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The Effectiveness of the Wayground Paper-Mode Method Assisted by Motion Media in Improving Science Learning Outcomes for Elementary School Students

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Abstract

The low quality of science learning in Indonesian elementary schools, reflected in Indonesia's 2022 PISA science score of 383 points, underscores the urgent need for effective yet inclusive learning media innovations, particularly for schools with limited digital infrastructure. This study aimed to analyze differences in science learning outcomes among fifth-grade students before and after the implementation of Wayground Paper Mode assisted by movement media, and to examine its effectiveness compared to a control class. A quantitative approach with a quasi-experimental nonequivalent control group design was employed. The subjects consisted of 18 students from class VA as the experimental group and 21 students from class VB as the control group. The instrument used was a multiple-choice test validated through Aiken's V and reliability-tested using Cronbach's Alpha. Data were analyzed using paired samples t-test and independent samples t-test via Jamovi, supplemented by Cohen's d as an effect size measure. Paired samples t-test results revealed a significant improvement in the experimental class ($t = -5.41$; $p < 0.001$; Cohen's $d = -1.28$, large effect) with an average gain score of 21.0 points, far exceeding the control class gain of 12.6 points. Comparison of posttest scores between both classes demonstrated a significant difference ($t = 2.691$; $p = 0.011$; Cohen's $d = 0.864$, large effect). This superiority stems from the dual coding visual-kinesthetic stimulation through Q-Cards and movement media, which strengthens long-term memory processing in alignment with students' concrete operational developmental stage. Wayground Paper Mode is proven to be an equitable learning solution that can be implemented in elementary schools without reliance on individual student devices.

Keywords: Game-Based Learning, Motion Media, Science Learning, Wayground Paper Mode

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Abstrak

Rendahnya mutu pembelajaran IPA di sekolah dasar Indonesia, yang tercermin dari skor PISA 2022 sebesar 383 poin, mendorong kebutuhan akan inovasi media pembelajaran yang efektif sekaligus inklusif bagi sekolah dengan keterbatasan infrastruktur digital. Penelitian ini bertujuan menganalisis perbedaan hasil belajar IPA siswa kelas V sebelum dan sesudah penerapan Wayground Paper Mode berbantuan media gerak, serta mengkaji efektivitasnya dibandingkan kelas kontrol. Penelitian menggunakan pendekatan kuantitatif dengan desain quasi experimental nonequivalent control group design. Subjek penelitian terdiri atas 18 siswa kelas VA sebagai kelompok eksperimen dan 21 siswa kelas VB sebagai kelompok kontrol. Instrumen yang digunakan adalah tes pilihan ganda yang telah divalidasi menggunakan Aiken's V dan diuji reliabilitasnya dengan Cronbach's Alpha. Analisis data dilakukan menggunakan paired samples t-test dan independent samples t-test berbantuan Jamovi, disertai perhitungan Cohen's d sebagai ukuran efek. Hasil paired samples t-test menunjukkan peningkatan signifikan pada kelas eksperimen ($t = -5{,}41$; $p < 0{,}001$; Cohen's $d = -1{,}28$, large effect) dengan gain score rata-rata 21,0 poin, jauh melampaui peningkatan kelas kontrol sebesar 12,6 poin. Perbandingan posttest antara kedua kelas menunjukkan perbedaan yang signifikan ($t = 2{,}691$; $p = 0{,}011$; Cohen's $d = 0{,}864$, large effect). Keunggulan ini bersumber dari stimulasi dual coding visual-kinestetik melalui Q-Card dan media gerak yang memperkuat pemrosesan memori jangka panjang sesuai tahap operasional konkret siswa. Wayground Paper Mode terbukti menjadi solusi pembelajaran berkeadilan yang dapat diimplementasikan di sekolah dasar tanpa ketergantungan pada ketersediaan gawai individual setiap peserta didik.

Kata Kunci: Game-Based Learning, Media Gerak, Pembelajaran IPA, Wayground Paper Mode

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INTRODUCTION

The quality of Natural Sciences (IPA) learning at the Indonesian basic education level faces structural challenges that have not been resolved comprehensively. The 2022 Programme for International Student Assessment (PISA) data recorded that Indonesia's science scores were at 383 points, which is not only far below the average of the Organisation for Economic Co-operation and Development (OECD) member countries, but also experienced a decline compared to the achievement in the 2018 measurement cycle (Bilad et al., 2024). This decline reflects a much more fundamental question than simply the low test pass rate. This problem stems from the dominance of conventional learning approaches that place teachers as the only source of knowledge, the lack of use of innovative learning media, and the inability of most basic education units to provide a contextual and dynamic learning experience (Musfiza et al., 2025). A systematic study of various forms of digital learning media confirms that the appropriate use of media has the potential to significantly increase motivation, active engagement, and learning outcomes of students at the basic education level (Salam et al., 2024). However, this potential can only be realized if the media chosen can be realistically applied in the conditions of limited facilities in the field.

