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Active Bodies, Active Minds: The Influence of Physical Activity on Science Learning Cognition in Elementary Students

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ABSTRACT

Background & objective: Growing evidence suggests that physical activity can enhance cognitive functioning and academic performance; however, empirical research examining movement-integrated science instruction in elementary education remains limited, particularly in developing-country contexts. This study investigated the effect of physically active science learning on science achievement among fifth-grade elementary school students.

Materials & Methods: A quasi-experimental study employing a posttest-only control group design was conducted with 60 Grade 5 students from an elementary school in Denpasar, Indonesia. Participants were assigned to either an experimental group ($n = 30$), which received physically active science instruction, or a control group ($n = 30$), which received conventional classroom instruction. Science achievement was assessed using a validated 20-item multiple-choice test (Content Validity Ratio = 1.00 KR-20 = 0.84). Data were analyzed using descriptive statistics, Kolmogorov-Smirnov and Levene's tests, independent-samples t-tests, and Cohen's d effect size analysis.

Results: The experimental group achieved significantly higher science achievement scores ($M = 86.07$, $SD = 6.19$) than the control group ($M = 75.60$, $SD = 6.39$). Assumption testing confirmed normality and homogeneity of variance. Independent-samples t-test results indicated a significant difference between groups, $t(58) = 6.447$, $p < .001$. The intervention produced a very large effect size (Cohen's $d = 1.667$) demonstrating a substantial educational impact.

Conclusions: Physically active science learning significantly improved elementary students' science achievement compared with conventional instruction. The findings support embodied cognition theory and highlight the potential of movement-integrated pedagogical approaches to enhance science learning outcomes in primary education. Future research should examine the long-term effectiveness of such interventions across diverse educational settings.

Keywords

active learning; embodied cognition; elementary education; physical activity integration; science achievement; science learning.

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INTRODUCTION

Global and Theoretical Context

The intersection of physical activity and cognitive development has emerged as one of the most consequential research frontiers in contemporary educational neuroscience. Globally, an accelerating body of empirical evidence has established that habitual engagement in structured physical activity exerts measurable effects on brain structure, executive function, memory consolidation, and academic performance in school-age children (Lubans et al., 2016). The Bull et al. (2020) recommends that children aged 6–17 years accumulate at least 60 minutes of moderate-to-vigorous physical activity daily; yet epidemiological surveillance data consistently reveal that the majority of elementary-age children in both high-income and middle-income countries fail to meet this threshold. The progressive displacement of physical education, recess, and movement-integrated instruction by sedentary academic practices constitutes a systemic policy risk that may compromise not only physical health but also cognitive and scholastic development.

In the Indonesian educational context, the Merdeka Belajar (Independent Learning) curriculum reform advanced by the Ministry of Education and Culture underscores the imperative of holistic, student-centered learning environments (Hunaepi & Suharta, 2024, p. 5026; Simangunsong, 2024). Yet classroom practice at the primary level remains predominantly sedentary, particularly in cognitively demanding subjects such as Ilmu Pengetahuan Alam (IPA; natural science) (Doherty & Miravalles, 2019, p. 2; Hartikainen et al., 2022, p. 179). This disjuncture between policy aspiration and pedagogical reality motivates the present inquiry into the extent to which physical activity-integrated instruction may amplify cognitive engagement and science learning outcomes among fifth-grade students.

Critical Examination of Existing Literature

The theoretical architecture underpinning this study rests upon three converging scholarly traditions. First, embodied cognition theory posits that cognitive processes are not confined to the brain but are constitutively shaped by the body's sensorimotor interactions with the environment (Ladouce et al.,

2017, p. 3; Trasmundi & Toro, 2023, p. 1061440; Wilson, 2002). From this perspective, physical movement during learning is not peripheral but constitutive of conceptual understanding, a view that has gained substantial empirical traction in developmental psychology and educational neuroscience (Glenberg et al., 2004) (Re, 2025).

