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INTERNALIZATION OF EMBODIED COGNITION IN EARLY NUMERACY COGNITIVE PROCESSES THROUGH A DEEP LEARNING APPROACH IN EARLY CHILDHOOD EDUCATION

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Abstract

This study aims to describe the internalization of embodied cognition in the development of early numeracy among young children through a deep learning approach. Employing a qualitative case study design, the research involved children aged 4–6 years and early childhood teachers engaged in numeracy learning activities. Data were collected through participant observation, semi-structured interviews, and documentation and analyzed using the interactive model of data analysis, including data condensation, data display, and conclusion drawing. The findings demonstrate that the internalization of embodied cognition occurs through children's active bodily engagement during numeracy learning. Sensorimotor experiences, including body movement, gestures, manipulation of concrete materials, and environmental exploration, facilitate children's conceptual understanding of counting, classification, one-to-one correspondence, pattern recognition, and sequencing. The deep learning approach further supports this process by promoting inquiry, active participation, reflection, collaboration, and contextual problem-solving, enabling children to construct mathematical understanding from authentic learning experiences rather than through rote memorization. The integration of embodied cognition and deep learning strengthens the relationship between sensory, motor, and cognitive processes, resulting in more meaningful, contextual, and sustainable numeracy learning. These learning experiences foster children's conceptual understanding, reasoning abilities, and confidence in applying numeracy concepts across different contexts. In conclusion, integrating embodied cognition with a deep learning approach provides a robust pedagogical foundation for early childhood numeracy instruction by positioning bodily experience as an essential medium for knowledge construction. This study contributes to the development of developmentally appropriate and meaningful pedagogical practices that support early numeracy competence in young children.

Keywords: embodied cognition, early numeracy, deep learning, early childhood education.

INTRODUCTION

Early numeracy is one of the fundamental competencies that plays a crucial role in young children's cognitive development. It serves as an essential foundation for logical thinking, problem-solving, and learning readiness for subsequent educational levels. This competence extends beyond number recognition to include understanding number concepts, classification, patterns, and sequencing, which form the basis of children's logical reasoning (OECD, 2021). However, numeracy instruction in early childhood education settings is still largely dominated by symbolic and rote-learning activities, such as writing numbers and completing worksheets, which provide limited meaningful learning experiences for children (Hastuti et al., 2025). Learning experiences that minimally involve bodily engagement and direct interaction with the environment may hinder children's ability to internalize numerical concepts conceptually. From a cognitive developmental perspective, early numeracy develops gradually through children's active interactions with their environment. Children construct numerical understanding through concrete experiences, such as counting objects, comparing quantities, and classifying items in everyday play activities (Clements & Sarama, 2021). Therefore, numeracy learning that is detached from authentic experiences may impede the internalization of number

concepts. This issue can be addressed through the role of embodied cognition in early numeracy learning.

Embodied cognition-based learning provides opportunities for children to use their bodies as tools for thinking and learning. Activities such as jumping according to a specified number, pointing, manipulating objects, and using gestures have been shown to help children connect physical experiences with mental representations of numerical concepts (Fischer et al., 2020). In early childhood education, this approach aligns with the principle of learning through play, which positions children as active participants in the learning process. Embodied cognition theory emphasizes that human cognitive processes cannot be separated from bodily experiences and sensorimotor interactions with the environment (Wilson & Golonka, 2013). In the context of early childhood education, numeracy learning that incorporates body movements, manipulation of concrete objects, and gestures has been found to support children's deeper understanding of mathematical concepts (Way & Ginns, 2024). Through direct experiences, children learn numerical concepts not only symbolically but also conceptually. In early numeracy, bodily engagement through manipulative activities, gestures, and physical exploration enables children to develop a more natural understanding of number concepts, classification, and sequencing through experiences integrated with play activities. This perspective is consistent with the current educational emphasis on deep learning.

