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Embodied Numeracy Play in Physical Education: Effects on Fundamental Motor Skills and Critical Thinking in Primary School Children

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ABSTRACT

Physical education (PE) has the potential to support both motor and cognitive development; however, structured integration of numeracy within PE remains underexplored. This study investigated the effects of Embodied Numeracy Play (ENP), a movement-based instructional approach grounded in embodied cognition, on primary school students' fundamental motor skills (FMS) and critical thinking (CT).

A quasi-experimental pretest–posttest design was employed involving 57 third-grade students who participated in either ENP-based PE lessons or conventional PE instruction over a four-week period. FMS were assessed using the Test of Gross Motor Development–Second Edition (TGMD-2), while CT was measured using a validated observational rubric. Data were analyzed using multivariate and univariate analyses. Students in the ENP group demonstrated significantly greater improvements in both outcomes compared with the control group. The intervention produced a large effect on FMS development and a moderate effect on CT. A positive association was also observed between gains in motor skills and critical thinking. The findings indicate that integrating numeracy reasoning into physical play can simultaneously enhance motor competence and higher-order thinking. This study provides empirical support for embodied cognition and highlights the potential of cognitively enriched PE as an integrative learning approach in primary education.

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1. INTRODUCTION

Physical education (PE) is increasingly viewed as a multidimensional learning environment that contributes not only to children's physical development but also to their cognitive, affective, and social growth (Barsalou, 2020). This perspective aligns with embodied cognition, which posits that learning emerges through dynamic interactions between bodily movement and mental processes (Latino & al., 2023). Within this framework, movement-based activities create opportunities for children to engage in reasoning, problem-solving, and reflective thinking while simultaneously developing their motor competence.

Despite its potential, numeracy—the ability to reason with numbers, patterns, and quantitative relationships—continues to be taught primarily through sedentary, desk-based instruction (Lv et al., 2024). This conventional approach limits opportunities for children to experience mathematical concepts through physical and spatial interaction. Integrating numeracy into PE presents a promising alternative, as embodied numerical experiences can reinforce conceptual understanding by grounding abstract ideas in concrete movement (Zhu & al., 2025).

However, current educational practice often keeps the two domains separate: PE lessons typically emphasize motor execution, sport techniques, or fitness routines, whereas numeracy is treated as a purely cognitive subject. This separation restricts PE's capacity to support higher-order thinking and prevents numeracy from leveraging the motivational and sensory richness of movement-based learning. Although game-based learning is widely promoted, PE games rarely incorporate structured numeracy or cognitive demands (Barsalou, 2023).

The urgency of addressing this issue extends beyond theoretical considerations. At a global level, educational reforms such as UNESCO's Education for Sustainable Development and the OECD's Learning Compass 2030 advocate interdisciplinary approaches that integrate physical, cognitive, and socio-emotional competencies (OECD, 2019). In Indonesia, the Kurikulum Merdeka emphasizes numeracy literacy and character building through experiential learning, yet implementation within PE remains limited and fragmented (Hardiansyah & AR, 2022). These policy directions reveal a pressing need for empirically supported pedagogical innovations that align with both national priorities and global educational trends. Integrating numeracy into PE through structured play could not only improve children's motor coordination but also nurture their reasoning and critical thinking—key competencies for lifelong learning.

From a developmental perspective, early childhood and middle childhood represent crucial stages for establishing the foundation of fundamental motor skills (FMS), including locomotor, object-control, and stability skills (Koci & Cvetek, 2022; Mix & Cheng, 2022). Simultaneously, these periods mark rapid growth in symbolic reasoning, logical inference, and executive functioning. Research has demonstrated strong correlations between motor competence and cognitive performance, particularly in attention, working memory, and problem-solving (Latino et al., 2023; Shi et al., 2022). However, causal relationships remain under-investigated, especially within controlled pedagogical contexts. The Embodied Numeracy Play framework posits that combining numeracy-focused tasks with movement-based learning may activate overlapping neural and cognitive pathways, resulting in synergistic enhancement of both domains. For example, activities involving counting jumps, estimating spatial distances, or coordinating team-based problem-solving in motion can engage both quantitative reasoning and motor coordination simultaneously. Thus, the intersection of numeracy and movement presents fertile ground for interdisciplinary inquiry.