Second, research on the acute and chronic effects of exercise on neurocognition provides a mechanistic substrate for the observed associations between physical activity and academic performance. Aerobic exercise stimulates the release of brain-derived neurotrophic factor (BDNF), promotes hippocampal neurogenesis, enhances prefrontal cortical activity, and strengthens white matter connectivity, all processes critically implicated in learning and memory (Chaddock-Heyman et al., 2013). Pontifex et al. (2012) demonstrated through neuroelectric (ERP) methodology that a single 20-minute bout of moderate aerobic exercise significantly improved inhibitory control and reading comprehension in preadolescent children, with effects persisting for at least 30 minutes post-exercise.

Third, at the level of educational effectiveness research, several systematic reviews and meta-analyses have synthesized the relationship between school-based physical activity and academic achievement. Rasberry et al. (2011) reviewed 50 studies and concluded that increasing physical activity in the school environment does not impair academic performance and frequently enhances it. Fedewa & Ahn (2011) conducted a meta-analysis of 59 studies ($n = 8,690$ students) and reported a mean effect size of $d = 0.40$ for the relationship between physical activity and cognitive outcomes. Poitras et al. (2016) further established in a comprehensive systematic review of 36 studies that engagement in structured physical activity was positively associated with cognitive performance, academic achievement, and executive function in school-age children.

At the primary school level specifically, Donnelly et al. (2016) conducted the seminal Physical Activity Across the Curriculum (PAAC) randomized controlled trial, demonstrating that classroom-based physical activity integration significantly improved standardized academic achievement scores over a three-year intervention period compared with control classrooms. (Coe et al., 2006) similarly found that students participating in vigorous physical education classes demonstrated significantly higher academic grades than those in less active conditions, even after controlling for socioeconomic variables. In the domain of science education specifically, Howie & Pate (2012) documented that children who met physical activity guidelines showed significantly stronger performance on science assessments, reinforcing the domain-specific relevance of physical activity for science learning cognition.

Identification of Research Gaps

Despite the robustness of the broader evidence base, several critical lacunae persist. First, the overwhelming preponderance of existing research has been conducted in North American and Western European educational settings, limiting cross-cultural and cross-contextual generalizability to Southeast Asian and developing-nation school environments such as those found in Indonesia. Second, the majority of intervention studies have focused on generic academic outcomes or mathematics and language arts, with comparatively scant attention to science-specific cognitive outcomes as a discrete dependent variable. Third, few studies have employed systematically designed, classroom-embedded physical activity protocols for natural science instruction at the Grade 5 level, leaving an important empirical and practical gap between research and pedagogical application. Fourth, within the Indonesian context, the nexus of physical activity, embodied learning, and IPA cognition remains markedly underexplored in the peer-reviewed literature, constituting a clear priority for indigenous educational research.

Rationale for the Research

The present study was motivated by converging practical and theoretical imperatives. Observational evidence gathered prior to the study at SD Galang Kasih Denpasar revealed that a substantial proportion of Grade 5 students performed below the established Minimum Completion Criteria (KKM) in natural science, despite adequate content exposure under conventional instructional conditions. Qualitative observation suggested low motivational engagement and limited active participation in lessons centered on human and animal respiratory systems, a topic with rich potential for embodied, kinesthetic exploration. These field realities, taken in concert with the theoretical and empirical arguments outlined above, established a compelling case for implementing and rigorously evaluating a physically active instructional model.

Research Objectives

The primary objective of this study was to determine whether physically integrated science learning would yield significantly superior science cognitive outcomes and academic achievement compared with conventional, sedentary instruction among Grade 5 elementary students. Specifically, this investigation sought to: (1) describe the distribution and central tendency of science learning achievement scores in both the experimental and control groups; (2) statistically test the hypothesis that mean science achievement scores in the physically active instruction group would be significantly higher than those in the conventional instruction group; and (3) contribute empirical evidence to the growing international discourse on movement-integrated pedagogy in primary-level science education.