The root of the problem that often goes unnoticed in the discourse on improving the quality of science learning in Indonesia is the inequality of technological infrastructure between educational units. The implementation of digital-based learning media in most elementary schools is constrained by the limited number of devices available, so that the one-to-one device model of one device for each student cannot be realized (Rahmani et al., 2025). This condition is exacerbated by the uneven digital readiness of teachers, especially in educational units located in suburban areas and rural areas (disadvantaged, frontier, outermost), where teachers often do not have adequate abilities to utilize learning software despite being aware of its availability (Fatimah et al., 2024). Purnama et al. (2023) emphasized that the low quality of science learning in elementary schools is closely correlated with the lack of use of interactive multimedia software that is able to provide meaningful learning experiences for students. Thaqi &Atanasoska (2025) added that the integration of multimedia in science learning has been proven to have a significant positive impact on improving the learning outcomes of elementary school students. But ironically, most of the digital-based solutions offered actually require the availability of adequate devices in each student's hands, so the narrative that digital learning is high costs has become a psychological as well as a structural obstacle that locks innovation at the classroom level.

The game-based learning approach has garnered substantial empirical support globally as a dual solution for elevating student engagement and conceptual understanding. In the international landscape, a meta-analysis of 22 experimental studies by Resta & Kodri (2023) demonstrated that integrating game elements yields a moderate yet significant positive effect on academic achievement. Interestingly, the potency of this approach appears to vary across educational tiers. Evidence from a large-scale meta-analysis by Wang et al. (2022) revealed that digital games in STEM learning achieve their peak effectiveness at the elementary school level, substantially outperforming outcomes in secondary and higher education. This cognitive benefit is rooted in early development; as highlighted by Destriana & Farida (2025), playful learning triggers high-level cognitive processes, including critical thinking and problem-solving, which are vital for fostering early science literacy.

A similar positive trajectory is mirrored in national contexts, particularly within science education. Rather than merely driving motivation, interactive multimedia and gamified frameworks consistently unlock concurrent gains in both student affection and academic

performance. This multidimensional impact is well-documented across Indonesian elementary classrooms, ranging from animated video interventions to interactive Canva-based platforms (Rahmawati et al., 2021; Rozaky et al., 2025; Sukma & Handayani, 2022).

Despite these advancements, a critical gap remains in the literature regarding whether a hybrid, low-device game-based learning framework can be effectively deployed in resource-constrained classrooms. Integrating physical responses, such as tangible cards and body movements, with centralized digital feedback activates multi-sensory information processing pathways across visual, kinesthetic, and cognitive dimensions. Grounded in Dual Coding Theory, this hybrid approach bridges the pedagogical transition from concrete experiences to abstract science concepts for elementary students (Zuroida et al., 2025). This physical-digital synergy is supported by Othman et al. (2025), who demonstrated that hybrid board-style games optimize science knowledge acquisition and collaboration, thereby challenging the assumption that digital efficacy depends solely on device sophistication. Furthermore, utilizing QR codes as a tangible-digital bridge offers immense pedagogical potential for creating inclusive STEM experiences in technology-limited settings (Tsoukala et al., 2024). Consequently, these conceptual and technological elements converge directly into the architecture of Wayground Paper Mode—a hybrid system explicitly designed to operationalize these multi-sensory and low-device benefits within the classroom.

To address this infrastructure barrier, this study investigates the effectiveness of motion-media-assisted Wayground Paper Mode as a low-device, hybrid game-based learning framework. This approach integrates QR-based physical evaluations with dynamic visual-kinesthetic stimuli, offering an alternative configuration that operates via a single centralized device. Academically, this research challenges the premise that digital learning efficacy is inherently tied to high-cost hardware, proposing instead that student engagement is driven by strategic pedagogical design. Practically, the insights gained serve as a scalable reference for implementing inclusive educational technology in suburban and remote regions. Consequently, this study aims to examine the capacity of this hybrid model of Wayground Paper Mode assisted by motion media to enhance science learning outcomes in elementary education.

