Integrating game-based learning into Physical Education: effects on literacy and numeracy in early primary students

Integración del aprendizaje basado en el juego en la Educación Física: efectos sobre la alfabetización y la numeración en alumnos de educación primaria inicial

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Abstract

Introduction: Physical Education (PE) can incorporate academic objectives without diminishing activity levels. Integrating Game-Based Learning (GBL) into PE may improve students' reading and numeracy while sustaining engagement.
Objective: The study to investigate the impact of GBL-integrated PE sessions on the literacy and numeracy skills of early primary students.
Methodology: A quasi-experimental pretest–posttest control group design was implemented, which included 154 first-grade students (mean age = 6.8 years). The experimental group (n = 78) engaged in five PE–GBL sessions that integrated physical activity with academic activities, while the control group (n = 76) attended conventional PE lessons. Performance-based evaluations evaluated literacy and numeracy prior to and subsequent to the intervention. Data were examined employing non-parametric test.
Results: The experimental group exhibited substantial enhancements in literacy ($Z = -7.38$, $p < 0.001$, $r = 0.83$) and numeracy ($Z = -7.68$, $p < 0.001$, $r = 0.87$). Comparisons between groups indicated that the experimental group achieved superior posttest scores in literacy ($Z = -3.89$, $p < 0.001$) and numeracy ($Z = -5.63$, $p < 0.001$), with the most pronounced effect shown in numeracy improvements ($H(1) = 14.57$, $p < 0.001$).
Discussion: The findings confirm that physically active, GBL strengthens cognitive engagement and executive functioning relevant to academic learning.
Conclusions: GBL based on PE is a instructional model that is both effective and feasible for the purpose of improving academic performance, particularly in the area of numeracy, while simultaneously upholding the core objectives of PE.

Keywords

Game-based learning; Physical Education; embodied learning; literacy; numeracy; primary school.

Resumen

Introducción: La Educación Física (EF) puede incorporar objetivos académicos sin disminuir los niveles de actividad. Integrar el Aprendizaje Basado en el Juego (ABJ) en la EF puede mejorar la lectura y la numeración de los estudiantes, manteniendo su participación activa.
Objetivo: El estudio investigó el impacto de las sesiones de EF integradas con ABJ sobre las habilidades de alfabetización y numeración en alumnos de educación primaria inicial.
Metodología: Se aplicó un diseño cuasi-experimental con grupo de control pretest–postest que incluyó a 154 estudiantes de primer grado (edad media = 6.8 años). El grupo experimental (n = 78) participó en cinco sesiones de EF–ABJ que integraron actividad física con tareas académicas, mientras que el grupo de control (n = 76) asistió a clases convencionales de EF. Las evaluaciones basadas en el rendimiento midieron la lectura y la numeración antes y después de la intervención. Los datos se analizaron mediante pruebas no paramétricas.
Resultados: El grupo experimental mostró mejoras significativas en alfabetización ($Z = -7.38$, $p < 0.001$, $r = 0.83$) y numeración ($Z = -7.68$, $p < 0.001$, $r = 0.87$). Las comparaciones entre grupos indicaron que el grupo experimental obtuvo puntuaciones postest superiores en alfabetización ($Z = -3.89$, $p < 0.001$) y numeración ($Z = -5.63$, $p < 0.001$), con el efecto más notable en las mejoras de numeración ($H(1) = 14.57$, $p < 0.001$).
Discusión: Los hallazgos confirman que la actividad física combinada con ABJ fortalece la implicación cognitiva y las funciones ejecutivas relacionadas con el aprendizaje académico.
Conclusiones: El modelo de ABJ aplicado en EF es una propuesta instruccional eficaz y viable para mejorar el rendimiento académico, especialmente en numeración, manteniendo los objetivos fundamentales de la EF.

Palabras clave

Aprendizaje basado en el juego; Educación Física; aprendizaje corporizado; alfabetización; numeración; escuela primaria.

