






EXPLORING THE INFLUENCE OF PARENTAL-TEACHER ENGAGEMENT IN PLAY-BASED MATHEMATICAL LEARNING ON MOTOR DEVELOPMENT AND HEALTH OUTCOMES IN EARLY CHILDHOOD

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Abstract

This study examines the influence of parental-teacher engagement in play-based mathematical learning on the motor development and health outcomes of preschoolers. The research is grounded in socio-cultural and ecological systems theory, responding to the growing need for holistic, collaborative approaches in early childhood education that integrate academic, behavioral, and physical domains. Using a mixed-method sequential explanatory design, the study was conducted over three months in three early childhood centers in Bandar Lampung, Indonesia, involving 120 children aged 4–6 years, along with their teachers and parents. Quantitative data were collected using the Peabody Developmental Motor Scales–Second Edition (PDMS-2), a WHO-adapted Health Monitoring Checklist, and a validated observation rubric on adult collaboration. Results showed significant improvements in gross and fine motor skills (Cohen's $d = 1.98$ – 2.63), and in health behaviors, including increased physical activity (+28%), healthier eating habits (+25%), and more consistent sleep routines (+13%). Based on semi-structured interviews and focus groups with 25 participants, the qualitative phase revealed themes such as strengthened home-school partnerships, embedded learning in daily routines, enhanced child engagement, and challenges related to time and resources. The study concludes that collaborative, play-based learning environments effectively support integrated child development, with sustained benefits when reinforced across home and school. These findings empirically support family-inclusive pedagogies and suggest the need for differentiated engagement models and longitudinal follow-up to maximize developmental outcomes.

Keywords Child Health, Early Childhood Education, Motor Development, Parental-Teacher Collaboration, Play-Based Learning



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INTRODUCTION

The early years represent a crucial period for establishing the cognitive, physical, emotional, and social foundations necessary for long-term development and success (Bhutta et al., 2023; Stein et al., 2023; Stodden et al., 2023). During this phase, children exhibit rapid neurodevelopmental changes, making it an optimal period for interventions integrating health and education (Hadders-Algra, 2021; Jensen et al., 2021; Schiariti et al., 2021). One critical aspect of early development is the acquisition of gross motor skills (e.g., running, jumping, balance) and fine motor skills (e.g., hand-eye coordination, grasping). These motor domains are not only linked to physical competence but also correlate significantly with cognitive functions, academic performance, and behavioral regulation (Hill et al., 2024; Kamphorst et al., 2021; Laurent et al., 2021; Ma et al., 2024; Malambo et al., 2022). For instance, Shi and Feng (2022) highlight that motor activities stimulate the prefrontal cortex, influencing executive function. Research by Klupp et al. (2023) confirms this by showing that children with more refined motor coordination perform better in working memory and task-switching activities. Thus, embedding motor development within educational interventions holds promise for achieving broader developmental outcomes in early childhood.

Play-based learning, as a pedagogical strategy, is widely recognized for its alignment with the natural learning tendencies of young children (Cade, 2023; Qayyum et al., 2024; Van der Westhuizen, 2023; Vidal Carulla et al., 2021). Grounded in socio-constructivist theories, particularly those of Vygotsky, play-based learning emphasizes active exploration, imagination, and social interaction as essential mechanisms through which children construct meaning (Mwinsa & Dagada, 2025; Qayyum et al., 2024). In early mathematics learning, play allows children to engage with abstract concepts in a concrete and physically embodied manner (McCluskey et al., 2023; Nasution et al., 2024; Nergård, 2023). For example, when children sort blocks by size or measure objects using nonstandard units, they are simultaneously developing mathematical reasoning and fine motor precision. According to Lange et al. (2021), engaging in number board games improves counting, number identification, and numerical magnitude understanding among low-income preschoolers. These improvements are more pronounced when learning is physically interactive and socially mediated. Furthermore, Estevan et al. (2023) argue that movement-based learning activities are essential for fostering numeracy and supporting physical health outcomes such as body composition, motor fitness, and cardiovascular endurance. These findings support the call for integrated curricula holistically addressing cognitive and physical domains through playful learning experiences.

