved in school–home collaboration programs. These criteria ensured that participants had sufficient exposure to the learning context under investigation. Children with special educational needs requiring individualized learning programs were excluded, as the study focused on interactions within mainstream early childhood classrooms.

Ethical Considerations

Ethical approval for the study was obtained from the Institutional Review Board of Universitas Islam Makassar. Informed consent was secured from all adult participants, including teachers and parents, prior to data collection. Assent from children was obtained through age-appropriate explanations that emphasized voluntary participation. Confidentiality was maintained by assigning pseudonyms to all participants, and all research data were securely stored and used solely for academic purposes.

Data Collection Procedures

Data were collected over six weeks using multiple qualitative techniques to ensure depth and triangulation. Participant observation was conducted during five science learning sessions, each lasting approximately 60–90 minutes, to document children's engagement, interactions, and responses during clay-based activities. Semi-structured interviews were conducted with

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teachers and parents to gain insight into their perceptions of science learning, media utilization, and challenges encountered during implementation. Each interview lasted between 30 and 45 minutes, was audio-recorded with consent, and transcribed verbatim. Documentation analysis included lesson plans, children's clay products, photographs, and reflective teacher journals, which served as supplementary data sources to strengthen analytical rigor. Each data collection method fulfilled a distinct analytical function, with observations capturing behavioral engagement, interviews revealing reflective understanding, and documentation verifying patterns across sources.

Data Analysis

Data analysis followed the six-phase thematic analysis framework proposed by Braun and Clarke (2021). The process began with familiarization through repeated reading of field notes and interview transcripts. Initial codes were generated to identify salient features of science learning practices and the use of clay-based media. These codes were organized into potential themes representing recurring patterns, such as tactile engagement, teacher facilitation strategies, and material accessibility. Themes were reviewed and refined to ensure internal coherence and conceptual distinctiveness before being clearly defined and named. The final phase involved producing an integrated narrative supported by direct quotations and triangulated evidence. To enhance analytical clarity, the data analysis process was complemented by the framework of Miles et al. (2014), particularly in guiding data condensation, data display, and conclusion drawing, without overlapping conceptually with thematic analysis.

Trustworthiness of the Study

To ensure the trustworthiness of the findings, several strategies were implemented in accordance with established qualitative research criteria (Anderson et al., 2014). Credibility was enhanced through triangulation of data sources, including teachers, children, and parents, as well as member checking to confirm interpretive accuracy. Transferability was supported by providing thick descriptions of the research context, participant characteristics, and classroom conditions. Dependability was ensured through the maintenance of an audit trail documenting all stages of data collection and analysis. Confirmability was addressed through reflexive journaling and peer debriefing to minimize researcher bias. The researcher's positionality as a university lecturer and early childhood education practitioner provided contextual familiarity while necessitating continuous reflexive awareness to maintain analytical neutrality.

Result

Process of Media Production

The Process of Making Flour-Based Clay Media

The process of creating flour-based clay media was implemented through a series of systematic and participatory steps that teachers and children could easily replicate. This medium served as both a creative material and a pedagogical tool for understanding basic astronomical phenomena such as day and night cycles. The development of clay-based media followed three primary stages: ingredient preparation, coloring, and modeling and assembling.

Ingredient Preparation Process

Table 1 summarizes the main components used in the production of flour-based clay.

Table 1. Elemental Composition of Flour-Based Clay

No	Material	Quantity
1	Flour	80 gram
2	Tapioca flour (or starch flour)	80 gram
3	Rice flour	80 gram
4	Benzoate (as a food preservative)	1 gram
5	White glue	200 gram

All ingredients were combined in a clean container and kneaded by hand until the dough reached a soft, elastic, and non-sticky consistency. This stage extended beyond a technical preparation process and functioned as an initial pedagogical experience that activated children's sensory awareness and engagement. High levels of enthusiasm were observed, reflected in children's spontaneous references to the material as "magic clay," which can be interpreted as an early expression of curiosity and imaginative engagement. The direct manipulation of the dough encouraged children to explore texture, pressure, and movement through their hands. Such interaction positioned the preparation phase as an experiential entry point to learning rather than a preliminary task.

The combination of three types of flour produced a texture that was both soft and structurally stable, enabling safe motor exploration while supporting intentional manipulation. This balance allowed children to develop procedural understanding by experiencing clear cause-and-effect relationships during kneading and shaping. From an interpretative perspective, these tactile interactions reinforced the role of sensory-rich activities in strengthening early conceptual foundations in science learning (Fragkiadaki et al., 2023; Eshach & Fried, 2005). The preparation process thus functioned as an integral learning phase, linking play-based manipulation with emerging scientific reasoning. This interpretation supports the research objective regarding the feasibility and pedagogical value of developing materials for early childhood science learning contexts.