Introduction

Physical Education (PE), an inherently active discipline, can function as a cohesive platform to enhance cognitive and academic abilities while preserving its fundamental movement-oriented essence. PE as an inherently active discipline, can function as a cohesive platform to enhance cognitive and academic abilities while preserving its fundamental movement-oriented essence. Recent studies suggest that PE-based interventions can extend beyond physical skill enhancement to encompass cognitive and academic objectives as well. Research utilizing low-organization games has demonstrated that engaging and movement-oriented activities can enhance problem-solving, collaboration, and focus (Wiseman et al., 2019; Morales-Belando et al., 2022). The ecological-dynamics viewpoint of physical literacy posits that children acquire knowledge most effectively through embodied engagement with tasks that integrate motor and cognitive demands (Rudd et al., 2020). Incorporating academic content into PE, rather than simply adding movement to academic classes, coincides with this approach by establishing PE as a domain where physical, cognitive, and social realms converge concurrently.

Numerous studies have documented the association of students' academic performance that integrated learning in the PE classroom helps improve cognitive functions in students (Rodriguez et al., 2020; Sneck et al., 2019). In addition, cognitively stimulating physical active can significantly enhance problem-solving, memory, and executive functions and improve primary school children's math and literacy skills (Singh et al., 2019). Study conducted by Haverkamp et al. (2020) shown that integrating PE with numeracy content effectively improves children's on-task behavior and learning scores. The math-juggling program significantly increased children's enjoyment during math lessons (Berg, 2019) and was more effective in teaching new words (Schmidt et al., 2019). However, learning that integrates learning on PE to simulate cognitive skills still focuses primarily on students' numeracy abilities. Many students still fail to master basic skills despite years of primary school attendance (Friedlander, 2020), and 20% of adolescents cannot read simple texts with understanding (Ricketts et al., 2020). Stimulating literacy skills in primary school students is crucial because it encourages them to become competent citizens and acquire the necessary skills for full civic participation (Manu et al., 2021). Literacy skill stimulation is essential because it develops significantly over the last two years of middle school (grades 5–6) (Lindholm & Tengberg, 2019). Therefore, a concrete effort is needed simultaneously to stimulate students' numeracy and literacy performance.

GBL offers a pedagogical paradigm that inherently aligns with physical education by prioritizing active engagement, enjoyment, and cooperation. In the context of physical education, game-based learning has been shown to increase engagement, motivation, and perceived competence (Ratinho & Martins, 2023; Soriano-Pascual et al., 2022). It can also function as a medium for incorporating academic content, such as fundamental literacy and numeracy activities, into physically energetic games. Studies indicate that children develop physical engagement and essential academic competencies when cognitive components are incorporated into play-based movement activities (Segovia & Gutiérrez, 2022; Sarmantayev et al., 2020) . Thus, a PE-based GBL model can serve as an efficient method for promoting early academic growth while maintaining the core objectives of physical education.

This study examines integrated learning with PE to stimulate primary school students' numeracy and literacy skills. In this study, the terms literacy and numeracy specifically denote academic learning domains, rather than physical literacy. Literacy specifically refers to linguistic literacy, which encompasses students' capacity to identify, understand, and utilize letters, words, and meanings in basic reading and naming activities. Numeracy, on the other hand, pertains to fundamental mathematical literacy, involving the comprehension of numbers, the execution of simple counting, and the recognition of quantitative relationships. These domains were integrated into game-oriented physical activities necessitating mobility, teamwork, and cognitive engagement. Consequently, the study evaluates academic performance outcomes (linguistic and mathematical literacy) instead of motor proficiency or components of physical literacy, such as movement competence or confidence.

Ongoing global concerns about pupils' reading and numeracy skills underscore the importance of integrative teaching methods. Numerous young people continue to face challenges with reading comprehension and fundamental mathematical reasoning despite extensive education (Friedlander, 2020; Ricketts et al., 2020). The early development of these skills is crucial, as the foundations laid in the initial years of education significantly forecast long-term academic achievement (Lindholm & Tengberg, 2019;

Manu et al., 2021). Incorporating these learning objectives into PE sessions provides an efficient and comprehensive approach, fostering children's physical growth while enhancing critical cognitive skills.