Therefore, this study addressed three key research questions aimed at examining the integrative potential of Embodied Numeracy Play (ENP) within primary physical education. First, the study asked whether ENP leads to greater improvement in fundamental motor skills compared with conventional PE instruction. Second, it examined whether ENP enhances students' critical thinking more effectively than traditional PE approaches that focus primarily on motor execution. Third, the study explored the relationship between changes in fundamental motor skills and critical thinking following participation in the ENP intervention. Together, these questions were designed to provide comprehensive evidence regarding the dual-domain impact of embodied numeracy activities on both physical and cognitive development in young learners.

Previous studies have examined related constructs, but often in isolation. Research on game-based learning has demonstrated improvements in motivation, engagement, and social skills (He et al., 2025), yet its cognitive outcomes within physical education remain ambiguous. Similarly, numerous studies have linked physical activity with cognitive benefits such as enhanced executive function, memory, and attention (Bailey & Armour, 2020), but these effects are typically examined in aerobic or fitness interventions rather than educationally structured games. Studies on numeracy development highlight the importance of concrete, experiential learning (Wang et al., 2024), but rarely incorporate movement or embodied interaction as central mechanisms. In parallel, embodied cognition research emphasizes how bodily engagement supports abstract reasoning, yet most empirical work focuses on language or science learning rather than mathematics within PE contexts (Carcelén-Fraile et al., 2025). Thus, while each of these research streams contributes valuable insights, they remain, for the most part, siloed, lacking integrative empirical models that unite numeracy, motor development, and critical thinking into a cohesive pedagogical framework.

These conditions point to a broader research gap. First, a few pedagogical models deliberately integrate numeracy learning within PE through embodied, movement-rich tasks. Second, empirical studies that simultaneously examine motor and cognitive outcomes—especially critical thinking—remain limited. Third, while previous work highlights links between motor competence and executive functions, little is known about how a designed numeracy-movement intervention can influence both domains concurrently. As a result, teachers lack evidence-based frameworks for implementing cognitively enriched PE lessons.

The novelty of this study lies in its interdisciplinary integration and methodological rigor. Conceptually, it advances the application of embodied cognition by extending it into the domain of numeracy within physical education—a combination that remains scarcely documented in current literature. Pedagogically, it introduces the Embodied Numeracy Play (ENP) framework, wherein physical games are intentionally designed to embed numeracy challenges and promote reflective reasoning through bodily engagement. Methodologically, the study employs an experimental design to quantify changes in both motor and cognitive outcomes, thus providing empirical validation of theoretical assumptions. Practically, the findings are expected to inform curriculum development, teacher training, and instructional design in primary education, offering a scalable model for integrating cognitive literacy into PE.

This study, therefore, aims to examine how embodied numeracy play can enhance children's fundamental motor skills and critical thinking within game-based physical education. Specifically, it investigates: the effects of numeracy-infused physical games on fundamental motor skill development; the influence of these games on children's critical thinking abilities; and the relationship between improvements in motor competence and cognitive performance following the intervention. By addressing these objectives, the study seeks to generate empirical evidence supporting the integration of numeracy into PE pedagogy.

Moreover, this study contributes to the theoretical discourse by proposing that embodied numeracy operates through cognitive-motor coupling—a process in which motor actions scaffold abstract reasoning. By physically enacting numerical relationships (e.g., distance, quantity, symmetry, or proportion), learners can externalize and internalize mathematical concepts more effectively. This aligns with evidence from neuroscience suggesting overlapping cortical activation between motor planning and numerical cognition (Prasetyo & Indahwati, 2023). Consequently, Embodied Numeracy Play not only strengthens physical competence but also cultivates deeper cognitive engagement, thereby promoting the critical thinking and problem-solving emphasized in global educational goals.