Coloring Process

Children participated in the coloring stage using food dyes or poster paint. The activity evolved into a sensory experiment in which children discovered the relationship between color intensity and dye concentration. For instance, when too much dye was added, the clay became sticky and lost its shape. Teachers guided the children in adjusting proportions, turning the activity into a discussion about "cause and effect." A teacher noted, "It is amazing how quickly they realized that color can change the texture—one child said, 'too much red makes it mushy!'" This observation reflects active hypothesis testing and self-correction among the children. These findings support the second research objective by demonstrating that clay media stimulates exploratory behaviors that parallel early scientific inquiry, in which observation and adjustment are central learning processes.

Modeling and Assembling

Children used basic shapes—round, oval, and waterdrop patterns—to form celestial models such as the sun, earth, moon, and stars. Teachers provided minimal intervention to maintain child agency while scaffolding concept accuracy. For example, "the sun is yellow with rays," while "the earth has blue and green patches." Teachers and parents interviewed reported similar impressions: "When the children created the earth, they talked about land and sea as if they were explaining geography. It shows that clay encourages them to reason scientifically." (Parent interview, Group B). The activity integrated creativity, fine motor skills, and cognitive reasoning simultaneously. The modeling phase validates the effectiveness of flour-based clay in facilitating conceptual transfer—from tangible manipulation to abstract understanding of celestial structures.

Implementation of a Simple Science Experiment

Early Observation and Knowledge Activation

The experiment began with guided observation, where children identified their clay models and described their characteristics. Teachers employed open-ended questioning to activate prior knowledge, such as "Why is the moon gray?" or "What happens when the sun disappears?" Observation data showed that 87% of children could correctly name at least three celestial bodies and relate them to their daily experience (e.g., "I sleep when the sky is dark"). These initial expressions indicated baseline understanding before experimentation.

Motion and Position Simulation

Using a flashlight as the sun and clay balls as the Earth and the Moon, children simulated the Earth's rotation. They noticed that one side became bright while the other remained dark. Teachers guided them to connect this with the day–night cycle. An excerpt from a classroom dialogue illustrates comprehension:

Child: "The sun does not move; the earth is spinning!"

Teacher: "Yes, that is right. When the earth turns, what happens on the other side?"

Child: "It becomes night!"

Such moments reflect genuine conceptual shifts—from perceptual observation to logical reasoning. Teacher follow-up interviews confirmed that children who manipulated the clay models more actively displayed stronger verbal reasoning about natural phenomena. Member checking between teacher observations and parent reports validated these interpretations, ensuring data credibility. These findings confirm the third research objective—that flour-based clay media effectively supports young children's comprehension of natural phenomena through tangible experimentation and guided reflection.

Discussion and Reflection

After conducting the simulation, the teacher invites the children to discuss what they see and feel during the activity. Children are encouraged to express their opinions in simple sentences, such as the questions "If the earth rotates in this direction, day becomes night, ma'am?" and "If we are on the dark side, does it mean night, ma'am?" This discussion strengthens children's understanding while training their communication skills. Teachers can continue by strengthening the concept by embedding a human miniature on one of the Earth's that depicts the existence of children.

Expressive Activities

As part of the expressive activity, children are allowed to convey their understanding of the phenomenon of day and night. The content of children's stories and understanding can be seen in the following table 2 :

Table 2. Children's Story Content and Understanding

No	Children's Stories	Understanding Category
1	"If it is light here, it is day; the back is dark, that is night."	Spatial–causal reasoning
2	"The sun does not go anywhere; the earth spins."	Scientific causality
3	"Morning, afternoon, night, then morning again."	Temporal sequencing
4	"The moon goes around, too."	Orbital reasoning
5	"At night the moon shines; during the day we play."	Associative reasoning

The expressive activities reveal that children's verbalizations function as indicators of emerging scientific reasoning rather than simple repetitions of observed phenomena. Statements about light and darkness, rotation, and daily sequences demonstrate that children are beginning to construct causal explanations grounded in their experiential interactions with the clay models. These responses indicate an ability to coordinate the spatial, temporal, and causal dimensions simultaneously, a significant cognitive achievement at the early childhood level. The articulation of ideas such as the earth's rotation or the alternation of day and night suggests that children are not merely naming objects but are engaging in relational reasoning. From an analytical perspective, this finding supports the argument that expressive storytelling serves as a cognitive bridge between concrete manipulation and abstract scientific concepts.

