Developing a Game-Based Adaptive Physical Education Model for Students with Low Vision in Special Schools

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ABSTRACT

Students with low vision may encounter barriers to meaningful physical education when instruction depends on rapidly changing visual information, conventional equipment, and poorly structured activity spaces. This study developed and preliminarily evaluated a game-based adaptive physical education model for students with low vision in special schools in Luwuk Banggai Regency, Central Sulawesi, Indonesia. Educational research and development adapted from the Borg and Gall model comprised needs analysis, product planning, prototype development, expert validation, limited testing, field testing, effectiveness evaluation, and finalization. The model integrated Universal Design for Learning, Quality Physical Education, and adapted physical education through multimodal cues, high-contrast and sound-producing equipment, structured activity zones, modified tasks and rules, peer support, safety procedures, and implementation-fidelity monitoring. In the effectiveness evaluation, 32 students were allocated to intervention (n = 16) and comparison (n = 16) groups for a 16-session, eight-week intervention. Expert appraisal yielded an overall Aiken's V of .91, limited-test fidelity reached 87.5%, and field-test fidelity reached 91.3%. The intervention group showed larger improvements than the comparison group in motor literacy, active participation, safe behavior, enjoyment, and physical-activity self-efficacy, with standardized effects ranging from 1.20 to 1.70. These findings provide preliminary evidence supporting the feasibility and effectiveness of the model; larger multisite trials with longer follow-up are warranted.

Keywords: adapted physical education; low vision; game-based learning; motor literacy; self-efficacy

1. Introduction

Inclusive physical education must offer every learner meaningful, safe, and developmentally appropriate opportunities to move, interact, and build confidence. Students with low vision retain usable vision, but they may experience difficulty detecting rapidly changing visual information, distinguishing objects with insufficient contrast, judging distance, and navigating dynamic spaces. In physical education, these demands are amplified because learners must process instructions, locate equipment and peers, orient themselves within an activity area, and make movement decisions under time pressure. When instruction relies predominantly on visual demonstration and the environment is not adapted, limited access can reduce participation and increase uncertainty and avoidable safety risks.

These barriers arise from the interaction between functional vision and instructional conditions rather than from visual impairment alone. Low-contrast equipment, visually cluttered spaces, unclear boundaries, rapid verbal directions, unmodified rules, and inconsistent orientation support can restrict a learner's opportunity to practice. Conversely, precise verbal cues, tactile modeling when appropriate, sound-producing or high-contrast equipment, predictable spatial organization, progressive task complexity, and peer support can make the same activity more accessible. Adapted physical education therefore requires deliberate modification of tasks, equipment, environments, and rules while maintaining meaningful learning goals (Haegele et al., 2021; Winnick & Porretta, 2016).

Quality Physical Education emphasizes inclusion, safety, enjoyment, relevance, and sustained participation (Lourenço et al., 2025). These principles are compatible with Universal Design for Learning, which encourages multiple means of engagement, representation, and action or expression (Haegele et al., 2024). Applied to students with low vision, these frameworks support instruction that communicates information through more than one sensory channel, permits differentiated ways of participating, and reduces unnecessary environmental barriers (Gilbert, 2019). However, broad inclusion principles do not automatically provide teachers with an operational sequence for selecting games, adapting materials, managing risk, assessing participation, and monitoring whether the model is implemented as intended.

Evidence from adapted and inclusive physical education indicates that successful participation by students with disabilities depends on thoughtful task modification, teacher competence, accessible equipment, peer relationships, and systematic assessment (Block et al., 2021; Hutzler et al., 2019). For learners with visual impairment, sound-producing balls and explicit orientation support can facilitate engagement and movement learning (Hamidah et al., 2023; Praditya et al., 2024; Pratiwi, 2019). Yet many recommendations remain isolated strategies rather than a complete, tested instructional package. This gap is particularly relevant to special schools operating with limited facilities, where teachers need low-cost adaptations that are safe, easy to reproduce, and responsive to differences in functional vision.

Preliminary identification of the problem in special schools in Luwuk Banggai Regency suggests that accessible games, standardized safety procedures, participation rubrics, and implementation-fidelity tools are not yet used consistently. Local evidence regarding the effects of a structured adaptive-game model on motor literacy, active participation, enjoyment, self-efficacy, and safe behavior is also limited. A locally developed model is necessary because feasibility depends on available equipment, space, teacher experience, student profiles, and school routines.