However, the efficacy of such integrative learning approaches significantly depends on the role of adult mediation especially the collaborative involvement of both parents and teachers. The ecological systems theory proposed by Anderson et al. (2024) underscores the significance of mesosystem interactions, such as those between home and school, in shaping child development. Research consistently supports the notion that when parents and teachers work collaboratively, children experience more consistent support, increased motivation, and improved learning outcomes (Ashfaq et al., 2024; Ateş & Köroğlu, 2024; Caparoso, 2024). Cui et al. (2023) concluded that parental involvement, particularly when aligned with teacher expectations, positively influences students' achievement in early mathematics. Moreover, Ashfaq et al. (2024) found that preschool children whose parents and teachers engaged in structured collaboration showed significant gains in early academic and behavioral skills. Significantly, this collaborative approach also facilitates the early identification of developmental delays and health concerns, enabling timely intervention and support (Macy, 2022; Rivard et al., 2024; Sapiets et al., 2023).

Despite these insights, current research often examines the contributions of play-based learning, parental involvement, and teacher support in isolation rather than exploring how their intersection influences key developmental outcomes such as motor skill proficiency and health status. For instance, while Barnett et al. (2022) emphasize the strong association between motor competence and positive health trajectories, few studies have examined how mathematical learning environments designed collaboratively by parents and teachers can serve as dual cognitive and physical development platforms.

Moreover, the role of play in mediating the relationship between collaborative adult engagement and child health remains underexplored in the empirical literature. Although Duncan et al. (2021) and Ma et al. (2024) demonstrate that motor proficiency in preschoolers is significantly associated with increased physical activity and decreased sedentary behavior, these findings have not yet been integrated into the pedagogical discourse surrounding early mathematics education. This disconnect reveals a critical gap in the literature and highlights the need for a more interdisciplinary approach.

Given these considerations, the present study explores the influence of parental-teacher engagement in play-based mathematical learning on preschoolers' motor development and health outcomes. By employing a mixed-method sequential explanatory design, this study first quantifies the extent of influence these variables exert on children's gross and fine motor skills as well as selected health indicators (e.g., BMI-for-age, physical activity levels). In the subsequent qualitative phase, the research delves into how parents and teachers perceive their roles, collaboration strategies, and challenges in co-constructing a learning environment that is both cognitively enriching and physically engaging. This comprehensive approach aims to inform future pedagogical models and early childhood policies by emphasizing the value of integrated learning frameworks that foster child development in a multidimensional, contextually relevant manner.

RESEARCH METHOD

This study employed a mixed-method sequential explanatory design (Creswell & Creswell, 2023), integrating both quantitative and qualitative approaches to comprehensively examine the influence of parental-teacher engagement in play-based mathematical learning on preschoolers' motor development and health outcomes. The design allowed robust quantitative results through a quasi-experimental approach and in-depth qualitative exploration to provide contextual explanations and insights. Conducted over three months, from March to May 2025, the research took place in three early childhood education centers (PAUD) in Bandar Lampung, Indonesia. These institutions were purposively selected based on their readiness to implement collaborative learning models and their existing infrastructure for integrating play-based activities. With structured indoor and flexible outdoor learning spaces and active parent forums, these centers provided an ideal environment for embedding home-school collaboration into daily instructional practice.

Participants included 120 children aged 4 to 6, classroom teachers, and parents or primary caregivers. Children were selected through purposive sampling based on their classroom enrollment with existing or potential collaborative practices between teachers and parents. For the qualitative component, 10 teachers and 15 parents were selected using criterion-based purposive sampling, focusing on those who demonstrated consistent participation and consented to provide deeper insights through interviews and group discussions. The intervention consisted of an eight-week structured program co-designed and co-implemented by teachers and parents. It included physical and mathematical games such as hopscotch counting, jump-and-count tasks, number-based block constructions, and shape-sorting activities. These were conducted at school and home, supported by weekly coordination meetings, training sessions, and distributed learning materials, including video tutorials and guidance sheets.

Data collection relied on several standardized and researcher-developed instruments. The Peabody Developmental Motor Scales-Second Edition (PDMS-2) was adapted and contextualized based on the work of Zanella et al. (2021) and was used to measure gross and fine motor skills, assessing subdomains such as locomotion, grasping object manipulation, and visual-motor integration. This instrument is widely validated, with internal consistency coefficients between 0.89 and 0.96 and test-retest reliability exceeding 0.90, ensuring the robustness of motor development measurements. Health indicators were tracked using a checklist adapted from WHO Child Growth Standards, covering BMI-for-age, daily physical activity, nutrition practices, and sleep duration. This checklist was validated by early childhood and pediatric health experts and piloted for clarity and contextual appropriateness, achieving an inter-rater reliability coefficient of 0.87. In parallel, the researcher designed an observational rubric to measure the quality of parental-teacher engagement, focusing on frequency of interaction, communication quality, joint planning, and consistency of home support. The rubric was validated through a Delphi process with five early childhood experts, yielding an Aiken's V of 0.89 and a Cronbach's alpha of 0.91 during the pilot phase, indicating strong content validity and internal consistency.