MATERIALS AND METHODS

Participants and Competition Context

The study cohort comprised all Grade 5 students enrolled at SD Galang Kasih Denpasar during the 2024/2025 academic year. The total eligible population consisted of 60 students distributed evenly across two parallel classes (Class VA, $n = 30$; Class VB, $n = 30$). Participants ranged in age from 10 to 11 years ($M = 10.4$ years, $SD = 0.5$), reflecting the normative age range for Grade 5 enrollment in the Indonesian elementary system. The cohort comprised 31 male students (51.7%) and 29 female students (48.3%), representing a near-balanced gender distribution. All participants were Indonesian nationals of Balinese and Javanese ethnic backgrounds, reflecting the demographic composition of

the urban Denpasar catchment area. Inclusion criteria required: (a) enrollment in Grade 5 at the study school for the full academic year, (b) absence of diagnosed neurological or physical conditions that would preclude participation in light-to-moderate physical activity, and (c) provision of informed parental or guardian consent. Students with chronic absenteeism (defined as missing $>20\%$ of intervention sessions) were identified a priori as exclusion criteria, though no participants ultimately met this threshold.

Study Organization and Design

This study adopted a quantitative experimental approach employing a quasi-experimental, posttest-only control group

design. This design was selected due to the pre-existing, administratively determined class structures, which precluded full individual randomization; class-level randomization was performed instead. Class random sampling was used to assign the intact classes: Class VA was designated the experimental group and Class VB the control group. Prior to the intervention, the academic equivalence of the two groups was confirmed through a pre-intervention independent-samples t-test using end-of-semester science scores from the preceding term, which yielded $t(58) = 0.904$, $p = .373$, confirming no statistically significant baseline difference.

The experimental group received science instruction on the topic of human and animal respiratory organs through a physically active learning protocol designed in accordance with embodied cognition principles and active learning frameworks (Diamond & Lee, 2011). The protocol incorporated structured movement sequences, kinaesthetic simulation activities (e.g., whole-body modelling of breathing mechanics), manipulative experiments, collaborative physical demonstrations, and active station rotations. Each instructional session of 70 minutes included approximately 20–25 minutes of structured moderate-intensity physical activity woven into the science content delivery. The control group received instruction on the same content under conventional didactic conditions: teacher-led lecture delivery, worksheet completion, and question-and-answer sessions without any structured physical activity integration. Both groups were taught by the same credentialed classroom teacher to control for instructor-related variance. The intervention spanned four consecutive weeks (eight instructional sessions).

Instruments and Measurement

Science learning achievement was measured using a researcher-developed, curriculum-aligned multiple-choice instrument comprising 20 items addressing cognitive levels of knowledge, comprehension, and application on the IPA topic of respiratory organs in humans and animals. The instrument was subjected to expert content validity evaluation using Gregory's formula, yielding a Content Validity Ratio of 1.0, indicative of excellent content validity. Item reliability was established through the Kuder-Richardson Formula 20 (KR-20), producing a reliability coefficient of 0.84, which is classified as high reliability. Item discrimination indices and difficulty levels were additionally computed; items with difficulty indices between 0.30 and 0.70 and discrimination indices exceeding 0.30 were retained, resulting in a psychometrically robust final instrument.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics Version 23.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were first computed to summarize students'

science achievement scores under both instructional conditions, including the mean, median, mode, standard deviation, variance, minimum score, maximum score, and range. To facilitate interpretation of score distributions and group differences, graphical analyses were additionally conducted using mean comparison plots and distribution visualizations (boxplots). Prior to inferential testing, the assumptions required for parametric analysis were evaluated. Normality of the posttest scores was assessed using the Kolmogorov–Smirnov test, while homogeneity of variance was examined using Levene's test. Statistical significance for all preliminary analyses was established at $\alpha = .05$.

Following confirmation that the assumptions of normality and homogeneity were satisfied, an independent-samples t-test was conducted to determine whether significant differences existed between the experimental group receiving physically active science learning and the control group receiving conventional instruction. In addition to hypothesis testing, the magnitude of the intervention effect was quantified using Cohen's d effect size and interpreted according to the benchmarks proposed by Cohen (1988), whereby 0.20, 0.50, and 0.80 represent small, medium, and large effects, respectively. Mean differences, effect-size estimates, and graphical representations were reported to complement significance testing and provide a comprehensive evaluation of both the statistical and practical significance of physically active science learning on elementary students' science achievement outcomes.

Ethical Considerations

This study was conducted in accordance with established ethical principles for research involving human participants, particularly research involving minors. Ethical approval was obtained from the Research Ethics Committee of Ganesha University under Approval No. RE-GU/Ed-25/11-3111, approved on November 26, 2025, prior to the commencement of data collection.

