

The Role of 4e Cognition Framework in Improving Early Childhood Fine Motor Skills Development through Learning Materials

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Abstract – Early childhood is a critical period that influences a child’s cognitive, social, emotional, and physical development. During this period, fine motor skills play a key role in promoting independence and academic readiness. This study focuses on the development of grasping as a core component of fine motor skills and examines how learning materials support its progress through the lens of the 4E cognitive framework. The framework views learning as embodied, embedded, enactive, and extended, highlighting the interactions between the child, the environment, and tools. Research was conducted with 30 preschool children representing urban, semi-urban, and rural areas of Sri Lanka. The findings indicated that children in urban environments exhibited better fine motor and grasping skills attributable to enhanced access to educational resources, whereas rural children exhibited slower development due to restricted exposure to such tools. Findings highlight the importance of equitable access to a variety of learning materials and provide insight into how the 4E cognitive principles can improve early childhood education practices.

Keywords: Early Childhood Development; Fine Motor Skills; Grasp Development; 4E Cognition Framework; Preschool Settings

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DOI: <https://doi.org/10.31705/IDR.2025.6>

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I. Introduction

Fine motor skills are essential skills that involve the small muscles in the hands and wrists to assist children with everyday tasks such as playing, drawing, writing, and manipulating objects. In early childhood, these skills are essential for developing independence in self-care, the ability to interact with the world, building confidence, and succeeding in both academic and daily life activities.

Grasp development is particularly important within the context of fine motor skills. It provides the foundation for later handwriting and self-care skills. Between the ages of three and five, pencil grasp techniques evolve into lifelong motor patterns that support academic achievement and functional tasks. However, incorrect or ineffective grip techniques can lead to fatigue, decreased efficiency, and, in some cases, long-term muscle strain.

The purpose of this study is to explore how environmental conditions and access to learning materials affect grasp development in early childhood, interpreted through the 4E cognitive framework. This study aims to compare grasp development among preschool children in urban, semi-urban, and rural areas of Sri Lanka, examine how exposure to tools, toys, and learning materials affects fine motor skill development, and apply the 4E cognitive perspective to understand how embodied, embedded, extended, and enactive factors contribute to fine motor development.

II. Research Problem

Many preschool children in Sri Lanka demonstrate delayed or incorrect grasping techniques and underdeveloped fine motor skills. These problems are linked to differences in socio-economic contexts (urban, semi-urban, rural), limited use of learning materials, and teacher-led rather than child-led activities. At the same time, the application of the 4E cognitive framework to fine motor development has not been adequately explored in Sri Lankan preschool settings.

III. Literature Review

A. *Fine motor skills and grasp development in Early Childhood*

More fine motor skills are the ability to make movements using the small muscles in hands and wrists. These skills are essential for everyday tasks at school, work, and in daily life. These skills consist of reaching, grasping and manipulation. They require coordination between the brain and muscles and develop the foundation of gross motor skills (Belsky, 2023; Jozsa et al., 2023).

Grasping, a fundamental component of fine motor skills, progresses through various stages during early childhood. (Greutman, 2010). Between the age of 12-15 months, child first develops a palmar supinate grasp. where the whole hand or fist surrounds an object, such as crayons. By 2-3 years, they develop a digital pronate grasp involving use of whole arm movements. Between 3-4 years, the appearance is transitional towards a quadruped grasp or a static tripod grasp. These require more delicate placement of fingers with minimal movement in the forearm. By 4-6 years, a dynamic

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tripod grasp represents the most mature stage with motion provided by the fingertip to maintain stability in place (Greutman, 2010). Parallel to this, the development of pincer grasp is another important milestone. The crude pincer grasp, appearing around 7 months which involves the pads of the thumb and forefinger, and the neat pincer grasp, which develops by 9 months, using the tips of these fingers. Pincer grasp significantly improves a child's ability in manipulating small objects, providing additional impetus in hand-eye coordination while laying the foundation for later fine motor tasks (Deyoung, n.d.).

Figure 1
Palmar supinate grasp (12-18 months)



Figure 2
Digital pronate grasp (2-3 years)



Figure 3
Immature Static tripod or quadruped grasps (3-4 years)



Figure 4
Dynamic tripod or quadruped grasp (4+ years)



Figure 5
Dynamic tripod grasp



Figure 6
Dynamic quadruped grasp



Figure 7
Crude ulnar- palmar grasp (3-5 months)



Figure 8
Palmar grasp (5-6 months)



Figure 9
Radial-Palmar Grasp



Figure 10
Radial digital and immature pincer grasps (10-18months)



Figure 11
Pincer Grasp (18-24 months)



Figure 12
Pincer Grasp (overall grasp patterns are well developed by age 5)



Note: Developmental progression of grasp - synaptic pediatric therapies (2021, January 8). Synaptic Pediatric Therapies.