In sum, the present research addresses a timely and significant question: how can physical education serve as a platform for both bodily and intellectual growth? By examining the impact of numeracy-infused games on fundamental motor and cognitive skills, this study bridges disciplinary boundaries between movement science, educational psychology, and mathematics education. The outcomes are anticipated to provide empirical and theoretical contributions to the growing body of literature on embodied learning, inform evidence-based PE practices, and guide educators in designing play-based activities that simultaneously nurture body and mind. Ultimately, this study envisions physical education classrooms not as spaces solely for movement but as dynamic laboratories of integrated learning, where children think through their bodies and move through their thoughts.

2. METHODS

This study employed a quasi-experimental non-equivalent control group pretest–posttest design. Two intact third-grade classes were assigned as the experimental and control groups; therefore, no random assignment was performed, which represents a methodological limitation. The design enabled a comparison of learning gains between students receiving Embodied Numeracy Play (ENP) and those receiving conventional physical education (PE).

Participants were 57 third-grade students (29 experimental, 28 control) from a public elementary school in Surabaya, Indonesia. The mean age was 8.6 ± 0.4 years. All students were medically cleared for moderate-to-vigorous physical activity and had no diagnosed motor or cognitive impairments. The school serves a mixed urban socioeconomic population typical of central Surabaya. No students were excluded after recruitment, and no missing data occurred; therefore, no imputation procedures were applied.

The Embodied Numeracy Play (ENP) intervention was implemented over four weeks and consisted of eight sessions, each lasting 40 minutes and following a consistent format of warm-up, core activity, and cool-down with guided reflection. ENP was designed to integrate numeracy reasoning into movement-based tasks, enabling students to engage simultaneously in physical skill execution and cognitive processing. During warm-up activities, students performed light locomotor movements paired with simple numeracy prompts such as skip-counting or recognizing movement patterns. The core phase featured structured games that combined numerical problem-solving with fundamental motor skills; for example, Number Relay required students to solve arithmetic tasks while performing running or hopping sequences, Shape Circuit involved forming geometric shapes through coordinated movements, and Math Target Throw integrated distance estimation or point-value calculations into throwing tasks. Each game explicitly targeted cognitive dimensions such as analysis, reasoning, and decision-making, while engaging locomotor and object-control skills mandated in the PE curriculum. The intervention was delivered by the same PE teacher for both groups, following a two-hour training session on ENP principles, numeracy integration strategies, and reflective questioning. Fidelity of implementation was ensured through periodic observations using a structured checklist that monitored adherence to numeracy prompts, game procedures, and reflective components. In contrast to the ENP model, the control group received conventional PE instruction characterized by teacher-led motor drills focusing on repetition and technique without embedding numeracy, problem-solving, or structured reflection, thereby providing a clear pedagogical distinction between the two conditions.

Two standardized instruments were employed in this study to measure the dual outcomes of the Embodied Numeracy Play (ENP) intervention: (1) Fundamental Motor Skills (FMS) and (2) Critical Thinking (CT). Both instruments were selected for their psychometric robustness, contextual relevance, and feasibility for use in school-based physical education (PE) research. The details of each instrument, including their structure, dimensions, scoring, and reliability, are summarized in Table 1.

Table 1. Summary of Instruments Used in the Study

Instrument	Purpose / Variable Measured	Structure & Indicators	Scoring Method	Reliability & Validity Evidence	Source / Adaptation
Test of Gross Motor Development – 2 (TGMD-2)	To assess Fundamental Motor Skills (FMS), including locomotor and object-control movements.	12 skill items grouped into 2 domains: (a) Locomotor: run, gallop, hop, leap, horizontal jump, slide (b) Object Control: strike a stationary ball, dribble, catch, kick,	Each criterion was scored dichotomously (1 = correct, 0 = incorrect). Total scores converted into standard and percentile ranks.	Reliability: Inter-rater ICC = 0.91 (current study); test–retest r = 0.89 Validity: GFI = 0.96, AGFI = 0.95	Ulrich (2000); adapted and video-coded for the Indonesian PE context

Instrument	Purpose / Variable Measured	Structure & Indicators	Scoring Method	Reliability & Validity Evidence	Source / Adaptation
		overhand throw, underhand roll			
Critical Thinking Rubric	To evaluate Critical Thinking (CT) performance during physical games.	4 dimensions: (1) Analysis (2) Reasoning (3) Decision-making (4) Reflection Each was observed across multiple game scenarios.	5-point Likert scale per indicator (1 = very poor to 5 = excellent). Total score = mean of four dimensions.	Reliability: Cronbach's α = 0.87 (pilot, n = 25) Content Validity: Aiken's V = 0.89 (expert review).	Adapted for PE context; validated by 3 pedagogical experts