The study was carried out by combining GBL approach implemented entirely within regular PE lessons to enhance literacy and numeracy performance. Conceptually, the intervention is a GBL-based PE model, not a classroom-based PAL program, designed to embed academic elements within structured, physically active play. the study aims to determine whether such a PE-anchored integrative model can effectively support both physical and academic development in young learners, contributing to current discussions on embodied and interdisciplinary education. This study uniquely integrates PA and GBL approaches to enhance primary students' numeracy and literacy skills. The results of this study provide strong evidence that GBL is a practical approach to integrated learning to stimulate primary school student's numeracy and literacy skills. For this reason, finding an operational model for using integrated learning with the PA and GBL approach that stimulates numeracy and literacy performance is necessary. It aligns with Xie and Chen (2023) state that integrated learning requires new content and pedagogical ideas beyond activities or lessons.

Method

Types of research

This study employs a quasi-experimental design with a pretest–posttest control group structure to investigate the impact of a GBL intervention, applied exclusively during PE courses, on enhancing students' literacy and numeracy skills. This research design incorporates two comparable groups: an experimental group that engaged in GBL-based PE activities integratively, and a control group that completed conventional PE sessions without academic content integration. Pretests and posttests are administered to assess variations in pupils' competencies. The gain score is determined as the difference between the posttest and pretest scores, thereby immediately representing the amount of learning that has occurred without the need for additional adjustments.

Participants

This study involved 154 first-grade elementary kids (86 boys and 68 girls; mean age = 6.8 years, SD = 0.38) from three public elementary schools in Pontianak City, West Kalimantan Province. Schools were selected using convenience sample methods, contingent upon their availability and willingness to participate. Consent for participation was obtained from the school, the student's parents or guardians, and the participating physical education instructors. Participation is optional, and the identities of all participants remain confidential throughout the data analysis process. Two whole classes were selected and recruited from each institution, resulting in a total of six classes. Due to the inability to randomize at the person level, randomization was conducted at the class level (cluster randomization). The quantity of available classes pragmatically defines the sample size. Three classes (n = 78) were designated as the experimental group, while three classes (n = 76) were allocated as the control group. The stratification process is employed to guarantee that each group comprises schools with similar social and pedagogical contexts. The inclusion criteria comprise physically fit students who consistently participate in physical education classes and do not have physical or cognitive disabilities. The physical condition was validated by school health records and corroboration from physical education instructors prior to the commencement of the investigation. Nonetheless, throughout the research implementation, all students in each class were retained to enhance its authenticity.

Procedure

All intervention and assessment activities were executed during PE class hours in accordance with the school timetable, with each session lasting 100 minutes as prescribed by the Indonesian primary school national physical education curriculum. The experimental group engaged in GBL-based integrative learning, merging physical activity with cognitive tasks related to literacy and numeracy, whereas the control group participated in traditional physical education activities centered on fundamental movements and collaboration, devoid of academic components. Four qualified physical education instructors conducted activities comprising two experimental class sessions and two control class sessions. Prior to implementation, all educators participated in a comprehensive two-hour training session conducted

by the research team to ensure a consistent understanding of GBL concepts, activity execution, and evaluation protocols.

The intervention consisted of five consecutive sessions spanning a five-week timeframe (refer to Table 1). The initial session was dedicated to orientation and pretest administration; the subsequent sessions two through four were allocated for the implementation of six low-structured GBL games modified from Gustian & Tomoliyus (2015) namely: (1) Gecko children's number play activity, (2) Guess the picture activity, (3) Guess the name activity, (4) Kangaroo counting activity, (5) Snakes and ladders activity, and (6) Number adventure activity.; and the final session was reserved for reflection and posttest administration. Due to schedule constraints, each school was permitted to conduct only two classes per week, culminating in a research series that spanned over 20 weeks across four schools. Nonetheless, the timetables for the experimental and control groups were coordinated to ensure that all participants engaged in the activities simultaneously, thereby reducing potential temporal bias. All games incorporated locomotor activities, such as running, jumping, and crawling. Cognitive tasks are inherently embedded within the game context; for instance, pupils leap in accordance with the numbers specified by the teacher, organize letter cards to construct words, or tally objects while in motion. Consequently, pupils are concurrently engaged both physically and cognitively, facilitating the process of experiencing learning (embodied learning).