A deep learning approach in early childhood education promotes meaningful, reflective, and child-centered learning. It encourages children's active engagement, connects learning experiences to real-life contexts, and fosters deep conceptual understanding rather than surface-level knowledge acquisition (Jayawardana, 2025). In numeracy learning, deep learning enables children to explore number concepts through authentic and contextualized experiences. This approach encompasses three key dimensions: mindful, referring to awareness of learning processes, thoughts, and sensations during learning; meaningful, referring to the connection between learning content, children's prior knowledge, interests, and real-life experiences; and joyful, referring to engaging and enjoyable learning experiences that stimulate curiosity and enthusiasm. Integrating embodied cognition within a deep learning framework allows children to develop a deeper understanding of numeracy concepts and strengthens the cognitive processes underlying early numeracy development. Learning is therefore oriented not only toward outcomes but also toward children's thinking processes in constructing conceptual understanding (Fullan et al., 2020). When deep learning is integrated with embodied experiences, children are not merely engaged in physical activities but are also encouraged to interpret, reflect upon, and connect these experiences with the numeracy concepts being learned. Nevertheless, empirical studies examining how embodied cognition is internalized within the cognitive processes of early numeracy through a deep learning approach remain limited, particularly in the context of early childhood education in Indonesia. Consequently, this study is important for providing an in-depth understanding of numeracy learning practices that align with the developmental characteristics of young children. It also seeks to provide empirical evidence regarding how bodily experiences and meaningful learning contribute to the development of early numeracy skills.

Therefore, investigating the internalization of embodied cognition in early numeracy cognitive processes through a deep learning approach is both relevant and significant. This study is expected to contribute theoretically to the development of early childhood numeracy education and practically to assist educators in designing numeracy learning experiences that are meaningful, contextualized, and developmentally appropriate for young children.

RESEARCH METHODS

This study employed a qualitative approach with a case study design to gain an in-depth understanding of the process of internalizing embodied cognition in the development of early numeracy through a deep learning approach. A case study design was selected because it enables researchers to examine phenomena contextually and comprehensively within a natural learning environment. The study focused on how bodily experiences, sensorimotor interactions, and children's active engagement contribute to the development of early numeracy understanding. The research was conducted at an Early Childhood Education (ECE) institution. The participants consisted of children aged 4–6 years who were involved in early numeracy learning activities and classroom teachers who served as supporting informants. Participants were selected purposively based on their involvement in numeracy learning

activities that integrated body movements, play, manipulation of concrete objects, and environmental exploration as part of the learning process. Teachers were included because of their important role in designing and facilitating learning experiences based on deep learning principles.

Data were collected through participant observation, semi-structured interviews, and documentation. Participant observation was conducted to directly examine children's engagement in numeracy activities, such as counting through movement, classifying objects, matching quantities with number symbols, and using gestures to complete numeracy tasks. Semi-structured interviews were conducted with teachers to obtain information regarding lesson planning, instructional strategies, and the development of children's numeracy understanding throughout the learning process. Documentation, including photographs, videos of learning activities, field notes, and children's work samples, was used to complement and strengthen the observational and interview data. Data were analyzed interactively using the model proposed by Miles and Huberman (2014), which consists of three stages: data reduction, data display, and conclusion drawing. During the data reduction stage, data related to indicators of embodied cognition—such as body movements, object manipulation, interaction with the environment, and the meaning-making of numeracy learning experiences—were selected, categorized, and coded. The data were then presented in the form of narrative descriptions and thematic categories to facilitate the identification of patterns linking physical activities and the development of numeracy understanding. The final stage involved interpreting the findings to obtain a comprehensive understanding of the process of internalizing embodied cognition in deep learning-based early numeracy instruction.

The trustworthiness of the data was ensured through source triangulation and methodological triangulation. Source triangulation was conducted by comparing data obtained from children, teachers, and learning documents, while methodological triangulation involved comparing findings from observations, interviews, and documentation. In addition, prolonged engagement and persistent observation were employed to enhance the consistency and credibility of the data. Through these procedures, the study sought to reveal how bodily experiences, environmental interactions, and children's active engagement in deep learning contribute to the development of meaningful early numeracy understanding.