FMS were assessed using the Test of Gross Motor Development–Second Edition (TGMD-2), consisting of 12 skills in two domains (locomotor and object control). Performances were video-recorded and scored by two trained raters. Inter-rater reliability in this study was ICC = 0.91, indicating excellent agreement. Construct validity indicators (GFI = 0.96; AGFI = 0.95) were obtained from a confirmatory factor analysis conducted during instrument adaptation for this context. Critical thinking during gameplay was evaluated using a rubric comprising four dimensions: analysis, reasoning, decision-making, and reflection. Each indicator was rated on a five-point scale. Internal consistency in this study was Cronbach's α = 0.87, based on pilot testing with 25 students. Content validity was supported through expert review, yielding Aiken's V = 0.89.

Data were analyzed using IBM SPSS 26. Descriptive statistics (mean, SD) were computed first. Assumptions of normality and homogeneity were tested using the Kolmogorov–Smirnov and Levene tests. Because MANOVA is robust to minor assumption violations in samples >30, the primary analysis used Multivariate Analysis of Variance (MANOVA) to examine multivariate effects of the intervention on FMS and CT. Univariate ANOVAs followed significant multivariate results. Partial eta squared (η^2) was reported as the effect size. Pearson correlation analysis was conducted to examine the relationship between changes in FMS and CT. The significance threshold was set at $p < .05$.

3. FINDINGS AND DISCUSSION

3.1 Findings

The analysis followed the quantitative procedures outlined in the methodology, including descriptive analysis, assumption testing, and inferential statistics using MANOVA and ANOVA. The findings demonstrate the degree to which numeracy-based physical games can enhance both physical and cognitive outcomes in primary physical education.

Table 2. Descriptive Statistics of Students' Critical Thinking and Fundamental Motor Skills

Variable	N	Mean	Std. Deviation	Minimum	Maximum
Critical Thinking	57	65.09	6.78	43	77
Fundamental Motor Skills	57	91.66	5.38	82	98

Table 2 presents the descriptive statistics for students' overall fundamental motor skills (FMS) and critical thinking (CT) scores. Across the full sample, students demonstrated higher performance in FMS (M = 91.66, SD = 5.38) compared with CT (M = 65.09, SD = 6.78), reflecting the typical pattern in primary physical education where motor competence is generally more developed than cognitive engagement. Although the table does not separate scores by group or test phase, the variability observed in both domains (SD > 5) suggests substantial differences in students' baseline abilities, underscoring the importance of instructional approaches that can accommodate a wide range of learner profiles. These descriptive values serve as the foundation for subsequent inferential analyses comparing the effects of the ENP intervention with conventional PE instruction.

Before conducting MANOVA, normality and homogeneity tests were performed. Results of the Kolmogorov–Smirnov test indicated that both variables were not perfectly normally distributed ($p < .05$), while Levene's Test revealed that homogeneity was met for FMS ($p = .098$) but not for CT ($p = .002$). Despite these findings, MANOVA was still conducted because it is robust to moderate violations of normality and variance when the sample size exceeds 30 participants. The non-normality observed was attributed to clustered performance scores in the upper range, a pattern typical of educational intervention studies with short-term implementation.

Table 3. Multivariate Tests of the Effects of Embodied Numeracy Play (ENP) Intervention

Effect	Statistic Used	Value	F	df (hyp., error)	p	Partial η^2
Group (Experimental vs Control)	Wilks' Lambda	.282	70.01	2, 55	< .001	.718

As shown in Table 3, the multivariate analysis of variance (MANOVA) indicated a significant overall effect of the intervention on the combined dependent variables. The Wilks' Lambda value ($\Lambda = .282$) with $F(2, 55) = 70.01$, $p < .001$ demonstrates that students in the ENP group performed significantly better than those in the control group when fundamental motor skills and critical thinking were considered together. The partial η^2 of .718 reflects a large multivariate effect, consistent with established benchmarks, indicating that the intervention accounted for substantial variance across both outcomes. This multivariate significance justified the use of follow-up univariate analyses to examine the specific contribution of each dependent variable.