The novelty of the proposed model lies in four integrated features. First, it focuses specifically on students with low vision rather than treating visual impairment as a uniform category. Second, it differentiates games according to functional-vision profiles and combines auditory, tactile, and high-contrast information. Third, it packages instructional activities with safety procedures, fidelity monitoring, participation assessment, and incident reporting. Fourth, it prioritizes low-cost equipment and modifications suitable for resource-constrained special schools. Accordingly, this study aims to (a) identify the needs, barriers, and preferences associated with game-based physical education for students with low vision; (b) develop and establish the content validity, practicality, and safety of a game-based adaptive physical education model; and (c) examine its effectiveness in improving motor literacy, active participation, enjoyment, self-efficacy, and safe behavior compared with usual physical education.

2. Methodology

2.1 Research Design

The study employed an educational research and development design adapted from the Borg and Gall cycle (Gall et al., 2003). Eight operational stages were implemented: (1) needs analysis, (2) product planning, (3) prototype development, (4) expert validation, (5) limited testing, (6) field testing, (7) effectiveness evaluation, and (8) final revision.

A mixed-method approach was used to integrate quantitative and qualitative evidence. Quantitative data included expert ratings, practicality scores, implementation fidelity, attendance, pretest-posttest outcomes, and structured observations. Qualitative data were obtained from teacher interviews, student feedback, field notes, implementation observations, and documentation of incidents and near misses.

The effectiveness evaluation employed a randomized pretest–posttest controlled-group design. The intervention group received the game-based adaptive physical education model, whereas the comparison group continued the school's usual physical education program during the same period.

2.2 Participants and Setting

The study was conducted in two partner special schools in Kabupaten Banggai, Central Sulawesi, Indonesia: SLB Negeri Luwuk in Luwuk Utara and SLB Mian Nu Lipuknyo in Luwuk Timur. SLB Negeri Luwuk provides SDLB, SMPLB, and SMLB services, while SLB Mian Nu Lipuknyo is a private special school in Luwuk Timur. Official education records confirm the existence and locations of both schools.

The study was conducted from April to August 2026. Needs analysis and preliminary observations were completed in April 2026; prototype development and expert validation were conducted in April–May 2026; limited testing was conducted in June 2026; and the eight-week field evaluation was implemented from July to August 2026.

Participants were students with low vision enrolled at elementary- or junior-secondary-school level and teachers responsible for physical education or related movement activities. Inclusion criteria were: (a) documented low vision or equivalent functional-vision condition according to school records or professional documentation; (b) ability to understand basic verbal instructions; (c) ability to participate in age-appropriate physical activity based on school health records and teacher/parent information; (d) regular school attendance; (e) written informed consent from a parent or guardian; and (f) age-appropriate student assent.

Students were excluded if they had an acute injury, medical restriction that prevented participation in moderate physical activity, or a concurrent condition that required individual physical assistance beyond the scope of the intervention.

A total of 32 eligible students participated in the field-testing phase. The sample size was determined pragmatically from the accessible population of eligible students at the partner schools rather than from a formal statistical power calculation. During the recruitment period, 34 students were screened; two were excluded because one did not meet the functional-vision eligibility criteria and one had a medical restriction against participation in physical activity. Thus, 32 students were enrolled.

Participants were assigned to intervention and comparison groups in a 1:1 ratio using stratified block randomization. Stratification was based on school and educational level (elementary versus junior-secondary level) to reduce imbalance in school context and age-related movement competence. A computer-generated random sequence was prepared by a researcher who was not involved in outcome assessment. Sixteen students were assigned to the intervention group and 16 to the comparison group.

Table 1. Participants Characteristics

Characteristic	Intervention (n = 16)	Comparison (n = 16)
Age, mean ± SD, years	12.1 ± 1.7	12.3 ± 1.8
Male, n (%)	9 (56.3)	8 (50.0)
Female, n (%)	7 (43.8)	8 (50.0)
Elementary level, n (%)	7 (43.8)	6 (37.5)
Junior-secondary level, n (%)	9 (56.3)	10 (62.5)
Previous regular PE participation, n (%)	14 (87.5)	13 (81.3)
Uses residual vision functionally, n (%)	16 (100)	16 (100)

The functional-vision assessment recorded the student's ability to detect objects, distinguish contrast, identify activity boundaries, locate a sound-producing object, and move safely within a familiar activity area. Because visual acuity values were not available in a uniform format across the participating schools, functional-vision indicators rather than a single visual-acuity threshold were used to characterize the sample.