<https://synapticpediatrictherapies.com/developmental-progression-of-grasp/>

Early childhood includes the first experiences of using a pencil and writing. Providing correct information about pencil grip is very important in early childhood (Yurtsever et al. 2017). Incorrect pencil grip causes hands to tire quickly and takes away from the exercises required to use a pencil (Polat, 2010b). Thus, the rapid and comprehensive handwriting skills that children acquire during the primary school years are slow to improve (Temur, 2011). This kind of incorrect pencil grip experience can last a lifetime.

B. The role of Early Play and learning materials

Learning materials and games closely support early grasp development. Purposefully designed activities and maneuvers help children refine their hand and finger movements, laying the foundation for later writing and self-care tasks. Research highlights that tools such as puzzles, pegboards, and building blocks stimulate fine motor development and encourage problem-solving (Kisitu, 2008; Dewey, 1966). As children develop, toys and objects that require thumb-index finger coordination, such as beads, buttons, and board books with flaps etc. directly support the emergence of pincer grasp (Hanlon, 2025).

C. Socio-Economic and Environmental Influences

Socio-economic conditions and the availability of preschool resources strongly affect children's performance (Kinyuwa, 2015). The resources of preschools in Sri Lanka act as indicators of the quality of their service delivery (Liyandara, 2024). Preschools in rural and estate sectors often face resource shortages (World Bank Group, 2014; Pathirana, 2017), which limits children's exposure to fine motor development tools. Therefore, these things also directly affect grasping development.

D. Consequences of incorrect grasping techniques

Grasp development progresses from immature to mature patterns, typically stabilizing in early childhood. Delayed or atypical grasp development can lead to decreased writing speed, poor legibility, hand discomfort, and long-term musculoskeletal strain (Schwellnus et al., 2012; Dennis & Swinth, 2001; Shah & Gladson, 2015).

E. The 4E Cognition Framework as a Theoretical Lens

The 4E Cognition framework offers a holistic understanding of fine motor development by emphasizing the interaction between the body, mind, and environment. Embodied cognition situates learning within bodily action and sensorimotor control, essential for grasp refinement. Embedded cognition highlights the role of environmental and social context in shaping perceptual skills. Enactive cognition views learning as an outcome of dynamic engagement between the child and their surroundings through play and exploration, while extended cognition recognizes tools and materials as extensions of cognitive capability (Lebert et al., 2024). Applying this framework to grasp development positions learning materials as active participants in cognitive and motor growth, rather than passive aids.

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IV. Methodology

This research, aligned with the principles of 4E cognition, explores how the preschool environment, teaching methods and available learning resources influence the development of children's Fine motor skills. The selected preschools are representative of different teaching curriculum and socio-economic settings that play a critical role in early childhood development.

The study was conducted over a two-month period (last week of October to first week of December 2024). Each preschool was observed for five consecutive days, allowing sufficient time to record fine motor behavior patterns across a variety of classroom activities.

Table 1

Preschool Sample Distribution By Types and Location

Preschool Type	Location	Sample
Urban	Colombo	10
Rural	Monaragala	6
Semi-Urban	Embilipitiya	14

Observation was the primary method, supported by photographs and checklists that recorded children's grasping patterns and grasping control during fine-motor activities. Unstructured teacher interviews provided contextual insight into children's handwriting readiness and grasping challenges.

To assess grasp development, four structured activities were used,

1. Pegboard - assessed hand-eye coordination, grip stability, and fine motor precision.
2. Bead stringing - measured pincer grasp, sequencing, and control of small objects.
3. Puzzle manipulation - tested precision grasp, dexterity, and problem solving.
4. Crayon/Pencil drawing - assessed pencil grasp style, grip strength, and endurance when making marks.

These activities were selected because they reflect typical preschool tasks that require effective grasping and they map onto the embodied and enacted dimensions of the 4E framework.

Data from 30 preschool children were analyzed using checklist scoring and descriptive statistics (mean, frequency).