Written informed consent was obtained from the parents or legal guardians of all participating students, and written assent was obtained from the students themselves. Participants were informed that participation was voluntary and that they had the right to withdraw from the study at any time without academic or other negative consequences.

Participant confidentiality and privacy were maintained throughout the research process. The collected data were anonymized prior to analysis, and no personally identifiable information is disclosed in this manuscript. The data were securely stored in a password-protected institutional repository and were handled in accordance with applicable ethical and institutional requirements.

RESULTS

Descriptive Statistics of Science Learning Achievement

The primary objective of this study was to determine whether physically active science learning produced superior science achievement outcomes compared with conventional classroom instruction. Descriptive statistical analyses were conducted to provide an overview of students' posttest performance under both instructional conditions.

Table 1 summarizes the central tendency and variability of science achievement scores for the experimental and control groups.

Statistic	Experimental Group (Active Learning)	Control Group (Conventional Learning)
n	30	30

Minimum	76	66
Maximum	98	89
Mean	86.07	75.60
Median	86.00	75.50
Mode	85	70
SD	6.19	6.39
Variance	38.27	40.80
Range	22	23
Achievement Category	High	Sufficient

As shown in Table 1, students who participated in physically active science learning achieved substantially higher science achievement scores than students who received conventional instruction. The experimental group obtained a mean score of

86.07 (SD = 6.19), whereas the control group achieved a mean score of 75.60 (SD = 6.39). The observed mean difference of 10.47 points suggests a considerable educational advantage associated with the movement-integrated instructional approach.

The superiority of the experimental group was further reflected across all descriptive indicators. The highest score recorded in the experimental group was 98, compared with 89 in the control group. Likewise, the minimum score was higher among experimental participants (76 versus 66), indicating that the benefits of the intervention were evident not only among high-performing students but also among those with relatively lower achievement levels.

Measures of central tendency demonstrated strong consistency. The mean (86.07), median (86.00), and mode (85) of the experimental group were closely aligned, suggesting a relatively balanced score distribution with minimal skewness. Similar consistency was observed in the control group, where the mean (75.60), median (75.50), and mode (70) indicated a stable distribution pattern.

Variability measures showed comparable dispersion across groups. The experimental group produced a variance of 38.27 and a standard deviation of 6.19, while the control group exhibited a variance of 40.80 and a standard deviation of 6.39. These findings indicate that the higher achievement observed in the experimental group cannot be attributed to increased variability but instead reflects a genuine upward shift in performance across participants. Based on the national grading criteria used in Indonesian elementary education, the experimental group was classified within the high achievement category, whereas the control group remained within the sufficient achievement category. This categorical distinction further reinforces the practical significance of the observed performance gap.

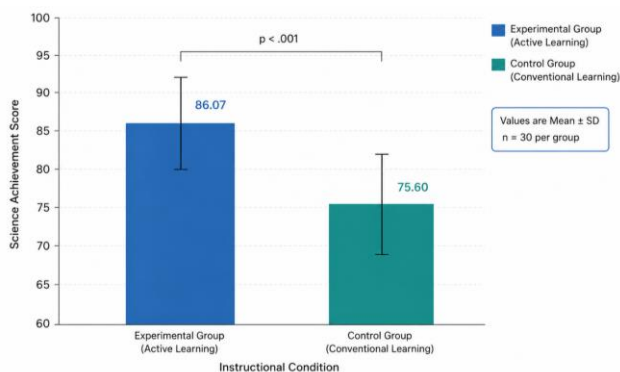


Figure 1. Comparison of Mean Science Achievement Scores Between Groups

Figure 1 visually illustrates the substantial difference in mean achievement scores between instructional conditions. The higher mean score and non-overlapping trend of the error bars provide an initial indication that physically active science learning may have generated a meaningful improvement in student achievement outcomes.

Distribution of Science Achievement Scores

Beyond differences in average performance, it is important to examine how scores were distributed within each instructional condition. Distributional analyses provide insight into whether the intervention influenced only a subset of students or whether achievement gains were broadly experienced across the group.