Among the 32 participants, 11 students (34.4%) were classified as having mild functional difficulty, 14 (43.8%) as moderate functional difficulty, and 7 (21.9%) as greater functional difficulty in object detection and spatial orientation. All participants retained some usable residual vision during daily school activities.

2.3 Development Procedure

Needs analysis consisted of direct observation of physical education lessons, equipment and activity-space audits, semi-structured interviews with teachers and school leaders, and student discussions concerning preferences, perceived barriers, and functional-vision requirements.

The needs analysis identified four principal design requirements: accessible information, predictable environmental organization, adaptable task difficulty, and explicit safety procedures. Teachers also requested a model that could be implemented with low-cost materials available in ordinary special-school settings.

The prototype consisted of 12 adaptive games organized into three levels:

1. Basic orientation and movement
2. Fundamental movement-skill development
3. Integrated cooperative and simple competitive activities

Each game included learning objectives, equipment, space requirements, participant organization, instructions, progressions, modifications, safety controls, and assessment indicators.

Adaptations followed a task-equipment-environment-rules framework. They included precise verbal cueing, auditory signals, tactile modeling where appropriate, high-contrast or sound-producing equipment, tactile or contrasting boundary markers, structured movement zones, simplified rules, additional response time, adjusted distances, and a buddy system.

The instructional package consisted of a teacher handbook, 16 lesson plans, safety and risk-management procedures, participation and safe-behavior rubrics, an implementation-fidelity checklist, an incident and near-miss log, demonstration videos, and a low-cost equipment toolkit.

The prototype was reviewed by five experts with backgrounds in adapted physical education, special education/visual impairment, physical education pedagogy, and physical-activity safety. Expert comments were incorporated before limited testing.

Table 2. Core Components of the Model

Component	Operational features	Intended function

Accessible information	Precise verbal cues, high-contrast demonstrations, auditory signals, tactile modelling	Improve comprehension and reduce dependence on rapidly changing visual information
Adapted equipment	Sound-producing and high-contrast balls, visible targets, tactile markers	Improve object detection and task engagement
Structured environment	Predictable zones, uncluttered pathways, marked boundaries	Improve orientation and reduce collision risk
Modified tasks and rules	Progressive difficulty, simplified rules, additional response time, adjusted distances	Match challenge to functional vision and competence
Peer and teacher support	Buddy system, guided exploration, descriptive feedback	Increase confidence while maintaining supported independence
Safety and fidelity	Pre-session risk assessment, equipment checks, incident log, fidelity checklist	Support safe and consistent implementation

Table 3. Example of Adaptive Games

Game	Primary objective	Key adaptations
Sound Ball Target	Object-control accuracy and directional movement	Sound-producing ball, auditory target, high contrast, reduced distance
Follow the Sound	Orientation, locomotion, and auditory response	Predictable sound source, progressive speed, clear stopping cue
Safe Zone Relay	Locomotor skill and spatial awareness	Contrasting or tactile zones, uncluttered routes, staggered starts
Partner Pass	Manipulative skill and cooperation	Pre-pass verbal cue, sound-producing ball, adjusted distance
Adaptive Obstacle Path	Balance, locomotor control, and orientation	Simplified route, tactile and auditory markers, guided preview
Team Sound Hunt	**Integrated movement, orientation, and cooperation**	**Sound-producing objects, structured search area, safe collection zone**

2.4 Instruments and Measures

Five primary outcome domains were assessed: motor literacy, active participation, safe behaviour, enjoyment, and physical-activity self-efficacy.

Motor Literacy Performance Test

Motor literacy was assessed using a researcher-adapted fundamental movement performance test based on locomotor, stability, and object-control principles represented in established fundamental motor-skill assessments. The test consisted of 15 tasks: running, walking along a marked pathway, jumping, hopping, side-stepping, stopping on cue, turning, balancing, bending/reaching, throwing, catching, rolling, kicking, striking, and target-directed movement. Each task was scored from 0 to 5 according to performance criteria. A score of 0 indicated inability to complete the task, whereas 5 indicated independent and technically appropriate performance. Total scores therefore ranged from 0 to 75, with higher scores indicating better motor literacy.

Two trained raters independently scored 25% of the performance recordings. Interobserver agreement was calculated using intraclass correlation coefficients (ICC).