METHODS

Research Design

This study uses a quantitative approach with a quasi-experimental design of the nonequivalent control group design in the form of giving pretests and posttests to two groups that are not randomly selected, but using classes that are already available in schools. The experimental group was a VA class with a total of 18 students who received treatment in the form of the application of Wayground Paper Mode assisted by motion media. In comparison, the control group was a VB class with a total of 21 students who participated in learning without the treatment. The application of Wayground Paper Mode assisted by motion media in the experimental group was carried out through a series of learning stages that were systematically structured in each meeting. The science material used specifically includes two subthemes, namely the human respiratory system in the subtheme "How Does Breathing Help Perform Daily Activities?" and the human digestive system in the subtheme "Why Do We Need to Eat and Drink?", in accordance with the big theme "How Do We Live and Grow" for elementary school grade V students.

Learning Procedure

The learning procedure is structured in four main stages. First, orientation: the teacher conveys the learning objectives and the mechanism of the Wayground Paper Mode, then distributes the Q-Card with the symbol of the digestive and respiratory organs to the students. Second, implementation: the teacher projects digital questions about organ function, classification of body systems, digestive tract, and respiratory simulation, which students answer by lifting or matching Q-Cards while performing structured (visual-kinesthetic) body movements that simulate respiratory airflow and intestinal peristalsis, so that abstract concepts such as diaphragmatic contraction and the work of the enzyme become concrete (Widiana, 2022). Third, collaboration: students discuss in small groups of three to four people to evaluate answers and formulate scientific arguments, in line with Ulfa et al. (2022) about game-based learning. Fourth, confirmation: the teacher provides feedback and conceptual explanations to correct misconceptions as a reinforcement of understanding (Darmulyani et al., 2024). This syntax is implemented for four meetings (2×35 minutes) before the posttest, utilizing a naturally formed class as a unit of analysis because it does not allow for full randomization (Safira & Nahdi, 2024).

Data Collection Instrument

The data collection instrument used in this study is a science learning outcome test in the form of multiple-choice questions, which are given at two stages of measurement, namely before treatment (pretest) and after treatment (posttest). The instrument was developed based on the material relevance and indicators as mentioned in Table 1.

Table 1. Instrument Indicators

No	Basic Competencies	Concept Indicators	Question Indicator	Item Number
1.	Understand the concepts of the digestive system and the respiratory system	Able to restate a concept	Students can use the right terminology in explaining the function of one of the organs of the digestive system.	1
			The student's explanation shows his understanding of the breathing process occurring.	2
2.	Classifying food based on the digestive organs that digest it correctly	Classify images according to certain characteristics according to a concept.	Students can classify images related to the digestive system based on their characteristics.	6
			Students can classify food based on the digestive organs that digest it correctly.	8
3.	Provide examples and non-examples of the respiratory system and digestive system	Provide examples and non-examples of concepts.	Students can mention ways of breathing other than using their noses.	9
			Students can explain why an organ is categorized not as a digestive organ!	3
4.	Converting information about the digestive and respiratory systems into various forms of representation, such as drawings, diagrams, tables, concept maps, and writing.	Expressing concepts in various forms.	Students can express the concepts of the digestive and respiratory systems in various forms, such as pictures, diagrams, tables, concept maps, and writing.	7
			The student's expression shows his or her understanding of the concept and the relationship between its parts.	10

5.	Determine the necessary and sufficient conditions for the process of digestion of food and the occurrence of the respiratory process.	Develop the necessary conditions and sufficient conditions of a concept.	Students can determine the necessary and sufficient conditions for concepts in the digestive system.	4
			Students can determine the necessary and sufficient conditions for concepts in the respiratory system.	5
6.	Explain why these actions are appropriate to overcome shortness of breath during exercise.	Can use, utilize, or select certain procedures and options.	Students can choose the right actions to maintain respiratory health.	11
			Students can explain why these actions are appropriate to address shortness of breath during exercise.	12
			Students can exemplify healthy eating habits.	13
7.	Understand the concept of the human digestive system.	Implement concepts or solve problems.	Students can name several ways to deal with stomach pain from spicy foods.	14
			Students can solve problems to find out the part of the body that digests food.	15

Content validity was evaluated using Aiken's V formula involving three expert validators who rated item-indicator alignment on a 1–4 scale. Items were retained if they achieved a minimum coefficient of V = 0.75 (Nurjanah, 2023). Internal consistency was determined using Cronbach's Alpha coefficient. In addition to the validity of the content, the instrument was also tested for reliability using Cronbach's Alpha coefficient to assess the level of internal consistency between question items. The determination of the reliability category refers to the threshold limit commonly used in educational research, where the instrument is declared reliable if the alpha coefficient is at an adequate value (Zakariya, 2022). The analysis yielded an Aiken's V range of 0.78–0.92 and a Cronbach's Alpha of 0.82, confirming that the test instrument possessed adequate psychometric properties for educational measurement.