For the qualitative strand, data were gathered through semi-structured interviews and focus group discussions with parents and teachers. Questions explored their experiences implementing the intervention, observed changes in children, perceived challenges, and insights into sustaining collaborative learning. All interviews were conducted in Bahasa Indonesia, recorded with consent, transcribed, and translated into English for analysis. Thematic analysis followed Braun and Clarke’s six-phase method, with coding performed manually and assisted by NVivo software. Emergent codes were organized into themes and sub-themes that captured shared patterns and contextual variations across participants’ narratives. Quantitative data were analyzed using SPSS software. Descriptive statistics were used to examine baseline and outcome scores, followed by paired-sample t-tests to determine the significance of changes between pre-and post-intervention assessments, and Cohen’s d was calculated to measure effect sizes.

The study employed data triangulation, member checking, and audit trails to ensure the credibility and trustworthiness of the findings. Peer debriefings and consultations with external methodological experts strengthened confirmability and dependability. Ethical approval was obtained from the institutional review board, and informed consent was secured from all adult participants, with parental assent obtained for children. Confidentiality and voluntary participation were emphasized at every stage of the research. Integrating quantitative and qualitative data allowed for a holistic understanding of how structured collaboration and play-based mathematical instruction contributed to meaningful and sustainable improvements in children’s motor development and health while illuminating the real-world dynamics of adult engagement in early childhood education.

RESULTS AND DISCUSSION

This section presents the findings from the study's quantitative and qualitative phases, analyzed to explore the influence of parental-teacher engagement in play-based mathematical learning on preschoolers’ motor development and health outcomes. Combining statistical analysis and rich narrative insights from parents and teachers offers a multidimensional understanding of how structured, collaborative, play-based learning environments support holistic child development.

Improvements in Motor Development through Play-Based Mathematical Activities

The Peabody Developmental Motor Scales–Second Edition (PDMS-2) quantitative data revealed consistent and substantial improvements in children’s motor skills across four domains. As presented in Table 1, gross motor skills showed the largest improvement, with a mean gain of +13.3 points (from 42.3 to 55.6), followed by object manipulation (+12.7), visual-motor integration (+12.2), and fine motor skills (+11.3). These gains represent a performance increase of between 27.7% and 31.4%.

Table 1. Children’s Motor Development Scores (PDMS-2 Assessment)

Motor Domain	Pre-Test Mean (SD)	Post-Test Mean (SD)	Mean Difference	% Improvement
Gross Motor Skills	42.3 (±5.4)	55.6 (±4.7)	+13.3	+31.4%
Fine Motor Skills	40.8 (±6.1)	52.1 (±5.3)	+11.3	+27.7%
Visual-Motor Integration	41.7 (±5.6)	53.9 (±4.9)	+12.2	+29.3%
Object Manipulation	43.5 (±5.1)	56.2 (±4.6)	+12.7	+29.2%

The robust improvement in gross motor and object manipulation skills is particularly noteworthy, as these are directly supported by physical, movement-based learning activities such as jumping on numbered hopscotch grids, throwing beanbags at target numbers, and arranging math-related objects. These results are strongly aligned with embodied cognition theory, which posits that learning is rooted in physical interaction with the environment (Bandura, 2023; Peng et al., 2024). According to Piagetian developmental theory, preschoolers are preoperational, where hands-on, sensorimotor experiences are crucial for developing cognitive and spatial reasoning (Fisher & Zimmer, 2024).

Moreover, the findings echo Schäfer et al. (2024), who argued that motor activities stimulate the prefrontal cortex, improving executive functions such as attention, working memory, and problem-

solving all essential for mathematical understanding. These results are also reinforced by Kamphorst et al. (2021), who showed that early motor proficiency is positively associated with academic readiness and socio-emotional regulation in kindergarten-aged children.