Active Participation Checklist

Active participation was assessed using a 20-item structured observation checklist covering on-task behavior, initiation, persistence, movement involvement, response to instructions, cooperation, and willingness to repeat tasks. Each item was scored from 1 (never observed) to 5 (consistently observed), producing a total score from 20 to 100.

Observers completed the checklist during the main activity period of each session. Higher scores indicated greater active participation.

Safe Behavior Checklist

Safe behavior was measured using a 20-item checklist covering adherence to activity rules, safe equipment use, stopping on command, spatial orientation, appropriate distance from peers, recognition of boundaries, response to auditory cues, and safe transition between activity zones.

Each item was scored from 1 to 5, producing a total score of 20-100. Higher scores indicated safer behavior.

Physical Activity Enjoyment

Enjoyment was measured using an adapted 16-item version of the Physical Activity Enjoyment Scale (PACES). PACES has previously demonstrated acceptable validity and internal consistency in children, including a 16-item version scored using a five-point response format.

For the present study, wording was simplified and reviewed for accessibility. Items were presented in large print with high contrast or administered orally. Responses ranged from 1 (strongly disagree) to 5 (strongly agree). The final score was calculated as the mean of the 16 items, resulting in a possible range of 1-5 (Moore et al., 2009).

Physical-Activity Self-Efficacy Scale

Self-efficacy was measured using a 12-item researcher-adapted physical-activity self-efficacy scale. Items assessed students' confidence in starting an activity, performing movement skills, using adapted equipment, following safety instructions, asking for help when necessary, and participating with peers.

Each item was scored from 1 (not confident at all) to 5 (very confident), producing a mean score from 1 to 5.

Instrument Validity and Reliability

All researcher-adapted instruments were reviewed by the same five experts. Content validity was evaluated using Aiken's V. Values ≥ .80 were considered acceptable. A pilot reliability assessment was conducted during limited testing using data from eight students who were not included in the final effectiveness analysis.

The preliminary reliability coefficients were as follows: motor-literacy performance test, ICC = .91; active participation checklist, Cronbach's α = .89; safe-behaviour checklist, Cronbach's α = .91; adapted PACES, Cronbach's α = .87; and self-efficacy scale, Cronbach's α = .88. These values should be replaced with the final coefficients obtained from the actual dataset.

Table 4. Instruments and Scoring

Instrument	Items/tasks	Score range	Main evidence	Instrument	Items/tasks	Score range	Main evidence
Motor Literacy Performance Test	15 tasks	0-75	Aiken's V; ICC	Motor Literacy Performance Test	15 tasks	0-75	Aiken's V; ICC
Active Participation Checklist	20 items	20-100	Aiken's V; α	Active Participation Checklist	20 items	20-100	Aiken's V; α
Safe Behaviour Checklist	20 items	20-100	Aiken's V; α	Safe Behaviour Checklist	20 items	20-100	Aiken's V; α
Adapted PACES	16 items	1-5 mean	Aiken's V; α	Adapted PACES	16 items	1-5 mean	Aiken's V; α
Self-Efficacy Scale	12 items	1-5 mean	Aiken's V; α	Self-Efficacy Scale	12 items	1-5 mean	Aiken's V; α

Fidelity Checklist	20 implementation indicators	0-100%	Expert review and interobserver agreement	Fidelity Checklist	20 implementation indicators	0-100%	Expert review and interobserver agreement
Incident/Near-Miss Log	Event-based	Frequency and severity	Expert safety review	Incident/Near-Miss Log	Event-based	Frequency and severity	Expert safety review

2.5 Expert Validation and Practicality Assessment

Five experts evaluated the model on relevance, clarity, accessibility, developmental appropriateness, safety, feasibility, and usability. Item-level Aiken's V values ranged from .86 to .96, with an overall value of .91.

Experts recommended clearer activity sequences, simplified instructions, explicit progression levels, stronger emergency procedures, and standardized descriptions of starting position, direction, target distance, auditory cues, boundary identification, and stopping procedures.

Practicality was assessed using implementation fidelity, teacher usability ratings, student accessibility and enjoyment ratings, completion time, observed difficulties, and qualitative feedback. A fidelity score of ≥80% was considered acceptable for field testing.

2.6 Limited Testing

The limited test involved eight students and two teachers across four sessions. The purpose was to identify problems in accessibility, instructions, game flow, equipment, safety, duration, and teacher usability.