Data Analysis

The analysis procedure began with a prerequisite test of the normality of data distribution using the Shapiro-Wilk method, which was chosen because it had a higher statistical power than other methods in detecting abnormalities in small to medium sample sizes (Gosselin, 2024). Statistical analyses were performed using Jamovi software. Data distribution normality was verified using the Shapiro-Wilk test ($p > 0.05$), while variance homogeneity was assessed via Levene's test ($p > 0.05$). An initial independent samples t-test was conducted on pretest scores to confirm baseline equivalence between the experimental and control groups. To evaluate the intervention's impact, a paired samples t-test examined within-group gains from pretest to posttest, and an independent samples t-test compared the posttest scores between the two classes. The practical magnitude of the learning gains was calculated using Cohen's d effect size.

RESULT AND DISCUSSION

Description of the Intervention

Wayground Paper Mode is a hybrid texted worksheet-based learning approach designed to stimulate students' sensory-motor engagement through exploring, coloring, and constructing representations of science concepts manually. This approach is combined with motion media in the form of animated flipbook cards and simple three-dimensional models that allow students to observe the phenomenon of science in a concrete way. Learning activities take place in three

phases: (1) self-exploration using paper mode sheets, (2) group discussions assisted by motion cards, and (3) structured reflection through the filling of concept summaries.

This study involved two groups of subjects, namely the VA class as an experimental group with 18 students and the VB class as a control group with 21 students. The following presents data on pretest and posttest scores of all respondents in each class. Table 2 presents a recapitulation of the individual grades of VA class students.

Table 2. Descriptive Statistics of Learning Outcomes

Classes	Measurement	N	Mean	Median	SD	SE	Min	Max
VA	Pretest	18	64.9	66	15.2	3.58	26	86
VA	Posttest	18	85.9	86	11.5	2.70	66	100
VB	Pretest	21	61.9	60	15.1	3.29	26	86
VB	Posttest	21	74.5	80	14.4	3.15	33	93

Table 2 presents a summary of the descriptive statistics of the measurement results of the two classes. The VA class, as the experimental group, showed a substantial increase in mean from 64.9 in the pretest to 85.9 in the posttest, accompanied by a narrowing of the range of value distribution, which was reflected in the decrease in standard deviation (SD). This indicates that student learning outcomes are not only increasing on average, but also becoming more even. The VB class, as the control group, also recorded an increase in the mean, but with a more limited amount, namely from 61.9 to 74.5. The equality of the initial ability of the two classes is shown by the difference in the mean pretest, which is only 3 points, so that the comparison of the effectiveness of treatment between the two groups can be carried out proportionally.

Analysis Prerequisites Test

Normality Test

Before conducting the hypothesis test, a prerequisite test was first carried out, which included the normality test and the homogeneity test. This prerequisite test serves to ensure that the data obtained meets the basic assumptions of parametric statistics, so that the results of the hypothesis testing can be accounted for methodologically. The normality test aims to find out whether the distribution of data follows the normal distribution or not. Data is said to be normally distributed when the values are symmetrically scattered around the mean, which is one of the important requirements in the use of parametric statistical tests such as independent samples t-tests. In this study, the normality test was carried out using the Shapiro-Wilk method, which was chosen because it was more sensitive and appropriately used in small to medium-sized samples. The decision-making criterion is that if the p-value > 0.05, then the data is declared to be normally distributed.

Table 3. Shapiro-Wilk Normality Test Results

Classes	W	p	Remarks
VA (Pre − Post)	0.937	0.256	Normal
VB (Pre − Post)	0.969	0.705	Normal

Table 3 presents the results of the normality test using the Shapiro-Wilk method on the pretest-posttest difference data in both classes. The test results showed that the VA class obtained a W value of 0.937 with a significance of p = 0.256, while the VB class obtained a W value of 0.969 with a significance of p = 0.705. The two p-values were above the threshold of 0.05, so that the data in both the experimental class and the control class were declared to be normally distributed. These findings indicate that the distribution of values in both groups meets parametric assumptions, so that further analysis using a paired samples t-test or independent samples t-test can be carried out without requiring data transformation or a non-parametric approach at all.