Furthermore, triangulated evidence from field notes and video transcripts indicates that conceptual understanding, motor–sensory engagement, and imaginative expression operate as interconnected learning processes rather than isolated outcomes. The manipulation of clay sustained children's attention and embodied their thinking, anchoring abstract ideas in physical action. At the same time, imaginative storytelling enabled children to internalize scientific explanations, strengthening conceptual coherence emotionally. Interpreted through a sociocultural lens, these processes illustrate how learning emerges through mediated interaction, where tools, language, and social dialogue collectively shape understanding (Vygotsky, 1987). Consequently, clay-based expressive activities can be understood as pedagogical mechanisms that integrate imagination and reasoning, transforming playful expression into a meaningful pathway for early scientific sense-making.

Supporting and Inhibiting Factors

Supporting Factors

Empirical data indicate that high levels of child engagement functioned as a central enabling condition in the implementation of clay-based science learning. The observation that 92 percent of children actively participated across all learning stages suggests that engagement was not incidental but structurally produced through interaction with the material. Children who were typically passive became visibly curious once tactile contact with the clay occurred, indicating that engagement emerged through embodied interaction rather than verbal instruction alone. This pattern implies that learning participation is closely tied to the affordances of the learning medium. Such findings align with evidence that hands-on, inquiry-based environments promote early scientific literacy through active engagement and multimodal interaction (Eshach & Fried, 2005).

In addition to child engagement, teacher–parent collaboration and material flexibility operated as reinforcing enablers within the learning process. Joint preparation of materials extended the learning ecology beyond the classroom and supported continuity between school and home contexts. The adaptable nature of clay enabled children to externalize understanding through both visual and physical representations, accommodating diverse expressive tendencies. Data indicate that this flexibility allowed children to move between manipulation, observation, and expression without rigid constraints. These conditions collectively supported integrated learning outcomes, particularly during expressive and simulation phases, where conceptual reasoning, motor–sensory engagement, and imaginative expression converged. Such integration resonates with findings that structured, hands-on play supports scientific sense-making through embodied and narrative experiences (Fleer, 2021; García-Rodeja et al., 2024; Yilmaz et al., 2024).

Inhibiting Factors

Despite these enabling conditions, the data also reveal several inhibiting factors that affected the flow and efficiency of learning activities. Limited supporting equipment, such as molds and placemats, caused delays and occasional frustration, disrupting the continuity of exploration. Variability in dye concentration influenced the quality and consistency of the clay, indicating that technical aspects of material preparation directly affected learning conditions. Additionally, uneven prior experience among children led to divergent activity focus, with some children focusing more on shaping the clay than on the intended scientific concepts. These findings suggest that without adequate structuring, manipulative activities risk being interpreted primarily as motor play.

Empirically, these constraints led to longer activity durations, increasing session time by approximately twelve minutes and necessitating additional scaffolding to maintain conceptual focus. However, the data indicate that these inhibiting factors did not negate children's conceptual gains but did somewhat influence learning fluency and instructional pacing. This distinction suggests that the challenges observed were procedural rather than conceptual. The findings point to a need to strengthen teacher capacity to manage media-based science activities, particularly in aligning technical preparation with pedagogical intent. In this sense, inhibiting factors function as indicators of areas requiring refinement in facilitation practices, underscoring the importance of structured guidance and reflective iteration within early science learning design (Eshach & Fried, 2005; Fleer, 2021; García-Rodeja et al., 2024; Yilmaz et al., 2024).

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Discussion

This study provides evidence that clay-based science learning positively stimulates curiosity, concretizes scientific concepts, and creates meaningful learning experiences for young children. These outcomes reflect the operationalization of constructivist principles in early childhood science education, where knowledge emerges from children's active engagement with materials and phenomena rather than from passive instruction. The findings align with the global movement to integrate inquiry, play, and creativity in science learning for early years education. (Fleer, 2021; John, 2022).

Clay-Based Learning and the Development of Scientific Curiosity

Clay-based learning is shown to stimulate curiosity and exploration of natural phenomena by positioning children as active participants in simple experimentation and model construction. Engagement with clay serves as a mediating process through which abstract scientific ideas are translated into observable, manipulable actions, indicating the operation of sociocultural learning mechanisms (Vygotsky, 1987). When children model the solar system or simulate Earth's rotation, the activity goes beyond simple manual manipulation. It becomes an act of symbolic meaning-making that connects sensory experience with conceptual reasoning. This interaction suggests that learning emerges through the interplay between material engagement and cognitive interpretation. From an analytical standpoint, the data indicate that tactile media enable children to externalize thinking processes that would otherwise remain abstract at the early childhood level.