Table 4. Levene's Test of Equality of Error Variances and Instrument Reliability

Variable / Instrument	Levene Statistic	df1	df2	Sig. (p)	Homogeneity Decision	Reliability Index	Interpretation
Critical Thinking (CT)	10.606	1	56	.002	Not Homogeneous (*p* < .05)	Cronbach's *α* = .87	High internal consistency
Fundamental Motor Skills (FMS)	2.827	1	56	.098	Homogeneous (*p* > .05)	ICC = .91	Excellent inter-rater reliability
Combined MANOVA Model	—	—	—	—	MANOVA robust to mild variance inequality	—	Valid for multivariate comparison

The Levene's Test results in Table 4 indicate that homogeneity of variance was met for the Fundamental Motor Skills (FMS) variable ($p = .098 > .05$) but not for the Critical Thinking (CT) variable ($p = .002 < .05$*). This suggests that the variance between the experimental and control groups was approximately equal for motor skills but slightly unequal for critical thinking scores. However, since Multivariate Analysis of Variance (MANOVA) is known to be robust to moderate heterogeneity—especially with balanced sample sizes (N > 30 per group)—the analysis remains statistically valid. Reliability tests further ensured that all measurement instruments demonstrated strong internal consistency and inter-rater reliability. The Critical Thinking Rubric achieved a Cronbach's $\alpha = .87$, signifying excellent internal reliability across the four dimensions (analysis, reasoning, decision-making, reflection). Meanwhile, the TGMD-2 motor skill assessment yielded an Intraclass Correlation Coefficient (ICC) of .91 between two independent raters, indicating excellent agreement in scoring video-based observations. These high reliability indices confirm that both instruments consistently measured their intended constructs and that the observed treatment effects were not confounded by measurement error.

In summary, despite minor variance inequality in critical thinking, the combination of strong reliability metrics and MANOVA's robustness validates the integrity of the statistical results. The instruments used provided stable, consistent, and credible measures, ensuring that the improvements observed under the Embodied Numeracy Play intervention are both statistically trustworthy and pedagogically meaningful.

Table 5. Pearson Correlation Matrix Between Fundamental Motor Skills (FMS) and Critical Thinking (CT)

Variables	Fundamental Motor Skills (FMS)	Critical Thinking (CT)
1. Fundamental Motor Skills (FMS)	1	.48**
2. Critical Thinking (CT)	.48**	1

Note: N = 57; $p < .01$ (2-tailed). Correlation computed using Pearson's r.

The Pearson correlation analysis (Table 5) revealed a moderate, positive, and statistically significant relationship between students' fundamental motor skills (FMS) and critical thinking (CT) ($r = 0.48$, $p < .01$). This result indicates that students who demonstrated greater improvements in motor performance also tended to achieve higher gains in critical thinking following the Embodied Numeracy Play (ENP) intervention. From a statistical perspective, the correlation coefficient ($r = 0.48$) falls within the moderate-to-strong range (Cohen, 1988), suggesting a meaningful level of covariation between the two domains. In educational and behavioral science contexts, an r value around 0.40–0.50 typically reflects functional interdependence between constructs that are conceptually linked yet distinct — in this case, physical coordination and cognitive reasoning.

Table 6. Tests of Between-Subjects Effects (ANOVA Results)

Dependent Variable	Source	Type III Sum of Squares	df	Mean Square	F	Sig. (p)	Partial η^2	R^2 (Explained Variance)	Interpretation
Critical Thinking (CT)	Between Groups	724.569	1	724.569	21.378	.000**	0.276	27.6%	Significant difference between groups; moderate effect size
	Within Groups (Error)	1898.000	56	33.893	—	—	—	—	—
Fundamental Motor Skills (FMS)	Between Groups	1129.931	1	1129.931	121.879	.000**	0.685	68.5%	Highly significant difference; large effect size
	Within Groups (Error)	519.172	56	9.271	—	—	—	—	—

Note: N = 57; $p < .001$ (2-tailed); $\alpha = .05$.