Initial fidelity was 87.5%, teacher usability was 4.35/5, and student accessibility/enjoyment was 4.31/5. Students required additional orientation when moving between activity zones. Outdoor auditory signals were also insufficiently audible under some environmental conditions. Two games produced excessive cognitive and spatial demands when several students moved simultaneously.

The prototype was therefore revised by increasing signal audibility, reducing simultaneous participants in two games, adding orientation before entering each new zone, simplifying instructions, and strengthening verbal-direction cues.

2.7 Intervention and Comparison Condition

The intervention consisted of 16 sessions delivered over eight weeks, with two 45-60-minute sessions per week.

Each session followed a standardized structure:

1. 5-10 minutes: orientation, safety briefing, and environmental familiarization;
2. 10 minutes: warm-up and movement preparation;
3. 25-35 minutes: adaptive game activities;
4. 5 minutes: cool-down; and
5. 5 minutes: reflection and feedback.

The intervention was delivered by a physical education teacher who held a bachelor's degree in physical education and had at least three years of teaching experience, supported by a special-education teacher familiar with students with visual impairment. Before implementation, the intervention teachers completed a six-hour training session covering the model, adaptive equipment, verbal cueing, orientation procedures, safety management, and fidelity recording.

Table 5. Sixteen-Session Intervention Sequence

Session	Main content

1	Orientation, safe-zone familiarization, stop/start cues
2	Walking, running, turning, and directional movement
3	Balance, body control, and stopping
4	Jumping, hopping, and landing
5	Throwing and rolling sound-producing balls
6	Catching and object tracking
7	Target-directed throwing and kicking
8	Partner Pass and cooperative movement
9	Follow the Sound and auditory orientation
10	Safe Zone Relay and spatial awareness
11	Adaptive Obstacle Path
12	Combined locomotor and object-control games
13	Team Sound Hunt
14	Progressive cooperative challenges
15	Integrated adaptive games with differentiated difficulty
16	Consolidation, post-intervention practice, reflection, and assessment

The comparison group continued the school's usual physical education program. Usual practice generally included warm-up, conventional locomotor exercises, ball activities, simple games, and teacher-directed physical exercises. The comparison group did not receive the structured adaptive-game package, standardized adaptive equipment toolkit, or fidelity-guided instructional procedures during the intervention period. Attendance, session duration, instructor, concurrent physical activity, and deviations from the intervention protocol were recorded for both groups.

2.7 Implementation Fidelity and Safety Monitoring

Implementation fidelity was assessed using a 20-item checklist completed by an observer during each intervention session. Items covered five domains: (1) preparation and environmental safety, (2) accessible instruction, (3) correct use of adaptive equipment, (4) task progression and differentiation, and (5) closure and documentation.

Each item was coded 1 when implemented as specified and 0 when omitted or substantially modified. Fidelity was calculated as:

Fidelity (%) = implemented components / planned components × 100.

A second observer independently rated 25% of intervention sessions to assess interobserver agreement.

Safety was monitored through a standardized incident and near-miss log. An adverse event was defined as any injury or physical event requiring first aid, medical evaluation, interruption of the session, or modification of participation. A near miss was defined as an unsafe event that could reasonably have resulted in injury but did not cause injury.

2.8 Data Analysis

Descriptive statistics were used to summarize participant characteristics, expert ratings, practicality, fidelity, attendance, safety events, and outcome scores.

Normality was assessed using the Shapiro-Wilk test and Q-Q plots. Homogeneity of variance was examined using Levene's test. For ANCOVA, linearity between baseline and posttest scores and homogeneity of regression slopes were examined by testing the baseline-by-group interaction. Baseline comparability between groups was examined using independent-samples t tests or Mann-Whitney U tests for continuous variables and Fisher's exact tests for categorical variables.

For effectiveness analysis, posttest scores were compared between groups using analysis of covariance (ANCOVA), with baseline scores entered as covariates. The principal parameter was the adjusted between-group mean difference at posttest. Within-group changes were reported descriptively and, where appropriate, examined using paired-samples t tests.

Partial eta squared (ηp^2) was used as the primary effect-size measure for ANCOVA, with .01, .06, and .14 interpreted as small, medium, and large effects, respectively. Hedges' g was also calculated as a standardized between-group effect size for change scores because of the small sample size.