Table 1. Learning Schedule

Phase	Sessions/weeks	Game Activity
Introduction	1	Introduction and explanations of learning activities Pre-test
Intervention	2	playing games 1 and 2
	3	playing games 3 and 4
	4	playing games 4 and 6
Evaluation	5	Reflection and Post-test

Instrument

The reading and numeracy skills of students were assessed using a performance-based observation tool specifically developed for this research. This instrument was modified from the activity-based assessment model created by Gustian & Tomoliyus (2015) and enhanced through consultations with two physical education pedagogy specialists and two educational assessment authorities. The final instrument comprises 12 task indicators, including six literacy indicators and six numeracy indicators. Each indicator is evaluated on a four-point scale: (1) the task was accomplished solely with complete assistance from the teacher, (2) the task was accomplished with partial assistance, (3) the task was accomplished independently but contained minor errors, (4) the task was accomplished independently and was entirely accurate. Two trained evaluators per class, blinded to the student groups, made independent observations and assessments.

Validity and reliability assessments are performed to confirm that the study instrument accurately measures students' cognitive skills in accordance with the defined concept. The tool was evaluated on 100 students who possessed features similar to those of the primary research subjects to gather empirical data. This method was selected for its perceived objectivity and its ability to demonstrate the statistical efficacy of each instrument item in assessing the intended construct. Validity testing was performed utilizing Pearson's product-moment correlation analysis to assess the relationship between each item's score and the overall total score of the instrument. The validity test results indicated a correlation between each item score and the total score (calculated r > table r 0.164). The subsequent stage involves doing a reliability test to evaluate the internal consistency among items within each dimension of ability. Reliability assessment was performed with Cronbach's Alpha (α) coefficient. The research indicated that all assessed constructs exhibited a Cronbach's Alpha value of 0.937, surpassing the threshold of 0.70, hence confirming the instrument's strong internal consistency. The test findings demonstrate that the study instrument is appropriate for assessing students' cognitive ability in literacy and numeracy skills.

Data analysis

Student performance scores are determined by averaging all indicators within each reading and numeracy domain. All indications are assigned equal significance. Each performance index is categorized into four classifications: Very Effective, Effective, Moderately Effective, and Weak. The parameters of this category are established in accordance with the national curricular competency standards for early elementary grades. Descriptive statistics, including mean, standard deviation, and 95% confidence intervals, are computed for each domain. The Kolmogorov-Smirnov test indicated that the majority of variables exhibited non-normal distribution ($p < 0.05$). Consequently, non-parametric analysis was employed. Non-parametric tests, specifically the Wilcoxon Signed-Rank Test, were employed to ascertain significant differences between pretest and posttest scores within the same group. The Mann–Whitney U test was employed to assess significant differences between the experimental and control groups in pretest, posttest, and gain scores across two domains. The Kruskal–Wallis H test was used to determine significant differences in literacy and numeracy scores between the experimental and control groups at the pretest, posttest, and gain score phases. Utilized to compare pretest and posttest scores, as well as gains among groups, with effect sizes expressed using η^2. All analyses were conducted utilizing IBM SPSS Statistics software version 26, with a significance threshold of $\alpha = 0.05$.

Results

Table 2 illustrates the distribution of students' test scores in literacy and numeracy for both the experimental and control groups at the pretest and posttest phases. Both groups demonstrated progress from the pretest to the posttest; however, the experimental group exhibited a more significant transition toward higher performance categories, particularly in the numeracy domain. During the pretest phase, 48 students (61.5%) were classified as Effective, whereas merely one student (1.3%) fell into the Weak category. Following the intervention, the percentage of students in the Effective group increased slightly to 65.38% (51 students), and the number of students in the Moderately Effective category also decreased to 14 students (17.95%). In contrast, thirteen student achieved the highest category (Very Effective). This transition signifies that the GBL–PE intervention enhanced general literacy competencies, mitigated lower performance levels, and increased consistency in student achievement. In contrast, the control group had a more moderate enhancement. The count of students in the Effective group experienced a minor decline (from 51 to 45 students), whilst the Fairly Effective category exhibited relative stability. Crucially, no students in either group fell into the Weak category at the posttest stage, signifying that literacy learning outcomes were enhanced in both groups, although the experimental group exhibited a more pronounced transition towards higher categories.