Homogeneity Test

Meanwhile, the homogeneity test aims to find out whether the two groups, namely the VA class and the VB class, have equal or homogeneous variance. Homogeneity of variance means that the level of data diversity between groups is relatively the same, so comparisons between groups can be made fairly and unbiasedly. The homogeneity test was carried out using Levene's Test, with the decision criterion that if the p-value> 0.05, then the variance of the two groups was declared homogeneous. The prerequisite test includes the normality test and the homogeneity test presented in one sub-section

Table 4. Levene's Test Homogeneity Test Results

Data	F	p	Remarks
Pretest VA vs VB	0.006	0.941	Homogeneous
Posttest VA vs VB	0.222	0.640	Homogeneous

Table 4 presents the results of the variance homogeneity test using Levene's Test on the pretest and posttest data of the two classes. The test results on the pretest data showed an F value of 0.006 with a significance of p = 0.941, while in the posttest data, an F value of 0.222 was obtained with a significance of p = 0.64. Since both p-values were above the 0.05 threshold, the variance between the VA class and the VB class was declared homogeneous, both before and after the treatment was administered. This condition shows that the diversity of data between groups is relatively equal, so that the comparison of learning outcomes between the experimental group and the control group can be done fairly without bias due to differences in variance, while also meeting the requirements for the use of the next parametric test.

Hypothesis Testing

In order to validate the inferential equivalence of initial abilities before the hypothesis testing, an independent samples t-test was carried out on the pretest data of the two classes. The results showed that there was no significant difference between the VA class pretest and the VB class (t = 0.613; df = 37; p = 0.544), so that the two groups were statistically equivalent before the treatment was given. This condition guarantees that the difference in posttest results found later can be attributed to differences in treatment, not to disparities in initial ability.

Paired Sample T-Test

The Paired Samples T-Test is used to find out if there is a significant difference between the pretest and posttest scores in the same group. In this study, the test was used to analyze changes in students' learning outcomes before and after being given treatment in each class. In addition, Cohen's d is used to measure the effect size of the treatment.

Table 5. Paired Samples T-Test Results for Each Class

Classes	t	df	p	*Cohen's d*	Remarks
VA	−5.41	17	< 0.001	−1,28	Significant (large effect)
VB	−4.85	20	< 0.001	−1,06	Significant (large effect)

The results of the paired samples t-test in Table 5 show that there is a significant difference between the pretest and posttest in the VA class ($t = -5.41$; $df = 17$; $p < 0.001$) and the VB class ($t = -4.85$; $df = 20$; $p < 0.001$). Cohen's d value of the VA class of −1.28 and the VB class of −1.06 both belong to the large effect category, indicating that the improvement in learning outcomes in both classes has a practically significant effect. However, the significant increase in the VB class (control group) needs to be interpreted critically. The increase is estimated to be influenced by confounding factors such as the effect of testing (students' familiarity with the question format), exposure to regular material from teachers, and intrinsic motivation stimulated by the test situation. This phenomenon is in line with the concepts of history threat and maturation effect in quasi-experimental design. The difference in the magnitude of the increase in the average gain score of the VA class by 21.0 points compared to 12.6 points in the VB class shows that the Wayground Paper Mode intervention provides a substantial incremental effect beyond the conventional learning factor alone.

Independent Sample T-Test

The Independent Samples T-Test is used to find out whether there is a difference in the average learning outcomes between two independent groups. In this study, the test was used to compare the posttest results between VA classes and VB classes after each received learning treatment. In addition to looking at the significance of the differences, Cohen's d was used to measure the magnitude of the effect of the difference that occurred between the two groups.

Table 6. Independent Samples T-Test Results

Comparison	t	df	p	*Cohen's d*	Remarks
VA vs VB (Posttest)	2.691	37	0.011	0.864	Significant (large effect)

To test the difference in effectiveness between the two groups, an independent samples t-test was performed on the posttest data in Table 5. The results showed a significant difference between the VA class posttest and the VB class ($t = 2.691$; $df = 37$; $p = 0.011$), with Cohen's value $d = 0.864$, which was classified as a large effect. These findings indicate that VA classes that received the Wayground Paper Mode treatment assisted by motion media recorded statistically higher and more meaningful learning outcomes than VB classes.

