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Bridging Cognitive Scaffolding and Fine Motor Skill Acquisition: Jigsaw Cooperative Learning in Badminton Backhand Short Serve

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ABSTRACT

Acquiring fine motor skills in physical education poses a pedagogical challenge, as traditional teacher-centered instruction often fails to provide individual kinesthetic feedback, while peer-tutoring risks transmitting erroneous movement habits. This study evaluated the efficacy of the Jigsaw cooperative learning model integrated with a structured biomechanical scaffolding protocol to improve backhand short serve performance in badminton among tenth-grade vocational high school students (N = 21). Utilizing Kemmis and McTaggart's Classroom Action Research (CAR) framework across two cycles, motor skill acquisition was measured via a validated 12-point psychomotor rubric (Aiken's V = 0.88; inter-rater Cohen's $\kappa = 0.85$). Quantitative analysis revealed significant progressive gains in psychomotor execution: baseline mean score was 57.62 ± 5.82 (10% mastery), increasing to 74.52 ± 4.20 (38% mastery) in Cycle I, and achieving 86.43 ± 3.82 (100% mastery) in Cycle II. Non-parametric repeated measures confirmed significant longitudinal performance gains (Friedman χ^2 (2) = 42.00, $p < 0.001$), with post-hoc Wilcoxon signed-rank tests demonstrating substantial improvement from baseline to Cycle II ($Z = -4.021$, $p < 0.001$, Cohen's $d = 5.86$; average N-Gain = 0.68, moderate-to-high effect). Biomechanical task-card deconstruction and teacher quality control effectively facilitated kinetic feedback and reduced execution anxiety. Structured peer-dependence serves as a robust pedagogical bridge between cooperative cognition and motor skill mastery.

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1. INTRODUCTION

Physical Education, Sport, and Health (PESH) is an essential component of the secondary school curriculum designed to foster holistic development across physical, cognitive, affective, and social domains (Boke et al., 2025; Hasmyati et al., 2024). Within the vocational high school (*Sekolah Menengah Kejuruan, SMK*) curriculum, racket sports—particularly badminton—play a crucial role in enhancing physical fitness, hand-eye coordination, and tactical decision-making. Among fundamental badminton techniques, the backhand short serve serves as a tactical prerequisite for controlling rallies, particularly in double play (Ramadhan et al., 2024; Song, 2026; Suwardi et al., 2025). Achieving proficiency in the backhand short serve requires precise motor coordination, including consistent grip regulation, exact point of contact below the waist, constrained backswing amplitude, and fine trajectory control over the net (Kosasih et al., 2022).

Despite its pedagogical importance, preliminary observations at vocational high school 2 Ambon revealed persistent motor execution deficits among tenth-grade students. Under the standard Minimum Mastery Criterion (MMC = 75), baseline assessments indicated that 90% of students failed to achieve technical mastery. Observational analysis demonstrated that conventional direct instruction—characterized by teacher-led demonstration followed by mass unmonitored drill practice—failed to provide individual kinesthetic feedback. In a standard class setting, physical education instructors face severe temporal and physical constraints in delivering real-time movement corrections to individual students, resulting in the repetition and consolidation of flawed kinetic chains (Gao et al., 2025; Kosasih, 2026).

To address these instructional limitations, cooperative learning models have gained prominent interest in physical education pedagogy (Güngör et al., 2026; Zach et al., 2023). Aronson's Jigsaw model, structured around small heterogeneous groups where members become 'experts' in specific sub-topics before peer-tutoring their home group members, has demonstrated strong efficacy in academic and cognitive domains (Drouet et al., 2019; Hafsah et al., 2022; O'Leary et al., 2018; Supiarti et al., 2025). Meta-analytic reviews affirm that cooperative learning significantly enhances student engagement, self-efficacy, and academic achievement (Boke et al., 2025; Vivies et al., 2024). Contextual adaptations of Jigsaw in physical education have similarly reported gains in student participation and overall physical activity levels (Drouet et al., 2023; Maulana et al., 2026; Irham et al., 2024).

However, applying a cognitively driven, verbal-heavy cooperative framework like Jigsaw to fine motor skill acquisition creates a fundamental pedagogical paradox (Masruroh et al., 2022). Unlike cognitive tasks where conceptual knowledge is easily articulated verbally, fine motor skills rely on tacit kinesthetic awareness, proprioceptive control, and neuromuscular coordination. In novice peer-tutoring environments, there is a distinct risk that peer instructors may transmit biomechanically inaccurate movement patterns or provide vague, non-actionable feedback (Costouros, 2020; Darabi et al., 2025). Furthermore, prior physical education literature has predominantly investigated Jigsaw in gross motor skills (gymnastics, track and field) or broad engagement metrics, while relying on localized contextual gaps (e.g., testing in specific geographic regions) rather than resolving theoretical mechanisms of motor acquisition (González-Gálvez et al., 2023; Kebede et al., 2025).