Subsequently, the outcomes of the numeracy assessment. During the pretest phase, the majority of students in experiment group (26 out of 78, or 33.33%) fell into the Moderately Effective category, while 50 students (39.7%) were classified as Effective, and none were categorized as Very Effective. Following the intervention, a notable increase was observed: 63 students (80.76%) were classified as Effective, while 7 students (8.97%) were classified as Moderately Effective, with none students remaining in the Low category and 8 (1026&) were categorized as Very Effective. The GBL–PE strategy significantly enhances pupils' numeracy skills, notably elevating the majority from lower to middle and higher performance levels. The control group exhibited a lesser degree of improvement. The number of students in the Effective category increased from 31 to 54. In contrast, 20 students (26%) remained classified in the Fairly Effective category. Two students attained the Very Effective classification in the numeracy domain. Consequently, while both groups exhibited enhancement, the experimental group revealed a more equitable and elevated distribution, signifying a more pronounced effect of the GBL–PE intervention on students' mathematical thinking and performance consistency.

Table 2. Distribution of Student Performance Levels in Literacy and Numeracy

Range		Literacy				Numeracy				Descriptive
		Experiment Group		Control Group		Experiment Group		Control Group		
		pre	post	pre	post	pre	post	pre	post	
85	100	0	13	1	3	0	8	0	2	Very Effective performance
70	84	48	51	31	45	50	63	31	54	Effective performance
55	69	29	14	34	24	26	7	42	20	Moderately Effective
0	54	1	0	10	4	2	0	3	0	Weak Performance
Total		78	78	76	76	78	78	76	76	

The Mann–Whitney U test (Table 3) revealed a significant disparity in post-literacy scores between the experimental and control groups (U = 1894.00, Z = –3.89, p < 0.001), with the experimental group exhibiting a higher mean rank (91.22) than the control group (63.42). Nonetheless, the disparity in literacy enhancement scores was not significant (Z = –1.63), suggesting that while the experimental group attained superior end scores, their pace of development was not statistically distinct. In contrast, the findings in the numeracy domain revealed statistically significant disparities between the groups (U = 1420.50, Z = –5.63, p < 0.001), in both post-test scores and improvement (Z = –3.82, p < 0.001). The findings validate that the GBL–PE intervention significantly enhances students' numeracy skills in comparison to traditional PE training.

Table 3. Mann-Whitney Test Result

Variable	Mann–Whitney U	Z	p-value (Asymp. Sig. 2-tailed)
Literacy Pretest	2071.5	-3.244	0.001
Literacy Posttest	1894	-3.887	0.001
Numeracy Pretest	2020	-3.416	0.001
Numeracy Posttest	1420.5	-5.625	0.001
Gain Literacy	2516	-1.627	0.104
Gain M Numeracy	1910.5	-3.817	0.001

The Wilcoxon Signed-Rank test was performed to assess the changes between pre-test and post-test results in the experimental group following the GGBL–PE intervention (see Table 4). The data indicate that post-test scores surpass pre-test values in both domains. In reading, 72 kids (92.3%) demonstrated an improvement in scores, 6 maintained their results, and no students exhibited a decline. Likewise, in numeracy, every student (100%) demonstrated an improvement following the intervention. There is a statistically significant difference in pre-test and post-test scores for both literacy (Z = –7.379, p < 0.001, r = 0.83) and numeracy (Z = –7.677, p < 0.001,). Consequently, it can be inferred that the GBL model incorporated into PE activities significantly enhances the literacy and numeracy skills of elementary school children.