Statistical Significance and Practical Impact of the Intervention

The gains observed in motor development were further confirmed through paired-sample t-tests, as shown in Table 2. All domains showed statistically significant differences between pre-test and post-test scores ($p < 0.001$), with Cohen’s d values ranging from 1.98 to 2.63 categorized as large effect sizes.

Table 2. Inferential Statistics for Motor Development Gains (PDMS-2 Scores)

Skill Domain	Mean Difference	t-Statistic	df	Effect Size (Cohen’s d)
Gross Motor Skills	13.3	20.35	119	2.63
Fine Motor Skills	11.3	15.32	119	1.98
Visual-Motor Integration	12.2	17.96	119	2.32
Object Manipulation	12.7	20.26	119	2.62

These effect sizes indicate that the intervention had both statistical and substantial practical impact, supporting prior findings that movement-integrated academic tasks promote fine and gross motor development (Mavilidi et al., 2022; Petrić et al., 2023). These results are especially significant in light of growing concerns that many early childhood education programs are overly sedentary and place insufficient emphasis on movement. This study shows that academic rigor and physical engagement are not mutually exclusive but rather mutually reinforcing when integrated purposefully.

Daily Motor Skill Gains: A Cumulative Growth Trajectory

The progress is visualized in Figure 1, which depicts the steady daily increase in PDMS-2 scores over the eight-week intervention. The upward trajectory indicates consistent and accumulative growth, reinforcing that learning and motor development are dynamic and synergistic processes (Barela, 2021; Latash, 2021; Shi & Feng, 2022).

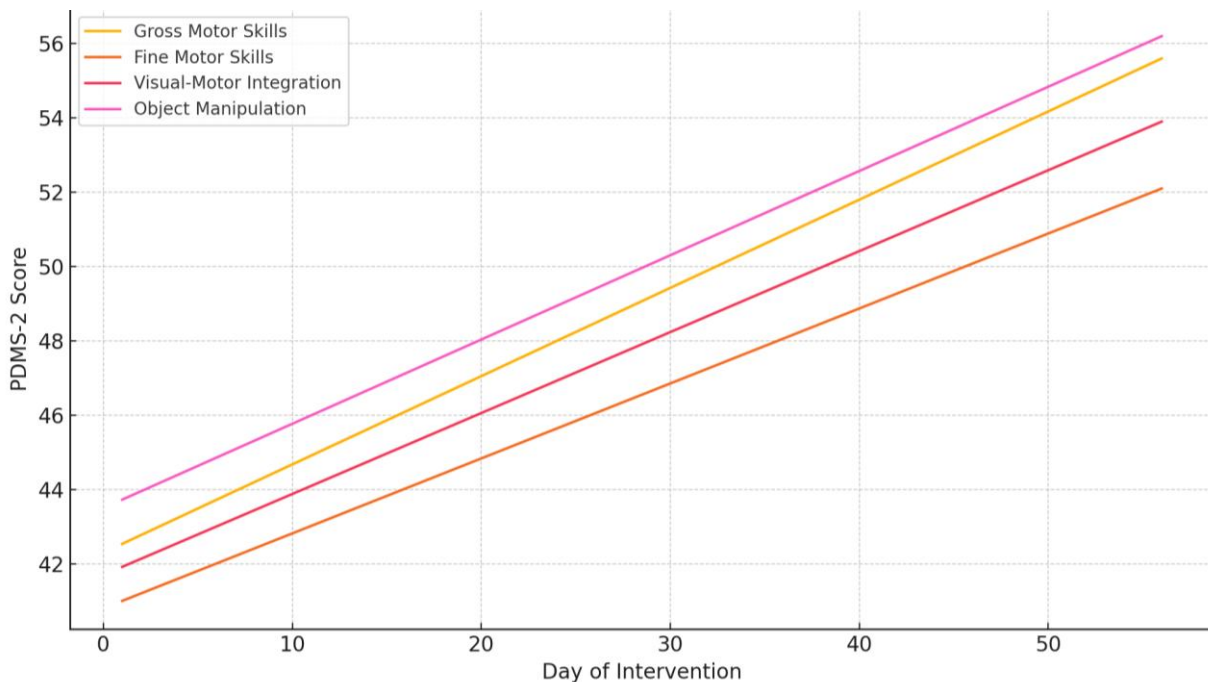


Figure 1. Daily Progress in Children’s Motor Development

Enhancing Health Behaviors through Collaborative Movement-Based Learning

Beyond motor development, the intervention also yielded positive changes in health-related behaviors, as illustrated in Table 3. The proportion of children within the normal BMI-for-age category

increased from 68% to 82%. Physical activity participation (≥ 60 minutes/day) increased by 28%, healthy eating adherence improved by 25%, and sufficient sleep rose by 13%.