RESULTS AND DISCUSSION

Internalization of Embodied Cognition in Early Numeracy Processes among Young Children. T Internalization of Embodied Cognition in Early Numeracy Processes among Young Children. The findings indicate that the internalization of embodied cognition in early childhood numeracy learning occurs naturally through play-based activities that engage children's bodies, senses, and social interactions. Children do not acquire numeracy concepts solely through teachers' verbal explanations; rather, understanding emerges primarily through physical engagement in manipulating objects, movement, and interaction with the learning environment. These findings reinforce the view that early numeracy is a cognitive process grounded in bodily experiences (*bodily grounded cognition*). The following section presents children's sensorimotor activities in the cognitive processes underlying early numeracy development.

Understanding Numbers and Quantities through Sensorimotor Activities

The findings reveal that children develop an understanding of numbers through manipulative activities, such as counting concrete objects, constructing with blocks, and participating in movement-based games. Children demonstrated one-to-one correspondence between objects and number words during counting and were able to recognize that the final number stated represents the total quantity of a set. This understanding emerged not through formal instruction but through children's active bodily exploration. These findings are consistent with those of Bernabini et al. (2020), who argued that early numeracy skills develop most effectively through the integration of cognitive abilities and concrete experiences. From an embodied cognition perspective, numbers are not understood merely as abstract symbols; rather, they are constructed as meaningful representations of physical experiences. Through

activities such as number-jumping games, children connect bodily movement with numerical concepts, enabling a deeper and more meaningful understanding of quantity and number relationships. This process is illustrated in the following **figure 1**.

Figure 1. Manifestations of Embodied Cognition in Children's Early Numeracy Learning through One-to-One Correspondence, Counting Concrete Objects, Block Construction, and Movement-Based Play Activities.

Symbolic Representation and Number Symbols

The findings indicate that children's recognition of number symbols emerged after they had acquired concrete experiences with quantities. Children were able to associate numerical symbols with the corresponding quantities through activities such as matching, attaching, and writing numbers in simple forms. Number symbols were understood as representations of previously experienced physical interactions rather than as isolated abstract concepts. These findings are consistent with those of Clements and Sarama (2021) and Way and Cartwright (2024), who emphasize the importance of symbolic representations grounded in bodily experiences. From an embodied cognition perspective, numerical symbols acquire meaning through children's actions and sensorimotor experiences. Through repeated interactions with concrete objects and meaningful learning activities, children gradually construct connections between physical quantities and their symbolic representations, leading to a deeper understanding of numerical concepts. This process is illustrated in the following **figure 2.**

Figure 2. Manifestations of Embodied Cognition in Children's Symbolic Number Representation through Matching, Pasting, and Simple Number-Writing Activities.

Quantity Comparison and Numerical Relationships

The The findings reveal that children demonstrated the ability to compare quantities through activities such as grouping objects and identifying sets with greater or fewer quantities. Numerical language, including terms such as *"more," "less,"* and *"equal,"* emerged spontaneously during children's interactions. This ability developed through direct exploration of objects and play-based situations, allowing children to construct an understanding of quantitative relationships through meaningful experiences.

The ability to compare quantities is a key indicator of early numeracy development and contributes significantly to the growth of mathematical reasoning skills. These findings support the study by Jylänki et al. (2023), which suggests that motor engagement and numerical relationships mutually reinforce one another in the development of early childhood numeracy. From an embodied cognition perspective, children's understanding of quantitative differences emerges through physical interaction with objects,

enabling them to experience and interpret numerical relationships in a concrete and meaningful manner. This process is illustrated in the following **figure 3**

Figure 3. Manifestations of Embodied Cognition in Children's Quantitative Comparison Skills, Including Concepts of "More" and "Less," Length (Long–Short), and Height (Tall–Short) Relationships.

Patterns, Measurement, and Basic Data Analysis

Other identified numeracy indicators include children's ability to recognize simple patterns, compare sizes, and classify objects into specific categories. Children were able to extend patterns through movements or object arrangements and to make informal comparisons of length and size. These activities indicate that numeracy is not limited to number concepts but also encompasses an understanding of basic mathematical relationships and structures. Basic data analysis skills were also observed when children grouped objects and identified the set with the greatest quantity. Although still informal in nature, these abilities represent an early foundation of data literacy that is relevant to the demands of 21st-century numeracy skills. From an embodied cognition perspective, these competencies emerge through children's active engagement with objects, movement, and environmental exploration, enabling them to construct meaningful understanding of mathematical patterns and relationships. This process is illustrated in the following **figure 4**.