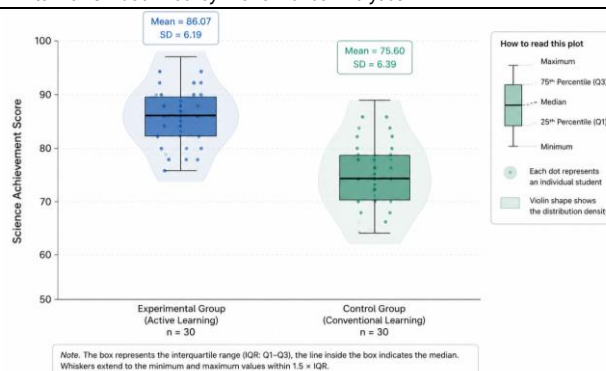


Figure 2. Distribution of Science Achievement Scores Across Groups

As illustrated in Figure 2, students in the experimental group displayed a distribution concentrated within the upper achievement range. The median score was notably higher than that observed in the control group, and the majority of students achieved scores above 80 points. The relatively compact interquartile range suggests that the positive effects of physically active learning were experienced consistently across participants.

In contrast, the control group demonstrated a lower score distribution, with a large proportion of students clustered within the 66–77 score interval. Although several students achieved scores above 80, such performances were less frequent than in the experimental group.

The visual comparison reveals limited overlap between the central distributions of the two groups, providing further evidence that the intervention shifted overall achievement levels upward rather than simply affecting a small number of exceptional students. To provide additional descriptive detail, frequency analyses were conducted. Within the experimental group, approximately 80% of students achieved scores within the high-performance range, while only a small proportion scored below 80. Conversely, most students in the control group were concentrated within the sufficient-achievement category. These findings indicate that physically active science learning not only improved average achievement but also increased the proportion of students reaching higher levels of academic performance.

Assumption Testing

Prior to hypothesis testing, statistical assumptions required for parametric analysis were evaluated. The Kolmogorov–Smirnov test indicated that posttest scores in both groups were normally distributed. The experimental group yielded a significance value of $p = .200$, while the control group also produced $p = .200$. Both values exceeded the predetermined alpha level of .05, supporting the assumption of normality. Homogeneity of variance was examined using Levene's test. The analysis produced $F = 0.090$ with $p = .766$, indicating that variance differences between groups were statistically non-significant. Therefore, the assumption of equal variances was satisfied. Because both assumptions were met, an independent-samples t-test was deemed appropriate for evaluating differences in science achievement between instructional conditions.

Table 2. Assumption Testing Results

Test	Statistic	P-value	Interpretation
Kolmogorov–Smirnov (Experimental)	–	.200	Normal
Kolmogorov–Smirnov (Control)	–	.200	Normal
Levene's Test	0.090	.766	Homogeneous

The satisfactory assumption test results provide confidence that subsequent inferential analyses are statistically valid and robust.

Comparison of Science Achievement Between Groups

To determine whether physically active science learning

significantly influenced student achievement, an independent-samples t-test was conducted.

Table 3. Comparison of Science Achievement Scores Between Instructional Conditions

Outcome Variable	Experimental Group M ± SD	Control Group M ± SD	Mean Difference	t(58)	p	95% CI
Science Achievement	86.07 ± 6.19	75.60 ± 6.39	10.47	6.447	< .001	7.22 – 13.72

Note. Higher scores indicate better science achievement. The confidence interval does not cross zero, indicating a statistically significant difference between groups.

The analysis revealed a statistically significant difference between groups, $t(58) = 6.447$, $p < .001$. The probability associated with the obtained t-value was substantially below the established significance threshold of $\alpha = .05$, indicating that the likelihood of obtaining such a large mean difference by chance alone was extremely small. Consequently, the null hypothesis (H_0), which stated that no difference existed between instructional conditions, was rejected. The alternative hypothesis (H_1) was accepted, confirming that physically active science learning significantly improved science achievement among Grade 5 students. The mean difference of 10.47 points represents a substantial educational advantage. In practical terms, students exposed to movement-integrated instruction demonstrated markedly better mastery of scientific concepts related to human and animal respiratory systems than students

receiving conventional classroom instruction.

Magnitude of the Intervention Effect

Although statistical significance indicates the presence of a difference, it does not reveal the practical magnitude of that difference. Therefore, effect size analysis was conducted using Cohen's d.