Table 3. Child Health Indicators (Health Monitoring Checklist)

Health Indicator	Pre (%)	Post (%)	% Change	Interpretation
BMI-for-Age in Normal Range	68%	82%	+14%	Improved nutritional balance and growth status
Daily Physical Activity (≥ 60 minutes/day)	45%	73%	+28%	Increased movement due to structured play interventions
Healthy Eating Habits	51%	76%	+25%	Better dietary awareness and food selection at home
Sufficient Sleep Duration (≥ 10 hours)	59%	72%	+13%	More consistent bedtime routines through parental support

These findings are consistent with the research from Daelmans et al. (2021) framework for nurturing care in early childhood, which emphasizes that health, nutrition, responsive caregiving, and early learning are interrelated. Studies such as those by Maćak et al. (2022) and Wang et al. (2022) have demonstrated that structured physical activities especially those integrated with curriculum goals significantly improve health markers in preschool-aged children, including body composition, cardiorespiratory fitness, and dietary patterns.

The Role of Family Reinforcement in Sustaining Health and Learning Routines

Moreover, parental modeling and home reinforcement cannot be underestimated. When parents actively participated in learning e.g., preparing healthy snacks based on counting tasks or using bedtime math stories the behaviors became part of the family’s ecological routine, enhancing sustainability. This supports Bronfenbrenner’s Ecological Systems Theory (El Zaatari & Maalouf, 2022; Panahandehpour et al., 2023), which posits that child development is most robust when learning environments (microsystems) like home and school are aligned.

The progress is also visually reflected in Figure 2, which shows the improvement in health indicators over time. The steady gains suggest that these changes were not episodic but likely influenced by the consistency and reinforcement of routines in school and home settings.