Table 4. Wilcoxon Signed Ranks Test Result

Domain	N	Negative Ranks	Positive Ranks	Ties	Z	p	*r*	Interpretation
Literacy	78	0	72	6	-7.379	< 0.001	0.83	Significant, large effect
Numeracy	78	0	78	0	-7.677	< 0.001	0.87	Significant, large effect

Table 5 illustrates that the Kruskal-Wallis H test was used to determine significant differences between the experimental and control groups for literacy and numeracy scores at the pretest, posttest, and gain score stages. This test is a non-parametric alternative to One-Way ANOVA, employed due to the non-normal distribution of the data. The results indicate that in the preliminary phase (pretest), there were significant disparities between the groups in reading skills (H(1) = 10.52, p = 0.001) and numeracy (H(1) = 11.67, p = 0.001), suggesting that the baseline competencies of the two groups were not entirely equitable. Post-intervention, the disparity increased notably, particularly in numeracy (H(1) = 31.64, p = 0.001*), with the experimental group exhibiting considerably superior scores compared to the control group. In the literacy domain, posttest differences were substantial (H(1) = 15.12, p = 0.001); however, the progress (gain) between groups was not significant (H(1) = 2.65, p = 0.104). In contrast, the enhancement in numeracy exhibited substantial differences (H(1) = 14.57, p = 0.001*), affirming that the GBL–PE intervention had a more pronounced effect on advancing numeracy than on literacy.

Table 5. The Kruskal-Wallis test statistics

Domain	Stages	H	df	p
Literacy	Pretest	10.52	1	0.001
	Posttest	15.12	1	0.001
	Gain	2.65	1	0.104
Numeracy	Pretest	11.67	1	0.001
	Posttest	31.64	1	0.001
	Gain	14.57	1	0.001

Discussion

This study's findings demonstrate that incorporating GBL into PE significantly enhances the reading and numeracy skills of early childhood learners. Statistical analysis indicates a substantial difference between the experimental and control groups following the intervention. While both reading and numeracy showed improvement, the most substantial enhancement was observed in the area of numeracy. The findings demonstrate that the integrative PE–GBL paradigm enhances physical participation while simultaneously stimulating cognitive processes that lead to higher academic achievement.

The notable enhancement in numeracy ability can be elucidated by the notion of embodied cognition, which posits that physical movement can reinforce neuronal processes associated with working memory, spatial thinking, and problem-solving (Rudd, 2020). The intervention's emphasis on movement and play necessitates that kids engage in computations, sequencing, and spatial estimates while in motion, thereby solidifying mathematical concepts through experiential learning. Prior studies Singh et al. (2019) and Haverkamp et al. (2020) indicated that cognitively challenging physical activity enhances executive function and academic performance, particularly when learners synchronize bodily movements with cognitive processes.

In contrast, the rise in literacy, while statistically significant on the posttest, exhibited diminished improvement scores. This may result from the abstract characteristics of language literacy, which depend more on symbolic and phonological processing than on spatial reasoning. The notable enhancement in performance distribution, evidenced by a significant rise in the proportion of students classified as very effective, suggests that the PE–GBL model offers a qualitative improvement in reading engagement and comprehension. This outcome aligns with the research of Schmidt et al. (2019), which demonstrated that integrating movement and word recognition tasks enhances vocabulary acquisition and attention in primary school children.

The incorporation of GBL into PE sessions effectively converted motor-oriented teachings into intellectually stimulating learning experiences. This corroborates the ecological-dynamics approach to physical literacy, which posits that learning occurs through active participation in tasks that concurrently present both motor and cognitive demands (Rudd, 2020). Games that necessitate students to engage with numbers, characters, or symbols physically facilitate embodied learning, hence enhancing attention, memory, and comprehension. This method aligns with the findings of Jarrett & Light (2019), who emphasize that game-based learning fosters collaboration, decision-making, and autonomy. This approach can sustain motivation and reduce learning inactivity in the classroom, as evidenced by Ratinho & Martins (2023), who found that game-based methods and gamification significantly enhanced student motivation and decreased disruptive behavior in physical education classes. The efficacy of this intervention demonstrates that physical education may fulfill a dual function: attaining physical literacy objectives alongside academic achievements. This reinforces the assertion of Álvarez-Bueno et al. (2017), who found that physically active learning has a positive influence on classroom behavior, concentration, and academic performance. Consequently, incorporating academic components into Physical Education does not obscure its physical objectives; instead, it amplifies its educational significance.