Table 4. Effect Size Analysis

Variable	Mean Difference	Cohen's d	Magnitude
Science Achievement	10.47	1.667	Very Large

The calculated effect size was $d = 1.667$. According to Cohen's (1988) benchmarks, values of 0.20, 0.50, and 0.80 correspond to small, medium, and large effects, respectively. The obtained value substantially exceeded the threshold for a large effect.

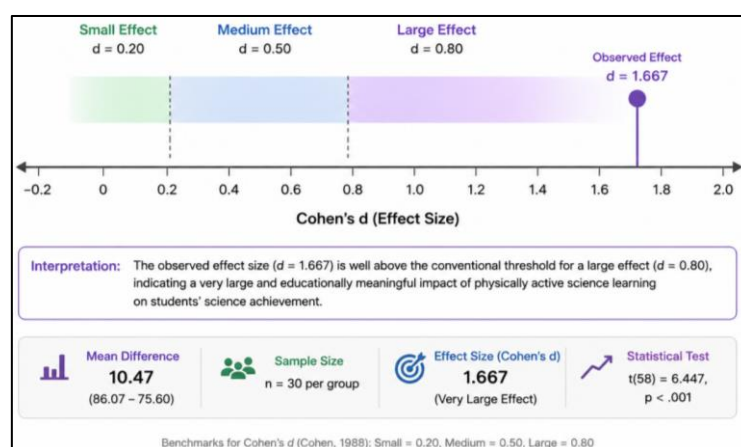


Figure 3. Effect Size of the Intervention

The magnitude of the effect suggests that physically active science learning produced not only statistically significant improvements but also educationally meaningful gains. In educational intervention research, effect sizes above 1.00 are relatively uncommon and generally indicate highly effective instructional practices. The present findings therefore suggest that integrating physical activity into science instruction has the

potential to generate substantial learning benefits within elementary school contexts.

Summary of Findings

To facilitate interpretation of the results, Figure 4 presents a conceptual synthesis of the statistical findings.

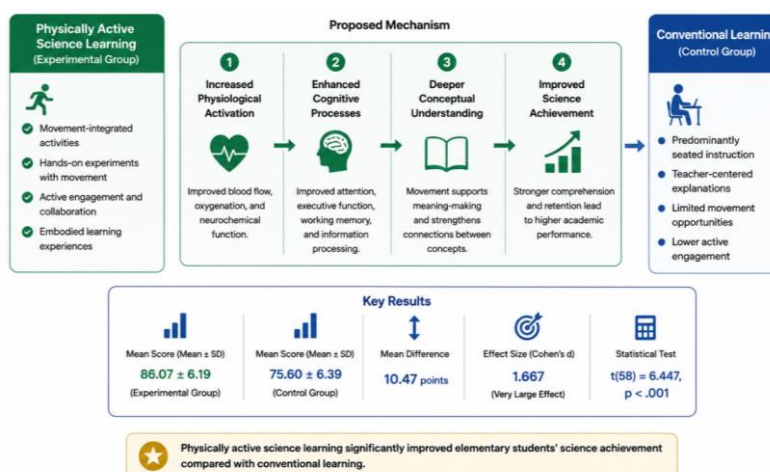


Figure 4. Conceptual Summary of the Intervention Outcomes

The results collectively demonstrate a consistent pattern. Students who participated in physically active science learning achieved higher average scores, exhibited stronger overall performance distributions, and showed substantially greater academic achievement than students receiving conventional

instruction. Taken together, the descriptive, inferential, and effect-size analyses provide robust empirical evidence that physically active science learning exerts a significant positive influence on elementary students' science achievement and cognitive learning outcomes.

DISCUSSION

Interpretation of Research Outcomes

The present findings constitute compelling evidence that the intentional integration of physical activity into science instruction produces measurable, statistically significant, and practically meaningful improvements in science learning achievement among Grade 5 elementary students. The experimental group's mean score of 86.07, representing the high achievement category, and the associated large effect size ($d = 1.667$) indicate that the observed benefit cannot be attributed to sampling variation but reflects a genuine instructional effect of considerable practical magnitude.