These findings reinforce the argument that early childhood science learning should be grounded in curiosity-driven exploration and hands-on inquiry rather than premature formalization (Andari et al., 2022; Wiguna et al., 2023). Active manipulation of materials appears to support both cognitive engagement and affective involvement, suggesting that emotional interest and conceptual understanding develop concurrently. The evidence indicates that tactile exploration promotes not only observational competence but also early metacognitive awareness, as children reflect on actions and outcomes during experimentation. Although the study is situated in a local kindergarten context, the learning patterns observed align with broader international efforts to cultivate curiosity and creativity in early science education (Plummer & Ricketts, 2023). The data therefore support the argument that sensory-based, well-scaffolded learning approaches are relevant beyond specific settings and may serve as a general strategy for fostering foundational scientific reasoning in early learners.

Clay as a Medium for Conceptual and Contextual Representation

The evidence indicates that clay media enable children to express abstract scientific concepts in concrete, contextually meaningful forms. Through modeling activities and simple experimental presentations, children were able to explain phenomena such as the rotation of the earth and the alternation of day and night using their own representations. This pattern reflects a mode of knowledge construction that relies on active sensory engagement, consistent with characteristics of the preoperational stage of development (Piaget, 1952). At the same time, the findings suggest that children's scientific reasoning is intertwined with aesthetic and expressive processes rather than being purely logical. Clay modeling, therefore, becomes a space where perception, imagination, and explanation converge in the construction of meaning.

Clay-based activities also reveal the intersection of scientific inquiry and artistic expression, aligning with the integrative orientation of STEAM education (Morari, 2023; Zhou, 2022). Inquiry-oriented and play-based interactions allowed children to explore cause–and–effect relationships, test emerging ideas, and communicate understanding through speech and bodily gestures, which are early indicators of scientific discourse (Kolb, 1984; Flegr et al., 2023). However, the findings also show that meaningful learning does not occur automatically through hands-on activity alone. Without deliberate guidance, tactile exploration risks remaining procedural and disconnected from conceptual understanding. Teacher mediation through reflective dialogue and guided questioning plays a crucial role in helping children link experience with explanation, reinforcing the importance of pedagogical scaffolding in transforming experiential play into scientifically meaningful learning (Dominguez & Stephens, 2022).

Supporting and Inhibiting Factors in Implementation

The findings indicate that several interrelated factors supported the implementation of clay-based science learning, particularly children's enthusiasm, the accessibility of locally sourced materials, and teachers' creative initiative. High levels of engagement suggest that learning environments designed with tactile and familiar materials can stimulate meaningful participation, especially in early childhood contexts. The use of locally made clay composed of flour, water, and glue proved not only economical but also culturally relevant, allowing learning activities to resonate with children's everyday experiences. Such contextual relevance reinforces the value of culturally responsive pedagogy, where learning materials are aligned with local realities rather than imported assumptions (Goulart et al., 2022; Nirwana et al., 2019). In this sense, the findings echo the view that stimulating and responsive environments play a critical role in fostering meaningful learning experiences (Bjerknes et al., 2024), while also pointing to the potential of local resources to broaden access to science education in settings with limited infrastructure.

At the same time, the study identified several constraints on implementation, including limited instructional time, insufficient teacher training, and uneven parental involvement. These constraints reflect systemic challenges rather than isolated classroom issues, particularly regarding professional development opportunities for early childhood science educators (Syarfina et al., 2024). The lack of targeted training underscores the need for integrated development frameworks that combine STEAM perspectives with play-based and inquiry-oriented pedagogies, rather than treating them as separate competencies. This concern aligns with broader discussions of the central role of teacher capacity-building in sustaining educational reform (John, 2022). The evidence further suggests that stronger systemic support, such as protected time for exploration, teacher mentorship, and structured parental engagement, could enhance the effectiveness of project-based science learning. Taken together, these findings imply that pedagogical innovation depends not only on creative materials but also on coordinated institutional and community support structures.

Interconnectedness of Curiosity, Conceptualization, and Pedagogical Support

The three thematic findings, namely curiosity, conceptual representation, and pedagogical support, can be interpreted as interrelated components within a shared learning process rather than as independent outcomes. Curiosity appears to function as an initial condition that prompts children's engagement with scientific phenomena. At the same time, clay operates as a mediating tool through which sensory experiences may be translated into emerging conceptual understanding. This process is not autonomous but is influenced by pedagogical and environmental conditions that shape how children attend to, interpret, and reflect on their experiences. In combination, these elements contribute to learning situations in which exploration is more likely to be purposeful rather than incidental.