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V. Findings and Discussion

Table 2

Motor skills assessment score chart

Participant	Age	Preschool Type	Balance (1-3)	Hand-Eye coordination (1-3)	Grasp Development				Total score	Mean
					Grip Control (Lacing & Threading) (1-3)	Object Handling & Placing (1-3)	Precision Grip (Puzzle) (1-3)	Pencil/crayon Grip (1-3)		
P1-R	5	Rural	2	2	2	2	1	3	12	9.5
P2-R	4		2	1	2	1	1	2	9	
P3-R	3		2	2	1	2	1	1	9	
P4-R	4		2	2	1	2	2	1	10	
P5-R	3		1	2	2	2	1	1	9	
P6-R	5		1	2	1	2	1	1	8	
P1-S	5	Semi-Urban	2	2	1	2	2	1	11	
P2-S	5		2	2	2	1	2	2	11	
P3-S	4		2	2	2	2	2	3	13	
P4-S	4		2	3	2	2	2	2	13	
P5-S	4		2	2	2	2	1	2	11	
P6-S	5		2	2	2	2	2	2	12	
P7-S	5		2	2	2	2	2	2	12	
P8-S	3		2	2	2	1	2	2	12	
P9-S	4		2	1	2	1	2	2	10	
P10-S	5		2	2	2	2	2	3	13	
P11-S	5		2	2	2	1	2	2	11	
P12-S	5		2	2	1	2	2	1	10	
P13-S	5	Semi-urban	2	2	2	2	2	2	12	11.5
P14-S	3		2	1	2	1	2	2	10	
P1-U	5	Urban	2	2	2	2	2	2	12	13.1
P2-U	5		2	2	3	2	2	2	13	
P3-U	3		2	2	2	2	2	3	13	
P4-U	3		2	2	2	3	2	2	13	
P5-U	5		3	2	2	2	2	3	14	
P6-U	4		2	2	3	2	3	2	14	
P7-U	4		2	2	2	2	2	2	12	
P8-U	4		2	2	2	3	2	3	14	
P9-U	5		2	2	2	2	2	2	12	
P10-U	5		2	2	3	2	2	2	13	

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A. Rural Area Participant's Pencil Grip

1. Rural area participant's pencil grip- Age 3

Figure 13
P3-R Pencil grasp technique



Figure 14
P5-R Pencil grasp technique



2. Rural area participant's pencil grip- Age 4

Figure 15
P2-R Pencil grasp technique

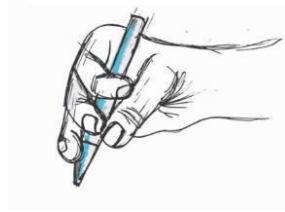
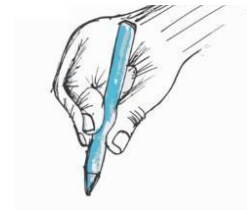


Figure 16
P4-R Pencil grasp technique



3. Rural area participant's pencil grip- Age 5

Figure 17
P1-R Pencil grasp technique



Figure 18
P6-R Pencil grasp technique



In the rural preschool, only one child (P1-R) used the quadrupod grasp to grasp pencils and crayons. The P2-R participant also used a technique similar to the quadrupod grasp to grasp pencils and crayons. Although the tripod and quadruped grasp should have developed by this 3-5 age/preschool age, the children in the study observed that they were engaged in the activity by holding their fingers in different positions and postures. There was no proper connection between the fingers and the pencil during the hold, and as a result, there was not enough support under the pencil. This instability made it difficult to control the pencil effectively, and as a result, the children could not properly handle the paper or book during the activity.

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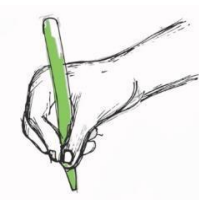
B. Semi-urban Area Participant's Pencil Grip