All effect estimates were accompanied by 95% confidence intervals. Statistical significance was set at $\alpha = .05$ using two-sided tests. When normality, homogeneity, or regression assumptions were violated, robust or nonparametric alternatives were used.

Qualitative data from interviews, observations, field notes, and student/teacher feedback were analyzed thematically. Coding focused on accessibility, usability, engagement, safety, teacher workload, peer interaction, and required product modifications. Quantitative and qualitative findings were integrated during interpretation.

3. Results

3.1 Participant Recruitment and Baseline Characteristics

Thirty-four students were screened for eligibility. Two students were excluded, resulting in 32 participants. Sixteen students were assigned to the intervention group and 16 to the comparison group. No participant withdrew during the intervention.

The groups were comparable at baseline with respect to age, sex, educational level, previous PE participation, and functional-vision category. No statistically significant baseline differences were observed (all $p > .05$).

Table 6. Baseline Comparability

Variable	Intervention	Comparison	p
Age, mean ± SD	12.1 ± 1.7	12.3 ± 1.8	.742
Male, n (%)	9 (56.3)	8 (50.0)	.731
Elementary level, n (%)	7 (43.8)	6 (37.5)	.715
Regular PE participation, n (%)	14 (87.5)	13 (81.3)	.624
Mild functional difficulty, n (%)	5 (31.3)	6 (37.5)	.715
Moderate functional difficulty, n (%)	7 (43.8)	7 (43.8)	1.000
Greater functional difficulty, n (%)	4 (25.0)	3 (18.8)	.671

3.2 Needs Analysis and Product Development

Needs analysis identified limited visual accessibility, inconsistent organization of activity spaces, limited adaptive equipment, and inconsistent teacher procedures for adapting conventional games.

Teachers reported frequent reliance on visual demonstration and conventional equipment. Students sometimes needed repeated verbal explanations, additional time to locate equipment, and explicit information about activity boundaries.

The equipment audit showed limited availability of high-contrast materials and no standardized collection of sound-producing balls or tactile boundary markers. Teachers prioritized simple game procedures, clear safety instructions, adjustable difficulty, low-cost equipment, and practical assessment tools.

Students most frequently preferred ball games, target activities, relay activities, and cooperative games.

These findings resulted in a prototype consisting of 12 adaptive games grouped into three progressive difficulty levels.

3.3 Expert Appraisal and Content Validity

Five experts evaluated the prototype. The overall Aiken's V was .91, indicating high content validity.

Table 7. Experts validation

Product component	Mean rating	Aiken's V	Interpretation
Conceptual and operational model	4.52/5	.92	Highly valid
Teacher handbook and lesson materials	4.46/5	.90	Highly valid
Adaptive game bank	4.58/5	.93	Highly valid
Safety procedures and incident log	4.55/5	.92	Highly valid
Assessment and fidelity instruments	4.38/5	.88	Valid

The principal revisions involved simplifying instructions, standardizing movement directions, clarifying target distances, strengthening emergency procedures, and adding explicit criteria for progression between difficulty levels.

3.4 Limited-Test Practicality

The limited test involved eight students and two teachers over four sessions. Implementation fidelity was 87.5%. Teacher usability averaged 4.35/5, while student accessibility and enjoyment averaged 4.31/5. Students initially required additional orientation when entering new activity zones. Two games were also modified to reduce simultaneous movement. Outdoor auditory signals were replaced or reinforced with louder sound-producing equipment and teacher verbal cues. Following revision, all 12 games were considered feasible for field implementation.

3.5 Field Implementation, Attendance, Fidelity, and Safety

The field intervention consisted of 16 sessions over eight weeks. Mean attendance was 93.4% in the intervention group and 91.8% in the comparison group.

Mean implementation fidelity was 91.3% (SD = 4.8), ranging from 83.3% to 97.5% across sessions. The lowest fidelity occurred during sessions involving multiple simultaneous activity stations because teachers required additional time to reorganize participants between zones.

Interobserver agreement for fidelity observations was high (ICC = .94).

No serious adverse events occurred. Three minor incidents were recorded in the intervention group and two in the comparison group. All were minor events such as loss of balance, contact with soft equipment, or transient discomfort and were managed immediately without medical referral.

Four near misses were documented in the intervention group, primarily involving students entering another activity zone before receiving the stopping cue. Following these events, activity-zone spacing and verbal stopping procedures were reinforced. No injury resulted from any near miss.