Figure 4. Manifestations of Embodied Cognition in Children's Activities of Size Comparison, Pattern Recognition, and Object Classification Based on Categories (e.g., Colour).

Shapes and Geometry

The shapes and geometry component in early childhood numeracy is designed to develop children's understanding of spatial concepts, shapes, and relationships between objects through concrete and meaningful learning experiences. The introduction of basic shapes such as circles, squares, and triangles, along with the manipulation of these shapes through exploration and play activities, enables children to construct initial representations of shape characteristics and spatial relationships. These activities not only facilitate children's ability to recognize and differentiate shapes but also provide an essential cognitive foundation for the later development of more complex geometric and spatial reasoning skills. Learning approaches that emphasize hands-on experiences in manipulating objects, as well as the understanding of positional language such as *above*, *below*, and *beside*, are crucial for strengthening children's comprehension of spatial relationships in real-life contexts. This also contributes to the broader development of mathematical concepts. The following section presents children's activities in early numeracy learning related to shapes and geometry in the following **figure 5.**

Figure 5. Manifestations of Embodied Cognition in Children's Shape and Geometry Learning through Matching Activities Using Puzzles and Three-Dimensional Geometric Objects.

Numerical Communication and Contextual Problem Solving

The findings also reveal that children were able to communicate numerical ideas verbally, such as explaining how they counted or providing reasons for selecting a particular quantity, while simultaneously using their fingers as a counting aid accompanied by spoken explanations. This ability developed through social interaction and simple reflective dialogue with teachers and peers. Numeracy functioned not only as a cognitive skill but also as a medium for communication and contextual problem solving within play-based situations. Through these interactions, children gradually learned to articulate their thinking processes, justify their answers, and engage in simple mathematical reasoning in meaningful contexts. This process is illustrated in the following **figure 6**.

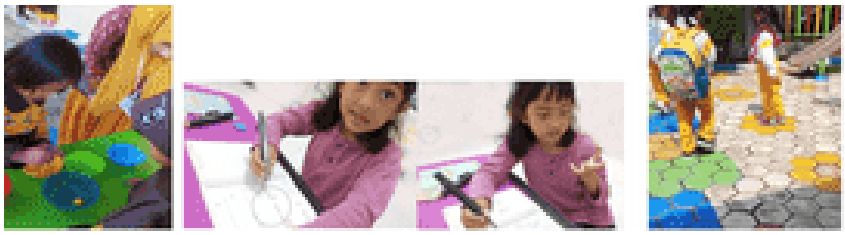

Figure 6. Manifestations of Embodied Cognition in Children's Verbal and Non-Verbal Numerical Communication within Social Interactions (Teacher–Student and Peer-to-Peer Interactions).

In addition, children were also engaged in counting activities that were directly related to their everyday experiences, such as counting friends, play materials, or movement steps. They also demonstrated informal strategies, including using fingers, pointing, and grouping objects to support their counting processes. These findings support the view that deep learning in early childhood education is realized through learning experiences that emphasize conceptual understanding, simple reflection, and the connection between learning experiences and real-life contexts. Numeracy, in this sense, functions as a tool for thinking rather than merely a technical skill. From this perspective, children are encouraged to actively construct meaning through interaction with their environment, enabling numeracy to develop as a meaningful cognitive process embedded in daily life experiences.

Based on the sensorimotor activities described above, the findings can be synthesized into an integrated relationship among numeracy, embodied cognition, and deep learning. This integration highlights how bodily experiences, cognitive engagement, and meaningful learning processes mutually reinforce one another in early childhood numeracy development. The synthesized relationship is presented in **Table 1** below. This table presents a synthesis of the study's findings, illustrating the integrated relationship between embodied cognition, early numeracy development, and the deep learning approach. It shows how sensorimotor experiences, cognitive processes, and meaningful learning interactions collectively contribute to children's numeracy understanding in early childhood education.