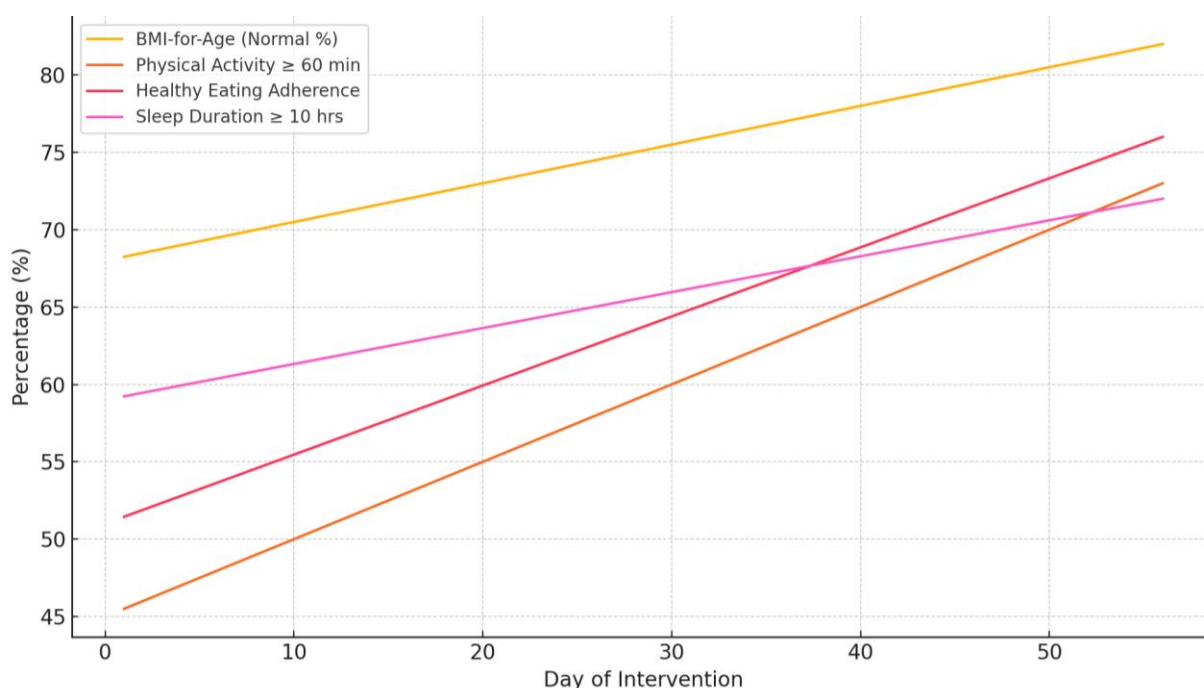


Figure 2. Daily Trends in Health Indicators During Intervention Period

Quality of Parental-Teacher Collaboration and its Observed Dynamics

The structured observation of adult collaboration revealed high levels of parental-teacher engagement, as shown in Table 4. Among the four dimensions assessed, consistency in support (M = 4.3) and frequency of interaction (M = 4.2) received the highest scores, followed by communication quality (M = 4.0) and joint planning (M = 3.8).

Table 4. Observation Scores on Parental-Teacher Engagement

Engagement Dimension	Mean Score (0–5)	Standard Deviation	Remarks
Frequency of Interaction	4.2	±0.6	Weekly dialogues through WhatsApp, journals, and face-to-face communication
Quality of Communication	4.0	±0.7	Parents provided learning feedback; teachers responded with suggestions
Joint Planning of Activities	3.8	±0.9	Lesson ideas were co-created in planning meetings and parental workshops
Consistency in Support	4.3	±0.5	Parents consistently followed up learning at home with structured activities.

These findings reflect the successful operationalization of Epstein’s Framework of Six Types of Involvement (Epstein, 2009; Li et al., 2024), particularly in communication, learning at home, and decision-making. Collaborative planning where parents contributed ideas for math activities using household items positioned them not as passive recipients of information but as co-creators of pedagogy. This aligns with Collins et al. (2024), who advocate for family-school partnerships as dynamic, reciprocal processes that enhance academic, behavioral, and health outcomes.

Mechanisms of Change: Insights from Qualitative Findings

The qualitative phase of the study enriched the quantitative findings by uncovering how and why the intervention was effective. Through thematic analysis, five core themes emerged, supported by insights from both parents and teachers. These are outlined in Table 5.

Table 5. Emerging Themes from Interviews and Focus Groups

Theme	Description	Parent Quote	Teacher Quote
Strengthened Home–School Partnership	Frequent, coordinated collaboration between school and home	“Now we are involved in planning and see their progress.” (Parent 3)	“They are not just observers but co-facilitators.” (Teacher 2)
Increased Child Engagement	Children became more motivated and focused during math-based play	“My daughter asks to play number games at home.” (Parent 5)	“Now they are excited when we start math games.” (Teacher 1)
Learning in Daily Routines	Parents used everyday routines as math learning opportunities	“I count with my child during meals or brushing teeth.” (Parent 7)	“Some parents even made math games using kitchen tools.” (Teacher 4)
Health and Behavioral Gains	Improved physical activity, stamina, and classroom participation	“He now counts stairs at home and is more energetic.” (Parent 10)	“They are now more coordinated and active in class.” (Teacher 6)
Implementation Challenges	Time/resource constraints and difficulty in replicating activities	“It’s difficult with work, and we lack some materials.” (Parent 12)	“We tried to simplify tasks, but it wasn’t easy for all parents.” (Teacher 5)

The qualitative findings revealed a dynamic interplay of factors that contributed to the effectiveness of the intervention, with several recurring themes offering more profound insights into the experiences of parents and teachers. One of the most salient themes was the strengthened home-school partnership. Parents reported feeling more connected and informed about their children’s learning,

while teachers noted an apparent increase in collaborative spirit and shared responsibility. This aligns strongly with Vygotsky’s socio-cultural theory (Tzuriel, 2021), which posits that cognitive development is deeply rooted in social interaction and mediated by more knowledgeable others—such as parents and educators who actively engage in children's learning environments.

Equally significant was the observed increase in child engagement. Parents and teachers consistently noted that children became more enthusiastic and focused, particularly when mathematical content was presented through playful and movement-rich experiences. This finding resonates with the work of Yu (2022), who emphasized that guided play facilitates deeper cognitive processing, supports motivation, and provides an effective alternative to traditional didactic instruction. In this context, the play served as an engagement strategy and a vehicle for meaning-making and concept internalization.