These outcomes are consistent with the embodied cognition theoretical framework invoked at the outset of this investigation. When students physically enacted respiratory mechanics, manipulated models, and engaged in kinesthetic exploration of the content, they activated a broader cortical network than passive listening alone would engage. Sensorimotor encoding, combined with semantic encoding through teacher-guided discussion, produced richer and more elaborated memory traces, leading to superior retrieval performance on the posttest (Markant et al., 2016, p. 144; Nair et al., 2019, p. 962; Weinstein et al., 2018, p. 13).

Evaluation in Relation to Antecedent Studies

The significant intergroup difference documented in this study aligns with and extends the evidence base established by prior international and national research. The findings are directly consonant with (Donnelly et al., 2016) PAAC trial, which demonstrated that classroom physical activity integration improved academic achievement without diminishing instructional time or curriculum fidelity. Similarly, the neurocognitive mechanisms identified by Kiyonaga et al. (2017), namely enhanced prefrontal cortical arousal, improved executive function, and elevated neurotrophic factor levels following acute exercise, provide a plausible biological substrate for the achievement gains observed in the present study (Hillman et al., 2009, p. 1054). Rasberry et al. (2011) systematic review finding that physical activity rarely harms and frequently enhances academic performance across diverse school subjects is further corroborated by the present science-specific evidence. The domain-specific resonance with (Howie & Pate, 2012) findings regarding physical activity and science achievement is particularly noteworthy, as it suggests that the active, exploratory, and investigative nature of science education may render it an especially amenable domain for physically active instructional integration (Yoh et al., 2025).

Within the Indonesian educational research literature, these findings resonate with Tryas & Hashim (2025) demonstration that student-responsive learning approaches combining active exploration with inquiry produce significant IPA achievement gains at the primary level (Endrawan et al., 2025). The present study advances this local evidence base by isolating physical activity integration as a specific instructional variable, providing a cleaner causal inference than prior correlational or mixed-design investigations.

Implications of the Discoveries

The educational implications of these findings are multi-layered and far-reaching. At the classroom level, the results furnish robust justification for elementary science teachers to incorporate structured movement activities, kinesthetic demonstrations, and whole-body learning experiences into their pedagogical repertoire. The finding that even a moderate physical activity integration of approximately 20–25 minutes per 70-minute session suffices to produce large-scale achievement gains is particularly encouraging, as it suggests that meaningful physical activity integration is achievable within existing curricular and temporal constraints.

At the systemic level, the findings challenge educational policy frameworks that implicitly or explicitly treat physical activity as ancillary to "real" academic learning. Within the Merdeka Belajar framework, which champions student-centred, holistic, and innovative pedagogy, physically active science instruction represents a high-fidelity instantiation of the curriculum's aspirations. School administrators and curriculum coordinators should be encouraged to develop institutional structures, timetabling arrangements, and professional development programmes that actively facilitate and incentivise movement-integrated teaching in core subjects.

At the teacher education level, the findings indicate that pre-service and in-service teacher development programmes should explicitly address pedagogical strategies for physical activity integration in academic subjects. Prospective elementary teachers require exposure to the theoretical foundations of embodied cognition, the empirical evidence base for physically active learning, and the practical competencies necessary to design, implement, and assess movement-integrated lessons safely and effectively.

Limitations and Directions for Future Research

Several methodological limitations of the present study must be acknowledged to appropriately contextualise the findings. First, the study was conducted within a single elementary school in Denpasar, limiting the geographic and institutional generalizability of the findings. Future multisite studies spanning diverse regional, socioeconomic, and cultural contexts within Indonesia are warranted to establish broader external validity. Second, the posttest-only design, while statistically justified by baseline equivalence testing, precludes examination of pre-to-post change trajectories within each group. Future investigations employing pretest-posttest designs with delayed retention assessments would permit stronger causal inference and documentation of learning durability. Third, cognitive outcome measures in the present study were limited to science achievement test performance; future research should incorporate neuropsychological measures of executive function (e.g., inhibitory control, cognitive flexibility, working memory) and physiological indicators (e.g., heart rate, BDNF levels) to elucidate the mechanistic pathways through which physical activity confers its cognitive benefits. Fourth, the study did not control for individual differences in physical fitness levels, which are known to moderate the cognitive effects of acute and chronic

exercise (Chaddock-Heyman et al., 2014). Finally, the eight-session intervention duration, while sufficient to demonstrate significant effects, does not permit conclusions regarding the

sustainability, dose-response relationship, or long-term maintenance of the observed benefits.