Discussions

Impact of the Hybrid Intervention on Science Learning

The pronounced cognitive enhancement observed in the experimental group underscores the pedagogical alignment between motion-media-assisted Wayground Paper Mode and the cognitive developmental architecture of fifth-grade students. At approximately eleven years old, these learners occupy the concrete operational stage, requiring tangible anchors to decipher complex, non-observable biological mechanisms. The hybrid framework directly addresses this requirement during instructions on the human digestive and respiratory systems. Rather than

passively digesting abstract texts regarding intestinal peristalsis or diaphragmatic contractions, students actively externalize their comprehension by manipulating physical QR-based Q-Cards matched with structured kinesthetic movements. This multi-sensory engagement operationalizes Paivio's Dual Coding Theory; by simultaneously processing visual question projections and executing kinesthetic responses, learners form interconnected cognitive pathways that facilitate deeper conceptual retention. Consequently, the intervention successfully bridges the gap between concrete interaction and abstract scientific reasoning. This substantial gain extends beyond a mere novelty effect, reinforcing prior assertions by Alyusfitri et al. (2024) and Azizah et al. (2025) that gamified, interactive architectures shift elementary science education away from passive lecture models toward sustainable intrinsic motivation and robust academic performance.

The Pedagogy of Low-Device Hybrid Learning

Although both groups exhibited significant learning gains, the experimental class demonstrated a highly superior incremental effect compared to the control group. In quasi-experimental setups, baseline improvements in a conventional classroom often capture confounding variables, such as testing familiarization or maturation threats. However, the substantial margin of variance favoring the experimental group can be explicitly attributed to the architectural advantages of Wayground Paper Mode. By projecting digital queries that necessitate instantaneous physical responses through QR-based Q-Cards, the framework successfully operationalizes Paivio's Dual Coding Theory. This seamless fusion of digital visual stimuli and kinesthetic body coordination (such as simulating peristaltic or respiratory movements) forms dual cognitive traces in long-term memory. This physical-digital synergy aligns perfectly with previous assertions that systematic integration of visual and motion elements consistently yields more sustainable conceptual imprints than single-medium instruction (Aryfien et al., 2025; Fajriah et al., 2022; Musfiza et al., 2025).

Beyond immediate classroom dynamics, the empirical weight of this study becomes highly significant when contextualized within global educational benchmarks. The robust effect size generated by this model aligns with international meta-analyses confirming that elementary school learners reap the highest academic dividends from gamified interventions (Li et al., 2023; Zeng et al., 2024). This optimization is further enhanced by the multi-medium configuration; as noted by Destriana & Farida (2025), utilizing concurrent learning media channels yields a significantly greater pedagogical impact than single-medium delivery, while Elfiana et al. (2025) confirm that highly interactive gamified frameworks consistently unlock superior learning outcomes. More importantly, the novelty of this research lies in its empirical refutation of the prevailing assumption that educational technology must inherently be high-cost and device-intensive. By matching or exceeding the effectiveness parameters of full-digital platforms documented in recent STEM literature (Wang et al., 2022; Wang et al., 2026), this framework substantiates that a well-designed, low-tech learning approach can serve as a powerful engine for educational equity in infrastructure-constrained schools (Othman et al., 2025). It proves that elementary institutions restricted by digital disparities can still deliver highly interactive, complex science instruction, provided the medium is strategically anchored in children's cognitive development rather than hardware sophistication.

CONCLUSION

This study concludes that the application of motion-media-assisted Wayground Paper Mode significantly improves the science learning outcomes of fifth-grade students, demonstrating a superior capacity to enhance conceptual comprehension compared to conventional instruction.

This pedagogical success stems from its alignment with the concrete operational stage of young learners, where physical-digital dual coding via Q-Cards and structured body movements actively reinforces long-term memory retention. Despite these positive outcomes, certain limitations must be acknowledged, including the restricted sample size and the potential presence of internal validity threats such as history and maturation effects. Nevertheless, the practical implication remains highly significant. This low-device configuration proves that impactful educational technology can be delivered without relying on high-cost hardware, serving as an equitable learning solution for infrastructure-constrained schools. Consequently, elementary school teachers are encouraged to adopt this hybrid model as an interactive alternative for teaching complex, procedural science topics. Furthermore, school administrations should support the deployment of such accessible digital-physical platforms to cultivate inclusive classrooms. Finally, future researchers are advised to replicate this study utilizing a true experimental design with larger, multi-site populations and to explore its long-term impacts on learning retention across diverse academic subjects.

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