1. Semi-urban area participant's pencil grip- Age 02

Figure 19
P14-S Pencil grasp technique



Figure 20
P1-S Pencil grasp technique



2. Semi-urban area participant's pencil grip- Age 4

Figure 21
P3-S Pencil grasp technique



Figure 22
P4-S Pencil grasp technique



Figure 23
P5-S Pencil grasp technique

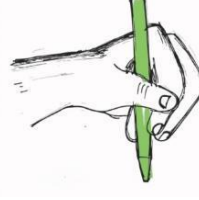


Figure 24
P9-S Pencil grasp technique



3. Semi-urban participant's pencil grip- Age 5

Figure 25
P1-S Pencil grasp technique

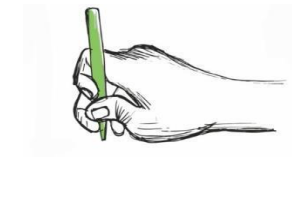


Figure 26
P2-S Pencil grasp technique

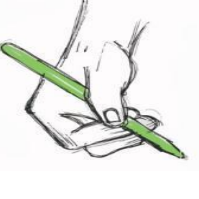


Figure 27
P6-S Pencil grasp technique

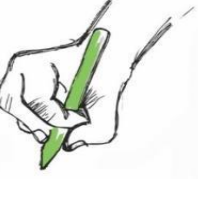


Figure 28
P7-S Pencil grasp technique



Figure 29
P10-S Pencil grasp technique



Figure 30
P11-S Pencil grasp technique



Figure 31
P12-S Pencil grasp technique

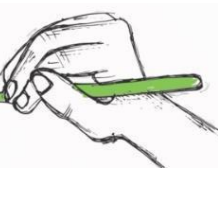
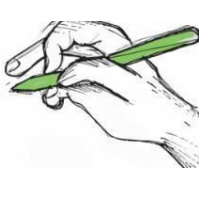


Figure 32
P13-S Pencil grasp technique



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There was notable difference observed when comparing the pencil grip of children from a semi-urban preschool compared to the pencil grip of children from a rural area. P3-S and P10-S, two of the children in the study, scored full mark for pencil grip. P10-S used a quadrupod grasp technique. P3-S used a tripod grasp approach. P4-S, P8-S, P9-S, P7-S, P14S and P11-S showed a tripod-like grasping style for pencils/ crayon grips that had not yet been fully improved. But these children were unable to stabilize the writing paper with their fingers despite having proper finger placement and writing techniques. P2-S and P7-S showed a less-developed quadrupod-like grasp style when holding the pencil or crayon. It was observed that the pencils are not stable when holding the P1-S, P6-S, P12-S and P13-S pencils.

C. Urban Area Participant's Pencil Grip

1. Urban area participant's pencil grip- Age 3

Figure 33
P3-U Pencil grasp technique

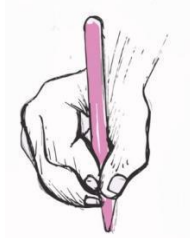
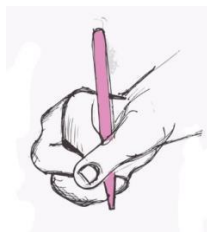


Figure 34
P4-U Pencil grasp technique



2. Urban area participant's pencil grip- Age 4

Figure 35
P6-U Pencil grasp technique

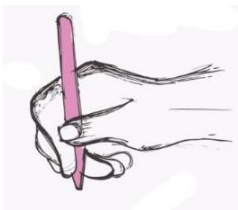


Figure 36
P7-U Pencil grasp technique

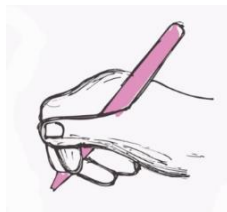


Figure 37
P8-U Pencil grasp technique



3. Urban area participant's pencil grip- Age 5

Figure 38
P1-U Pencil grasp technique



Figure 39
P2-U Pencil grasp technique



Figure 40
P5-U Pencil grasp technique



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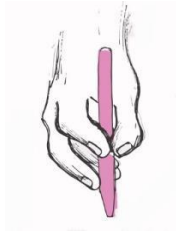
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Figure 41
P9-U Pencil grasp technique



Figure 42
P10-U Pencil grasp technique



The pencil grip of preschoolers in urban areas was more accurate and significantly different from that of preschoolers in the other two areas. Among the children observed here, P3-U, P5-U and P8-U scored full marks. They were observed to have a quadrupod grasp technique. P6-U, P2-U, P9-U and P7-U had a slightly less developed tripod grip. P1-U, P9-U and P10-U had a slightly less developed quadrupod grasp. Although they kept their fingers in a fairly accurate position, there were stability problems since their fingers did not support the pencil enough.

Compared to children in other locations, urban children performed better on the pencil/crayon grip test. This score was roughly 2.3 on average.

In all preschools, regardless of location, differences in grasping technique were clearly evident. about 70% of all preschoolers used their thumb and middle finger to pincer-grip small objects.