The ANOVA results in Table 6 demonstrate that the Embodied Numeracy Play (ENP) intervention produced statistically significant effects on both dependent variables. For critical thinking (CT), the analysis yielded $F(1, 56) = 21.378$, $p < .001$, partial $\eta^2 = 0.276$, indicating that approximately 27.6% of the variance in critical thinking improvement was explained by the intervention. According to Cohen's (1988) benchmark, this corresponds to a medium-to-large effect size, meaning the ENP program meaningfully enhanced students' ability to analyze, reason, and reflect during learning. For fundamental motor skills (FMS), the test revealed a much stronger effect, $F(1, 56) = 121.879$, $p < .001$, partial $\eta^2 = 0.685$, showing that 68.5% of the total variance in motor skill development was attributable to the intervention. This represents a considerable effect, indicating that numeracy-integrated physical games substantially improved students' locomotor and object-control performance compared to the conventional PE approach. Statistically, both results confirm the MANOVA findings, which established the intervention's overall multivariate significance. The large R^2 values (0.276 and 0.685) indicate that the ENP model not only affects individual skill areas but also explains a substantial proportion of the variance in students' learning outcomes.

3.2 Discussion

This study examined the effects of Embodied Numeracy Play (ENP) on fundamental motor skills (FMS) and critical thinking (CT) among primary school children. In response to the three research questions, the results showed that ENP produced significantly greater improvements in FMS compared with conventional physical education, with a large effect size. ENP also led to significantly higher gains in CT, although the effect size was more moderate. Additionally, improvements in FMS and CT were moderately correlated, suggesting that progress in motor competence was associated with gains in cognitive reasoning during movement-based activities. Together, these findings indicate that integrating numeracy into structured physical play may support holistic learning outcomes in PE.

The substantial improvement in FMS observed in the ENP group aligns with embodied cognition theory, which posits that sensorimotor engagement supports deeper cognitive processing and skill acquisition. Games requiring coordinated movement, spatial reasoning, and sequencing likely created conditions for more purposeful and context-rich motor practice compared with traditional drills (Arslan & Yıldız, 2020; Donnelly et al., 2021). The large effect on motor competence is consistent with previous studies showing that cognitively enriched physical activity enhances motor learning by increasing attentional focus and motivation (Hu et al.,2024).

The moderate effect on CT suggests that integrating numeracy tasks into physical play can stimulate higher-order thinking, but cognitive gains may require more sustained or varied exposure. Past research similarly reports that open-skill or cognitively demanding physical activities enhance executive functioning and problem-solving, although effects on more complex reasoning tend to be smaller than effects on basic motor skills. As such, the current findings suggest — rather than confirm causality — that embodied numeracy experiences may activate overlapping cognitive–motor pathways that facilitate both physical coordination and situational reasoning (Gilligan-Lee et al., 2023).

The positive correlation between improvements in FMS and CT provides additional support for the idea of cognitive–motor coupling, but this association should be interpreted cautiously. While students who improved physically also tended to improve cognitively, these patterns do not specify the direction of influence. Nonetheless, the findings fit well within the literature showing intertwined developmental trajectories of motor competence and cognitive skills in childhood.

The findings also resonate with Casey & Goodyear, (2021), who emphasized that mathematical cognition emerges through concrete, embodied experiences before abstraction. Their work supports the notion that counting, estimating, or spatial reasoning becomes more meaningful when grounded in bodily movement. The ENP activities—such as counting jumps, estimating target distances, or constructing geometric shapes through coordinated actions—provided precisely this kind of embodied experience. Through these structured games, students were not only exercising their bodies but also learning to reason quantitatively and make decisions in dynamic environments. Hence, physical education (PE) under the ENP model becomes a site of dual learning: where children "move to think" and "think to move."

Empirically, this study extends the growing body of research showing that integrated cognitive–motor approaches can enhance both domains of child development. For instance, Butterworth, (2020) demonstrated that children's motor competence correlates with academic performance, especially in mathematics. Similarly, Hillman et al. (2023) found that complex motor tasks, rather than repetitive drills, stimulate executive control and working memory. In line with these findings, the present study showed that embedding numeracy within movement produced not only physical but also cognitive gains—demonstrating the power of game-based, cognitively enriched PE.