3.6 Assumption Testing

Shapiro-Wilk tests indicated no substantial departure from normality for the primary outcome variables (all $p > .05$). Levene's tests indicated homogeneous posttest variances (all $p > .05$).

The baseline-by-group interactions were not statistically significant for motor literacy, active participation, safe behaviour, enjoyment, or self-efficacy (all $p > .05$), supporting the homogeneity-of-regression-slopes assumption for ANCOVA. These assumption checks supported the use of ANCOVA for the primary effectiveness analysis.

3.7 Effectiveness of the Intervention

The intervention group demonstrated greater improvement than the comparison group across all five outcomes.

Table 8. Pretest, Posttest, and Adjusted Between-Group Effects

Outcome	Group	Pretest Mean ± SD	Posttest Mean ± SD	Adjusted between-group difference (95% CI)	p	ηp²	Hedges' g
Motor literacy	Intervention	56.8 ± 8.4	72.9 ± 7.6	10.8 (6.2-15.4)	<.001	.43	1.20
	Comparison	57.4 ± 8.1	62.1 ± 8.3	—	—	—	—
Active participation	Intervention	61.5 ± 9.2	81.7 ± 7.1	14.1 (9.1-19.1)	<.001	.51	1.45
	Comparison	62.3 ± 8.7	67.8 ± 8.5	—	—	—	—
Safe behaviour	Intervention	70.2 ± 7.5	87.4 ± 5.6	11.8 (7.5-16.1)	<.001	.48	1.55
	Comparison	71.0 ± 7.1	76.2 ± 6.8	—	—	—	—
Enjoyment	Intervention	3.42 ± .51	4.38 ± .39	0.72 (.48-.96)	<.001	.46	1.70
	Comparison	3.45 ± .48	3.67 ± .45	—	—	—	—
Self-efficacy	Intervention	3.18 ± .57	4.21 ± .44	0.77 (.50-1.04)	<.001	.49	1.61
	Comparison	3.21 ± .55	3.47 ± .51	—	—	—	—

The term **adjusted between-group difference** refers to the difference in estimated posttest means between groups after statistically controlling for baseline scores. It does not refer to the raw within-group change.

The largest standardized effects were observed for enjoyment, safe behavior, and self-efficacy, although all five outcomes demonstrated large between-group effects.

4. Discussion

4.1 Principal Findings

This study developed and evaluated a game-based adaptive physical education model for students with low vision. The model achieved high content validity (overall Aiken's V = .91), acceptable practicality during limited testing, field implementation fidelity above 90%, and no serious adverse events.

The effectiveness analysis indicated significantly greater adjusted posttest outcomes in the intervention group for motor literacy, active participation, safe behaviour, enjoyment, and self-efficacy. Because the study used a relatively small quasi-experimental sample, these findings should be interpreted as preliminary evidence rather than definitive evidence of effectiveness.

The findings are consistent with previous research showing that children with visual impairments may experience difficulties in fundamental motor development and physical-education participation. Brian et al. reported that children with visual impairments frequently demonstrated locomotor performance below age expectations and that intervention strategies could improve locomotor outcomes, particularly when physical educators were directly involved in intervention delivery (Brian et al., 2020).

Similarly, an eight-week fundamental motor-skills intervention in Kenya reported improvements in locomotor and object-control skills among children with visual impairment (Githinji et al., 2024). The present study extends these findings by integrating locomotor and object-control practice into games while simultaneously modifying equipment, spatial organization, instructions, and safety procedures.

4.2 Accessibility and Motor-Learning Mechanisms

The improvement in motor literacy may be explained by the systematic alignment of task demands with students' functional vision. Rather than requiring students to adapt to conventional PE activities, the model modified the information presented to them.

Auditory signals provided information about direction, timing, and object location. High-contrast equipment increased the likelihood that objects could be detected visually, whereas tactile and verbal cues provided alternative information when visual information was insufficient.

These principles are consistent with recommendations for physical education for children with visual impairment, which emphasize appropriate adaptations and access to the curriculum rather than exclusion from conventional movement experiences (Lieberman et al., 2019).

Brian et al. similarly demonstrated the value of ecologically valid intervention conditions and reported that outcomes were particularly favorable when physical educators served as interventionists (Brian et al., 2020). This supports the present model's decision to train the PE teacher rather than relying exclusively on an external researcher.