Table 1. Integration of Findings on the Internalization of Embodied Cognition within a Deep Learning Approach

Early Numeracy Aspect	Forms of Embodied Cognition Activities	Key Findings in Children	Mindful Childrenl Learning Integration	Meaningful Learning Integration	Joyful Learning Integration
Number and quantity understanding	Counting concrete objects, block construction, movement-based games	Children understand one-to-one correspondence and the final quantity	Children become aware of counting processes through movement and manipulation	Number concepts are understood through real and concrete experiences	Play-based activities make children active and highly en
Symbolic representation of numbers	Matching numbers with objects, simple number writing	Number symbols are understood as representations of quantity	Children connect symbols with their thinking processes	Numbers gain meaning through association with real objects	Matching activities are embedded in playful contexts
Quantity comparison and numerical relations	Grouping objects, identifying more/less	Children spontaneously compare quantities	Children reflect on differences when making choices	Concepts of more, less, and equal emerge from play contexts	Light competitive group play enhances engagement
Patterns, measurement, and basic data	Pattern building, categorizing objects, comparing sizes	Children recognize patterns, group similarities, and compare lengths and distances	Children identify patterns and differences during exploration	Patterns are linked to real-life objects and environments	Exploratory and manipulative play activities
Shapes and geometry	Puzzle activities, 3D shape recognition, spatial positioning	Children recognize basic shapes and spatial relationships	Children become aware of shape differences through exploration	Shapes are understood through real-world objects	Shape and puzzle activities are enjoyable and interactive
Numerical communication and problem solving	Discussion, explaining answers, social interaction	Children explain numerical ideas verbally and nonverbally	Children reflect on numerical ideas through	Numerical understanding develops through social interaction	Interactive and playful group activities

DISCUSSION

The findings of this study identify six main indicators of early numeracy development in young children, namely: (1) number and quantity understanding, (2) symbolic representation of numbers, (3) quantity comparison and numerical relations, (4) patterns, measurement, and basic data, (5) geometry and shapes, and (6) numerical communication and problem solving. These findings indicate that children's numeracy development is not only related to the acquisition of basic mathematical concepts, but is also shaped by learning experiences involving sensorimotor activities, social interaction, and everyday contextual engagement. Number and quantity understanding develops through direct experiences with concrete objects, such as counting, grouping, and comparing items in daily life. From an embodied cognition perspective, numerical concepts are not constructed in an abstract manner but are grounded in sensorimotor experiences involving children's bodily perception and actions within their environment (Barsalou, 2008; Lakoff & Núñez, 2000). Recent studies also highlight the important role of finger use and manipulative activities in shaping early numerical representations (Fischer et al., 2020). Within the deep learning framework, these activities reflect meaningful learning, as concepts are constructed through real-life experiences; mindful learning, as children consciously process quantities; and joyful learning, as learning occurs through engaging play-based activities (OECD, 2021; Way & Ginns, 2024).

Symbolic representation of numbers reflects children's ability to connect quantities with numerical symbols, marking a transition from concrete experiences to abstract representation. In embodied cognition theory, number symbols do not carry intrinsic meaning but acquire meaning through bodily experiences such as finger counting, pointing, and object manipulation (Barsalou, 2008). This is supported by Fischer et al. (2020), who emphasize the significance of hand-based representations in the development of symbolic numerical understanding. Within the deep learning framework, this

process reflects meaningful learning through contextualized symbols and mindful learning as children become aware of the relationship between quantity and symbolic representation.

Quantity comparison and numerical relations represent children's ability to compare quantities, such as more, less, and equal, which reflects early mathematical reasoning development. Embodied cognition theory suggests that comparison processes are not purely mental but involve bodily actions such as organizing, separating, and grouping objects spatially (Wilson, 2002). These physical interactions support children's understanding of numerical relationships in a concrete manner. In the context of deep learning, these activities support mindful learning through active observation and meaningful learning through connections with real-life situations.

Patterns, measurement, and basic data skills develop through exploratory activities involving bodily movement and spatial experience. Embodied cognition theory explains that pattern recognition is not only visual but also motor-based, involving actions such as arranging, sequencing, and grouping objects physically (Lakoff & Núñez, 2000). Recent research indicates that movement-based learning significantly enhances children's understanding of mathematical structures and patterns (Way & Ginns, 2024). Within the deep learning framework, these activities reflect joyful learning due to their play-based nature and meaningful learning through real-world contextualization.