CONCLUSION

The present investigation provides robust empirical evidence that physically active science instruction constitutes a significantly more effective pedagogical approach than conventional sedentary instruction for promoting science learning achievement among Grade 5 elementary students. Students who received movement-integrated science teaching on the topic of respiratory organs in humans and animals achieved a mean posttest score of 86.07 (high category), compared with 75.60 (sufficient category) for students in the conventional instruction group, a difference of 10.47 points confirmed as statistically significant at the $p < .001$ level with a very large effect size (Cohen's $d = 1.667$).

These findings reinforce the core thesis that body and mind operate as integrated, mutually constitutive systems in the learning process. The theoretical premise of embodied cognition, which holds that sensorimotor engagement deepens conceptual encoding and retrieval, is borne out in these empirical results with practical implications that extend well beyond the immediate school context. The concordance between these findings and the international evidence base documented by Rasberry et al. (2011) Donnelly et al. (2016), and Fedewa & Ahn (2011) establishes cross-cultural generalisability and reinforces the ecological validity of physically active learning as a universal

pedagogical principle.

The implications of this study align directly with the aspirations of Indonesia's Merdeka Belajar curriculum framework and the broader global discourse on 21st-century competency development. If elementary educators are to cultivate active, curious, and cognitively engaged learners, the architecture of classroom instruction must honour the fundamental corporeality of human cognition.

The authors recommend that the Ministry of Education and Culture of the Republic of Indonesia formally incorporate physical activity integration guidelines into national elementary science curriculum standards. Teacher education institutions are urged to embed embodied cognition pedagogy and movement-integrated instructional design as core competencies in both pre-service and in-service teacher development programmes. School principals and curriculum coordinators should be supported through policy mechanisms and resource allocation to create enabling conditions for physically active learning across subject areas. Future research should examine these effects across multiple schools, grade levels, and subject domains, utilising longitudinal designs, physiological measures, and neuroimaging methodologies to advance mechanistic understanding of the active body–active mind relationship.

DECLARATIONS

Ethical Approval

This study received ethical approval from the Research Ethics Committee of Ganesha University (Approval No. RE-GU/Ed-25/11-3111, approved November 26, 2025). All procedures involving human participants were conducted in accordance with the approved ethical protocol and applicable ethical standards for research involving minors.

Consent to Participate

Written informed consent was obtained from the parents or legal guardians of all participating students prior to their participation in the study. In addition, written assent was obtained from the students themselves. Participants were informed of their right to withdraw from the study at any time without academic or other negative consequences.

Consent for Publication

Consent for publication was not applicable to individually identifiable information because no personally identifiable participant information is reported in this article. All research data were anonymized prior to analysis and reporting, and the manuscript does not disclose information that could reasonably identify individual participants.

Author Contributions (CRediT)

AP Tiumlafu: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Writing – Original Draft, Writing – Review & Editing, Funding Acquisition.

Nyoman Dantes: Conceptualization, Methodology, Investigation, Data Collection, Statistical Analysis, Writing – Original Draft, Writing – Review & Editing.

IM Gunamantha: Conceptualization, Methodology, Investigation, Data Collection, Statistical Analysis, Writing – Original Draft, Writing – Review & Editing.

All authors contributed to the development of the study and

manuscript, reviewed the final version, and approved the manuscript for publication.

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Conflict of Interest

The authors declare that they have no conflicts of interest, financial or otherwise, that could have influenced the design, implementation, analysis, interpretation, or reporting of this research.

Data Availability

The data supporting the findings of this study were anonymized prior to analysis and are stored in a password-protected institutional repository. Personally identifiable information is not included in the dataset or manuscript. Data may be made available for legitimate academic purposes subject to applicable ethical, institutional, and privacy requirements.

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Generative AI Disclosure

The authors declare that no generative artificial intelligence (AI) tools were used to generate, analyze, interpret, or substantially

modify the scientific content of this manuscript. The authors take full responsibility for the accuracy, originality, integrity, and final content of the work. No confidential, personally identifiable, or

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