This interaction suggests a developmental sequence in early science learning in which curiosity encourages exploratory activity, exploration provides opportunities for meaning construction, and guided reflection supports the stabilization of experience into tentative understanding. Within this sequence, tactile and creative activities do not serve solely motivational functions but also provide a contextual basis for early reasoning and sense-making. The learning pattern identified in this study indicates convergence among inquiry-oriented practices, socio-constructivist, and STEAM-related perspectives, in which material interaction, imaginative expression, and pedagogical guidance collectively shape the development of early scientific thinking.

Practical and Theoretical Contributions

The findings suggest that using low-cost, locally sourced materials, such as clay, may expand opportunities for science learning in early childhood settings and reduce reliance on commercially produced educational tools. This approach appears to be particularly relevant in resource-limited contexts, where access to specialized learning media is constrained. Rather than positioning clay as a superior medium, the study illustrates how familiar and readily available materials can be adapted to support science learning when aligned with appropriate pedagogical strategies. In this sense, the findings indicate the potential of culturally contextualized materials to function as viable alternatives within early childhood science instruction.

From a theoretical perspective, the study offers additional insight into constructivist and sociocultural frameworks by examining how tactile and art-based activities may mediate children's engagement with scientific concepts. The data suggest that sensory interaction, when guided and facilitated, can support the gradual emergence of conceptual reasoning in early childhood. These observations do not propose a new theoretical model but rather extend existing perspectives by providing empirical illustration of how material mediation and social interaction intersect in early science learning processes.

Limitations and Reflective Insights

Despite its contributions, this study is subject to several limitations that should be considered when interpreting the findings. The small number of participants and the context-specific nature of the research limit the extent to which the results can be generalized beyond similar early childhood settings. While the qualitative depth of the data supports analytical transferability, the study does not provide evidence for broader population-level claims. In addition, the absence of longitudinal observation restricts conclusions regarding the durability of children's conceptual understanding over time.

These limitations indicate directions for future research, particularly studies that examine the sustained development of scientific reasoning through hands-on and art-based learning across more extended periods and varied contexts. The findings also highlight structural challenges in early childhood education, including variability in teachers' preparation to integrate STEAM-oriented and play-based approaches into science instruction. Addressing these challenges may require coordinated efforts among teacher education institutions, policymakers, and early childhood providers to support consistent and contextually appropriate implementation. Within these constraints, the study offers a contextual account of how tactile, play-based activities can be incorporated into early science learning without overstating their scope or impact.

Conclusion

The findings indicate that the use of clay-based experimental media in early childhood science learning supports children's emerging understanding of natural phenomena, particularly the rotation of the Earth and the occurrence of day and night. Through hands-on and play-based activities, children engaged with concrete representations of abstract concepts by modeling the sun, Earth, moon, and stars using simple materials. These learning experiences aligned with young children's developmental characteristics and supported simple experimental activities facilitated by teachers. Children's participation in observation and explanation during the learning process suggests the development of early scientific reasoning. At the same time, identifying supporting and constraining contextual factors underscores the roles of pedagogical guidance and resource availability in shaping meaningful science learning experiences.

This study contributes to broader debates on early childhood science learning by illustrating how low-cost, tactile materials can mediate children's engagement with abstract scientific concepts and is relevant for contexts beyond Indonesia, as similar challenges related to resource availability and developmentally appropriate pedagogy are widely encountered in early childhood education. At the same time, the context-specific and qualitative nature of the study, along with the absence of longitudinal data, limits the extent to which broader generalizations can be made. Further research is therefore recommended to examine the longer-term development of children's scientific reasoning and to explore the integration of clay-based experimentation with other inquiry-oriented or digital learning approaches across diverse early childhood settings.

Declarations

Author Contribution Statement

Nirwana contributed to conceptualization, methodology, investigation, data curation, formal analysis, and writing the original draft. Rudi Amir was responsible for methodology, investigation, formal analysis, and writing review and editing. Sadaruddin contributed to conceptualization, validation, supervision, and writing review and editing.

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Data Availability Statement

The dataset generated and analyzed during the research is available from the corresponding author upon reasonable request.

Declaration of Interests Statement

The author declares that there are no competing interests, financial or personal, that could have influenced the work reported in this manuscript.

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