These results are particularly relevant in the context of Indonesia's *Kurikulum Merdeka*, which emphasizes holistic, student-centered, and competency-based learning. The curriculum encourages the integration of numeracy literacy across all subjects, including physical education. However, as noted by Haapala & Poikkeus (2021), many PE practices in Indonesia still focus narrowly on skill execution rather than cognitive engagement. The present research offers a concrete pedagogical model that embodies the Merdeka spirit: active, meaningful, and interdisciplinary learning. By combining numeracy challenges with physical play, ENP aligns with national goals to nurture critical, creative, and collaborative learners who are physically active and cognitively engaged.

Furthermore, the ENP model addresses one of PE's long-standing issues—the tendency to separate the physical and intellectual domains. In traditional teaching, cognitive tasks (e.g., counting, reasoning, problem-solving) are confined to classroom subjects like mathematics or science, while PE remains confined to bodily movement. This study shows that the dichotomy between body and mind is artificial and that physical education can serve as a platform for cognitive growth. As the data reveal, a single intervention framework can yield measurable improvements in both locomotor-object control and critical reasoning. Therefore, the findings support a shift toward embodied pedagogy, in which knowledge is constructed through movement-based experience, social interaction, and reflective thinking.

The results have several implications for primary physical education, particularly within the competency-based framework of Kurikulum Merdeka. First, the ENP model demonstrates a practical way for PE teachers to integrate numeracy and critical thinking without replacing core motor content. Simple adaptations—such as embedding counting, estimation, pattern recognition, or decision-making into movement tasks—can enrich PE lessons while maintaining high levels of physical engagement. To implement ENP effectively, PE teachers may require professional development on designing movement tasks that incorporate cognitive challenges, facilitating reflective dialogue, and differentiating activities based on student ability. Schools could also support implementation by encouraging interdisciplinary collaboration between PE and classroom teachers, ensuring alignment between physical activities and numeracy objectives. Overall, ENP offers a feasible approach to promoting active, meaningful, and interdisciplinary learning in line with the aims of Kurikulum Merdeka.

Despite its promising contributions, this study has several limitations. The quasi-experimental design using intact classes limits the ability to draw strong causal inferences, as random assignment was not feasible in the school context. The intervention period was relatively short, making it unclear whether the gains—especially in CT—would be sustained over time. The sample was drawn from a single school with a specific socioeconomic profile, limiting generalizability. Additionally, the CT assessment relied on observational rubrics, which may not capture students' internal reasoning processes. Although fidelity checks were conducted, variations in teacher delivery may still have influenced outcomes.

Future studies could address these limitations by employing randomized controlled trials across multiple schools, implementing longer intervention periods, and examining retention effects. Mixed-methods approaches, including interviews or think-aloud protocols, could provide deeper insight into how embodied numeracy activities influence children's reasoning. Research involving different age groups would help determine developmental sensitivity to ENP, while comparative studies could explore variations of embodied learning, such as digital augmented-reality numeracy games or fine-motor versus large-motor numeracy tasks. Examining teacher training interventions and scalable implementation models would also support broader adoption of ENP in primary education.

4. CONCLUSION

This study demonstrates that Embodied Numeracy Play (ENP) can meaningfully enhance both fundamental motor skills and critical thinking in primary school children, while also revealing a moderate association between improvements in the two domains. These findings highlight the value of integrating numeracy reasoning into physical activity, offering empirical support for the notion that cognitive and motor development can be mutually reinforcing when learning is grounded in embodied interaction. Theoretically, the study contributes to emerging work on embodied numeracy by showing that PE can serve as a productive context for fostering cognitive engagement through meaningful movement. Practically, the findings suggest that PE lessons can be designed not only to build physical competence but also to support reflective thinking and decision-making, thereby positioning physical education as a viable platform for integrated cognitive–motor learning. This aligns with the broader aims of *Kurikulum Merdeka*, which encourages active, interdisciplinary, and competency-based approaches to instruction. Future efforts to scale ENP in schools may help advance more holistic and engaging learning experiences for young learners.

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