Geometry and shape understanding in early childhood involves recognizing shapes, positions, and spatial orientation. From an embodied cognition perspective, geometric concepts are formed through bodily experiences in space, such as moving, touching objects, and exploring the environment (Wilson, 2002). Lakoff and Núñez (2000) further explain that spatial understanding develops through image schemas derived from physical experience. These activities provide an essential cognitive foundation for later geometric reasoning development (National Council of Teachers of Mathematics, 2000; Clements & Sarama, 2009). Recent educational studies also show that kinesthetic and manipulative activities enhance early geometric understanding (OECD, 2021; Way & Ginns, 2024). Within the deep learning framework, this reflects an integration of mindful, meaningful, and joyful learning through active exploration.

Finally, numerical communication and problem solving demonstrate that children construct numerical understanding through embodied engagement. The use of fingers, pointing gestures, body movements, and object manipulation indicates that numerical cognition is grounded in sensorimotor involvement. When children use their fingers while explaining quantities or point to objects being counted, they integrate bodily experience with cognitive and linguistic processes. In line with the study by Hasanah et al., (2022), the jarimatika method can serve as an effective medium in helping early childhood learners understand the concepts of addition and subtraction in a more concrete and meaningful way. It functions not merely as a calculation technique, but also as a learning tool that supports the internalization of numeracy concepts more deeply, meaningfully, and in accordance with children's cognitive developmental stages This embodied engagement supports children's conceptual understanding of numbers and facilitates communication of mathematical ideas. Consistent with the findings of Surahmi et al., (2018), gestures extend beyond their communicative function and serve as an essential component of the thinking process, facilitating students' construction of conceptual understanding and mathematical representations prior to articulating these concepts through symbolic notation. In other words, gestures serve as a bridge between children's sensorimotor experiences and their internal mental representations of mathematical concepts. By connecting concrete actions with abstract reasoning, gestures facilitate deep learning, enabling students to develop not only procedural fluency in computation but also a deeper and more enduring conceptual understanding of mathematics.

These findings align with the view that mathematical understanding develops through interactions among body, environment, and lived experience (Fischer et al., 2020; Way & Ginns, 2024). According to Surahmi et al., (2025), gestures and speech function as complementary modalities in the construction and communication of mathematical problem-solving. When students are unable to fully articulate their reasoning verbally, gestures provide visual representations of emerging mathematical ideas, allowing them to externalize and organize their cognitive processes prior to expressing them through language. From a deep learning perspective, children's ability to explain counting reflects mindful learning, application in daily life reflects meaningful learning, and engagement in play and discussion reflects joyful learning. Overall, children construct numeracy understanding through

reflective, meaningful, and enjoyable learning experiences (Dwijantie, 2025; Jannah et al., 2026; Ramadhani et al., 2025).

CONCLUSION AND SUGGESTIONS

CONCLUSION

Overall, the findings of this study are supported by various scholarly works indicating that early childhood numeracy development occurs through active, contextual, and meaningful learning experiences. Activities such as counting, grouping, comparing quantities, using gestures, and interacting with the environment demonstrate the involvement of the body in mathematical thinking processes, reflecting the perspective of embodied cognition. Meanwhile, learning experiences that encourage children to construct meaning (meaningful learning), reflect on their thinking processes (mindful learning), and engage in enjoyable activities (joyful learning) represent the application of a deep learning approach. Therefore, early numeracy development can be understood as the result of an integration between sensorimotor experiences, social interaction, and deep learning processes that emerge through play-based activities and environmental exploration.

SUGGESTIONS

Based on the findings, teachers and early childhood education institutions are encouraged to integrate embodied cognition and deep learning in numeracy learning through sensorimotor activities, concrete materials, environmental exploration, and activities that promote thinking, reflection, collaboration, and contextual problem-solving. Future research should examine the effectiveness of this integration on early childhood numeracy development across different contexts, participants, and research designs to produce stronger empirical evidence

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