Figure 43
Pincer grip during pegboard activity

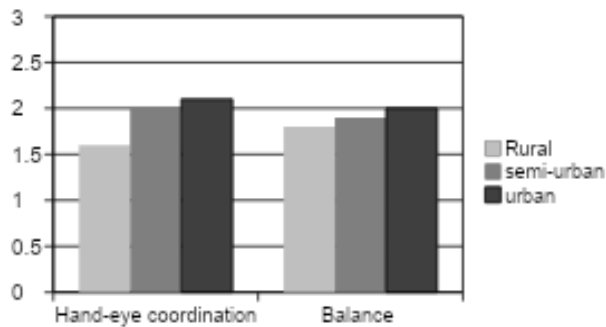


Figure 44
Pincer grip during puzzle activity



Graph 1

Comparison of Hand-Eye Coordination and Balance Among Different Settings



The puzzles and other activities that required hand eye coordination were generally completed at the same level by both urban and semi-urban preschoolers. In terms of balance, hand-eye coordination, and grip development, older children (age 5) performed better than younger children (age 3). On balance tasks, urban children performed best; one participant received a score of three (10% of urban participants). Preschool children in rural areas scored the lowest, with the majority receiving scores of 1 or 2, suggesting that they were not exposed to many activities that encouraged balance. Hand-eye coordination Children across all preschool groups showed moderate coordination (average score: 2). However, preschoolers in rural areas scored slightly lower, as they had less access to structured activities such as puzzles and pegboards. Threading and Lacing About 30% of preschoolers in urban settings scored a 3, indicating the maximum level of control. Preschoolers in rural areas, however, typically had scores of 1 or 2.

Preschoolers in urban areas have access to tools such as grip development nozzles. This is used to improve pencil grip. Such non-traditional teaching methods encourage active participation and promote fine motor skills development. Rural preschools depend mainly on teacher-led craft activities, which limits independent practice of their fine motor skills. In addition to that, semi-urban preschool often use pencil, scissors for making craft items, and stacking blocks activities.

Overall, the 4E perspective shows that fine motor skill development relies on more than practice alone. From an embodied perspective, children need regular hands-on interaction with materials. In terms of embedded cognition, they need resources and supportive learning environments. enactive cognition emphasizes children need more play-based and child-led activities. extended cognition shows that external supports such as pencil grips, manipulations, and adapted tools can significantly improve grasping skills.

Overall, no preschools have received a full score in the assessment. These assessed skills are those that should be fully developed for children aged 3-5. Therefore, it can be said that the fine motor skills of all these children should be further developed properly. Incorrect grasp technique may

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indicate an uneven pattern of fine motor development. This grip may sometimes occur as a temporary alternative, but it is not the most efficient or natural way to handle small objects and it may signal underlying problem that need attention.

VI. Conclusion and Recommendations

This study highlights the relevance of the 4E cognitive framework for early learning. Early learning contributes to motor development through physical interactions, social interactions and the use of materials. These interactions align with the principles of the 4E cognitive framework, thus reflecting the relationship between ECD and the 4E cognitive framework. Research conducted in rural, semi-urban and urban settings using the 4E framework found significant differences in fine motor skills.

This highlighted the impact of learning materials and teaching methods in each of these different settings. The study specifically observed that children have different and incorrect pencil grip techniques. This can have a negative impact on children. Because writing with a correct pencil grip is actually the foundation of education. Therefore, it can affect children's future. Also, an incorrect pencil grip can lead to hand fatigue and long-term muscle tension. A slightly better grasping development was observed in urban areas because they use tools to practice the correct technique.

Rural settings with fewer resources limit children's abilities and their potential. The use of learning materials directly contributes to fine motor skills. Active engagement with these materials develops fine motor skills. It seems that the child's fine motor and cognitive skills are not sufficiently developed within the current resources and learning methods in the selected preschool settings. However, overall, social interaction and community building in these contexts are positive. In this study, it was found that all preschool environments need to further improve their approach to fine motor skill development, with a particular focus on increasing the availability and effective use of learning materials, incorporating embodied and extended cognition, and providing opportunities for active and practical learning.

Based on the findings, it is recommended to develop and introduce early learning toys and manipulatives specifically designed to encourage fine motor skills, including grasp development. Provide age-appropriate writing tools to promote correct pencil grip patterns in the early years. Ensure that preschools, especially in rural and semi-urban areas, are equipped with low-cost, resourceful fine motor development materials that can be produced locally. Include play-based, child-led activities that emphasize active exploration and reduce over-reliance on teacher-led methods, supporting active learning. This study positions the 4E cognition framework as a valuable analytical model for designing early learning environments that integrate physical, social, and material engagement.

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Acknowledgment

I would like to express my sincere gratitude to Mr. Pumuditha Pelpola, design engineer for his valuable guidance and support during the observation activities. I would also like to thank Ms. Kaushadhi de Silva, early childhood and special needs educator, and Ms. Gimhani Fernando and Ms. Tharaka Madhumali, preschool teachers, for providing access to their preschool premises and sharing valuable insights on early childhood education.

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DOI: <https://doi.org/10.31705/IDR.2025.6>

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