The more pronounced effect on numeracy relative to literacy is likely due to the inherent compatibility between physical movement and numerical reasoning. PE-GBL representation facilitates the execution of numeracy tasks, including counting jumps, estimating distances, and correlating numbers with movement. In contrast, literacy includes phonemic awareness and vocabulary development, which are not inherently linked to motor tasks. This disparity corresponds with the conclusions of Sneck et al. (2019)Berg et al. (2019), indicating that physically active mathematics programs yield more significant outcomes than language-based programs. The noted rise in literacy involvement indicates that PE-GBL activities offer an effective avenue for language acquisition. Movement and play foster a favorable emotional environment, alleviate anxiety, and enhance perseverance all vital elements of reading motivation. This emotional aspect elucidates why descriptive data indicate substantial learning advancements, despite the inferential results for literacy enhancement scores lacking statistical significance.

This discovery validates the efficacy of movement-based integrative pedagogy in addressing key learning challenges in early childhood education. Global research indicates that numerous youngsters fail to meet fundamental reading and mathematics criteria, despite prolonged educational exposure (Friedlander, 2020; Ricketts et al., 2020)). This study presents a feasible methodology for incorporating

academic learning into the physical education curriculum without diminishing instructional time for core topics. This methodology effectively advocates for curriculum innovation and the professional development of educators. Implementing PE-GBL interventions requires educators to excel in cross-curricular planning, classroom management, and assessment methodologies. According to de Campos et al.(2024) and Husain et al. (2024), instructors' favorable dispositions towards inclusive and activity-oriented learning are essential for sustaining student engagement and psychological well-being. Consequently, teacher training programs must incorporate modules on embodied and game-based education.

This research theoretically broadens the embodied learning paradigm by demonstrating that physical education can provide a conducive environment for academic integration. This study offers empirical evidence that physiological engagement is essential to cognitive growth, rather than merely supplemental. This research contributes to the literature by operationalizing the GBL–PE integrative paradigm, which views physical exercise as a vehicle for conceptual learning, rather than merely an ancillary activity. Additional research is recommended to examine the long-term effects, including learning retention, transfer to classroom tasks, and the impact on motivation, while employing neurocognitive measurements to investigate the mechanisms linking motor and cognitive domains. Extending this approach to various cultural and curricular contexts would enhance the generalizability of the findings.

Conclusions

This study presents empirical evidence that incorporating GBL into PE sessions is a practical pedagogical approach for enhancing primary students' academic performance, particularly in numeracy. The experimental group, which participated in physically active, cognitively stimulating game-based learning during physical education sessions, attained markedly superior posttest results in literacy and numeracy compared to the control group, with a substantial effect size noted for numeracy. These findings validate that integrating movement with conceptual learning not only maintains student engagement but also enhances executive functions, including attention, working memory, and problem-solving abilities. The findings align with embodied cognition theory, which posits that learning occurs through the body's engagement with its surroundings. The PE–GBL approach utilized these embodied experiences to convert physical activity into a medium for mental comprehension. Although literacy increases were apparent in performance distributions and qualitative enhancements, the more pronounced impacts in numeracy underscore that motor-based tasks more effectively facilitate mathematical reasoning and spatial cognition. Nonetheless, the literacy results indicate that play-based and embodied contexts promote emotional involvement and reading motivation—essential antecedents to literacy advancement in early education.

This study highlights the importance of integrative, movement-based instruction as a comprehensive and practical educational approach. By integrating academic work into physically engaging games, educators can promote both physical and cognitive development without compromising instructional time. Schools should regard physical education not as apart from academic learning but as an integral framework for cognitive growth. These findings necessitate curricular innovation and professional development for educators to implement embodied and game-based learning methods in primary school. Future studies should examine the long-term retention, transfer effects, and scalability of these treatments, as well as investigate the brain mechanisms underlying embodied academic learning. Extending this paradigm to various educational and cultural contexts would enhance its validation and pedagogical efficacy.

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