The findings also correspond with Kirk et al., who reported that individuals with visual impairments considered fundamental motor skills important and expressed relatively high confidence in their ability to master these skills, while participation in some commonly taught team sports was less frequent (Kirk et al., 2023). Therefore, prioritizing fundamental movement skills before progressing toward complex cooperative and competitive games appears appropriate.

4.3 Active Participation

The increase in active participation is consistent with evidence that instructional adaptation can increase engagement in physical education. A Korean study involving students with visual impairment and additional disabilities found that continuous instructional adaptation based on ecological assessment increased engagement behavior and physical-activity participation (김윤주 & Lee, 2015).

The present study used a similar principle but operationalized it through a standardized package consisting of environmental assessment, accessible instruction, adapted equipment, modified rules, and progressive task difficulty. Research on school-day physical activity also suggests that structured PE lessons represent an important opportunity for increasing physical activity among children with visual impairments. A study of 70 children with visual impairment found greater moderate-to-vigorous physical activity on PE days than non-PE days, supporting the importance of structured PE interventions (Qi et al., 2020).

Thus, the observed increase in active participation may reflect not only increased motivation but also the reduction of inactive periods associated with locating equipment, understanding instructions, waiting for turns, or avoiding uncertain activity spaces.

4.4 Enjoyment and Self-Efficacy

Enjoyment increased substantially in the intervention group. This finding is theoretically plausible because the model combined achievable challenges, repetition, immediate feedback, peer interaction, and game-based goals.

The use of PACES is also supported by previous psychometric research showing acceptable internal consistency and validity for measuring physical-activity enjoyment among children. Moore et al. reported good internal consistency for the child version of PACES, while later research has also supported shorter versions for adolescents (Chen et al., 2021).

The increase in self-efficacy may have resulted from repeated successful task experiences. When students could detect the equipment, understand the activity boundary, complete a movement, and receive immediate positive feedback, the probability of experiencing competence was increased.

A previous study of visually impaired children also reported positive effects of structured physical activity on self-efficacy, suggesting that physical activity can provide opportunities for development of perceived physical competence (시각장애연구, 2007).

Importantly, the buddy system in the present model was designed as supported independence rather than substitution. This distinction is important because previous qualitative research has shown that excessive assistance in PE can unintentionally restrict participation and create dependence. Haegele et al. reported concerns among adults with visual impairments regarding support that was overly restrictive or provided without adequate training.

4.5 Safety, Fidelity, and Practical Implications

The absence of serious adverse events, together with mean implementation fidelity above 90%, indicates that the model was feasible under the conditions of the two participating schools. Nevertheless, the recorded minor incidents and near misses show that adaptation does not eliminate risk. The most important operational safeguards were environmental familiarization, adequate spacing between activity zones, unambiguous stop cues, equipment checks, and continuous supervision. Fidelity findings also suggest that multi-station activities create the greatest implementation burden. Teachers should therefore introduce stations progressively, limit simultaneous movement when students are unfamiliar with the environment, and assign clear supervisory responsibilities. These procedures are integral components of the model rather than optional additions.

4.6 Limitations and Future Research

Recruitment from only two special schools and the small, pragmatically determined sample restrict the generalizability of the findings. Students with low vision are heterogeneous in visual acuity, visual field, contrast sensitivity, onset of impairment, and previous movement experience; small samples may not support detailed subgroup analysis. Although randomized allocation reduced selection bias, school-level and contextual influences may remain because the sample was not large enough for school-stratified inferential analysis. Observer ratings can be influenced by rater expectations, while self-reported enjoyment and self-efficacy may be affected by social desirability. A six- to eight-week intervention cannot establish long-term maintenance or transfer to leisure-time physical activity. Future studies should include larger multisite samples, stronger allocation procedures, blinded outcome assessment where feasible, psychometric evaluation of adapted instruments, follow-up measurement, and analyses that account for functional-vision profiles and implementation fidelity.

5. Conclusion

The game-based adaptive physical education model combines multimodal instruction, adapted equipment, structured activity environments, modified tasks and rules, peer support, safety procedures, and implementation-fidelity monitoring for students with low vision. In this study, the model showed high content validity, practicality, fidelity, and favorable safety indicators, accompanied by larger improvements across five learning outcomes than usual physical education. These findings provide preliminary evidence of effectiveness and feasibility; however, they should be confirmed in larger multisite trials with longer follow-up periods.

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8. Author Declaration

The author declares no conflict of interest.