Another theme that emerged was the integration of learning into daily routines. Many parents described how they began incorporating numeracy tasks into everyday household activities such as counting fruit slices during snack time or comparing quantities while preparing meals. These actions reflect learning as guided participation within culturally meaningful contexts (Shadiev et al., 2024), highlighting that cognitive development is situated and experiential. By transforming daily practices into learning opportunities, families extended the classroom experience into home-life rhythms, reinforcing learning through authentic engagement.

Beyond academic and cognitive gains, notable improvements in health and behavioral outcomes were also observed. Children appeared more physically active, showed greater stamina, and displayed enhanced attention spans and participation during class. These observations are consistent with the whole-child approach advocated by Johnstone et al. (2022), which stresses the interconnected nature of physical, emotional, and cognitive development. The findings suggest that when learning experiences are holistically designed blending movement, meaningful content, and social interaction they can simultaneously positively influence multiple domains of development.

However, the implementation process was not without challenges. Some parents reported difficulties maintaining consistency due to time constraints, work obligations, or lack of access to materials used in class-based activities. These barriers point to the importance of providing differentiated support strategies to accommodate the varying capacities of families. They also bring to light broader equity issues, suggesting that even well-designed interventions must be sensitive to contextual and structural limitations to be sustainable and inclusive.

Thematic Structure of Engagement and Learning Processes

The richness of these qualitative insights is further articulated in the hierarchical coding structure presented in Table 6, which systematically organizes the emerging themes and sub-themes alongside representative quotes. This framework, constructed following Clarke and Braun's (2017) six-phase model of thematic analysis, offers a transparent and rigorous basis for understanding the complex mechanisms by which collaborative engagement and play-based learning foster developmental change in early childhood.

Table 6. Hierarchical coding structure

Level	Code	Description	Example Quote
Theme	Strengthened Home–School Partnership	Increased two-way communication and shared planning between teachers and parents	“We are now involved in planning and see their progress.” (P3)
Sub-theme	Regular Dialogue	Frequent interactions via journals, WhatsApp, meetings	“They [parents] are now co-facilitators.” (T2)
Theme	Increased Engagement	Children became more excited and focused during math and movement-based learning.	“She brings the activity from school into our living room.” (P5)
Sub-theme	Enthusiasm for Learning	Observable joy and motivation in doing math through play	“They are excited every time we play math games.” (T1)
Theme	Learning in Daily Routines	Use of household routines as platforms for mathematical learning	“I teach numbers while preparing food.” (P7)
Sub-theme	Math in Everyday Life	The natural integration of math concepts during home tasks	“Parents made games using kitchen tools.” (T4)

Level	Code	Description	Example Quote
Theme	Visible Behavioral and Health Gains	Positive changes in motor activity, stamina, and classroom attention	“He counts stairs at home, more energetic now.” (P10)
Sub-theme	Increased Physicality	Improved movement, activity level, and focus	“Some children who used to sit are now very active.” (T6)
Theme	Implementation Challenges	Constraints faced by parents in replicating or sustaining activities at home	“It’s difficult with work and materials.” (P12)
Sub-theme	Time and Resource Constraints	Parents' schedules, lack of resources, or difficulty understanding instructions	“Some parents struggled to follow through.” (T5)

The conceptual interplay among these themes is synthesized in **Figure 3**, which presents a **visual thematic map** of collaborative engagement and child development outcomes. This diagram illustrates how parental-teacher collaboration is a central mechanism, linking play-based math learning to measurable improvements in children’s motor skills, health behaviors, and emotional engagement.

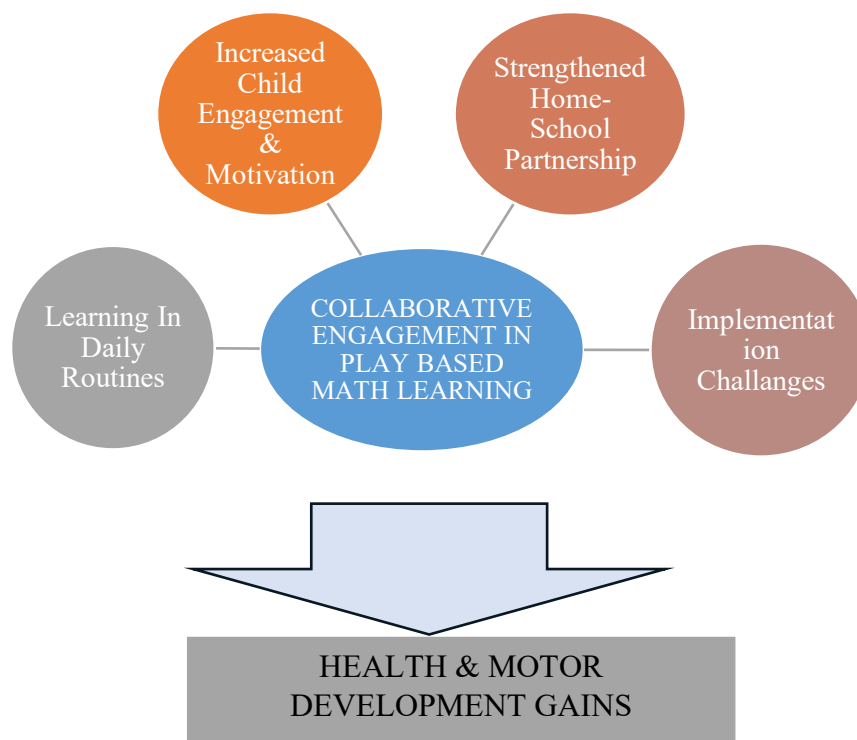


Figure 3. Thematic Map of Collaborative Engagement and Child Development Outcomes

At the culmination of this study, several important reflections emerge regarding its novelty, limitations, and avenues for future research. One of the key contributions of this research lies in its integrated approach to early childhood development specifically, the combination of parental-teacher engagement, play-based mathematical learning, and child health promotion within a single intervention framework. Unlike previous studies that often focus solely on cognitive or motor domains in isolation, this study presents compelling evidence that a collaborative, movement-integrated instructional model enhances preschoolers’ motor and cognitive abilities and positively influences behavioral regulation and physical health. Moreover, using a mixed-method sequential explanatory design enriches this contribution by quantifying developmental outcomes and uncovering the underlying mechanisms through which these outcomes were realized offering a rare, multidimensional perspective in early childhood education research. The inclusion of home-based replication of school activities adds further originality, responding to calls in the literature for more ecologically valid and family-centered pedagogies that reflect children’s everyday realities.

Despite these contributions, several limitations must be acknowledged. First, the study was conducted in three purposively selected early childhood centers in an urban Indonesian context, which may limit the generalizability of findings to more rural or culturally diverse settings. Second, while the PDMS-2 and health monitoring checklist provided robust quantitative data, the reliance on teacher and parent reports for specific health indicators introduces the potential for reporting bias. Third, although the study emphasized collaboration, the varying degrees of parental availability and digital literacy inevitably influenced the consistency of home-based implementation. Finally, while the qualitative findings offered rich insight, future research may incorporate children's voices directly—through age-appropriate interviews or observational narratives to deepen understanding of their experiences within such integrative learning environments.

Given these insights and limitations, several recommendations can be proposed for future research. Subsequent studies should aim to replicate and extend this intervention in more diverse sociocultural contexts to examine its adaptability and scalability. It would also be valuable to conduct longitudinal follow-ups to assess the persistence of developmental gains over time, particularly about academic readiness, self-regulation, and long-term health behaviors. Additionally, future interventions may benefit from integrating digital technologies for instructional delivery and real-time monitoring and feedback between families and educators. Lastly, researchers are encouraged to explore further differentiated strategies for family engagement responsive to structural inequities and individualized needs, ensuring that collaborative learning models are both inclusive and sustainable across varying educational landscapes.

CONCLUSION

This study concludes that integrating parental-teacher engagement with play-based mathematical learning significantly enhances preschoolers' motor development and health outcomes. Quantitative results showed consistent improvements across all motor domains, supported by large effect sizes, while health indicators such as physical activity, nutrition, and sleep behaviors also improved markedly. These outcomes affirm that when learning is rooted in physical, playful, and socially collaborative experiences, it supports cognitive and academic growth and fosters holistic child development. Qualitative findings reinforced these results, revealing strengthened home-school partnerships, increased child engagement, and the integration of learning into meaningful daily routines such as time and resource constraints among parents suggests the importance of equity and contextual adaptability in future interventions. Overall, this research emphasizes the value of collaborative, movement-integrated learning models that position families as co-educators and promote developmentally responsive practices in early childhood education.

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AUTHOR CONTRIBUTIONS

Author 1 creates articles, creates instruments and responsible for research; author 2-3 Analyzes research data that has been collected, and author 4-5 assist in research data analysis, instrument validation, and input research data.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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