This study addresses this theoretical and practical gap by examining how the Jigsaw cooperative learning model—when integrated with an explicit three-tier biomechanical scaffolding protocol—facilitates fine motor skill acquisition in the badminton backhand short serve. By deconstructing complex kinetic movements into modular biomechanical task components and embedding teacher-led quality control prior to home-group peer tutoring, this intervention bridges cooperative cognitive processing with precise motor execution. Specifically, this study evaluates: (1) the quantitative psychomotor performance gains across Action Research cycles, (2) the inferential significance and effect size of skill acquisition, and (3) the biomechanical mechanisms through which peer interaction refined movement execution among vocational high school students.

2. METHOD

This study employed a Classroom Action Research (CAR) design following the cyclic framework of Kemmis and McTaggart (Planning, Acting, Observing, Reflecting). Action research was selected as the optimal methodology to systematically identify instructional deficiencies, implement pedagogical adaptations, and evaluate real-time skill acquisition in a naturalistic educational environment. The study was conducted at vocational high school 2 Ambon over a 6-week period, comprising two complete action cycles (3 weeks per cycle, two 90-minute sessions per week). Participants comprised a single intact class of 21 tenth-grade vocational students (8 males, 13 females; mean age = 15.8 ± 0.6 years). Vocational students were intentionally selected due to their strong kinesthetic learning preferences and peer-collaborative dynamic.

To eliminate the risk of novice peer tutors transmitting erroneous movement mechanics during Jigsaw interactions, the standard four-stage Jigsaw syntax was integrated with a three-tier instructional scaffolding protocol:

- **Tier 1: Biomechanical Modular Deconstruction.** The backhand short serve was deconstructed into four distinct sequential kinetic phases: Phase 1 (Stance, Weight Distribution, and Backhand Thumb-on-Ramp Grip); Phase 2 (Racket Elevation, Backswing Constraint, and Shuttlecock Hold); Phase 3 (Point of Contact Below Waist, Pushing Motion, and Trajectory Clearance); Phase 4 (Follow-Through Constraint, Spatial Accuracy, and Balance Recovery).
- **Tier 2: Expert Group Task-Card Scaffolding & Instructor Quality Control.** Students assigned to specific expert groups were provided with biomechanically validated visual Task Cards detailing exact kinetic markers. Prior to returning to home groups, all expert groups underwent a mandatory 10-minute 'Instructor Quality Control' check, where the primary physical education teacher verified both technical understanding and physical execution accuracy.
- **Tier 3: Dyadic Peer-Observation & Kinesthetic Feedback.** Within home groups, peer-tutoring was structured around execution-observation dyads. While Tutee A executed 10 serve trials, Tutor B utilized an analytical checklist to provide immediate visual and kinesthetic feedback based on specific task-card criteria before alternating roles.

Psychomotor execution was evaluated using a validated 12-point analytical rubric assessing four fundamental technical dimensions on a 1–3 scoring scale (1 = Inadequate/Incorrect, 2 = Developing/Inconsistent, 3 = Proficient/Consistent). To eliminate historical inconsistencies where cognitive/affective metrics conflated motor skill data, psychomotor scores were isolated for primary inferential testing and converted to a standard 100-point scale. Table 1 details the analytical psychomotor evaluation matrix.

Table 1. Analytical Psychomotor Evaluation Matrix.

Dimension	Score 1 (Inadequate)	Score 2 (Developing)	Score 3 (Proficient)
Stance & Grip	Forehand/incorrect grip; feet static; weight unbalanced.	Backhand grip inconsistent; correct staggered feet position.	Proper backhand thumb-on-ramp grip; weight front-loaded; balanced stance.
Backswing & Elevation	Excessive wrist swing; racket head above wrist level.	Controlled swing but elbow elevation fluctuates; trajectory high.	Compact pushing wrist motion; racket head below wrist level consistently.
Contact Point	Impact above waist level; shuttle hit with upward flick.	Impact at waist level; occasional net clipping.	Impact clearly below waist; smooth pushing contact without wrist snap.
Trajectory & Target	Shuttle lands out/high; net error rate > 50%.	Shuttle clears net (10-20cm clearance); lands near service line.	Shuttle grazes net tape (<10cm clearance); precise placement in front corner.

Content validity of the 12-point psychomotor rubric was established through expert judgment by a panel of three physical education and biomechanics specialists, yielding an Aiken's V coefficient of 0.88. To eliminate instructor bias inherent in action research, performance trials across Baseline, Cycle I, and Cycle II were independently and simultaneously evaluated by the primary physical education teacher and an external co-researcher. Inter-rater reliability was calculated using Cohen's Kappa coefficient, demonstrating strong agreement across evaluation sessions ($\kappa = 0.85$, $p < 0.001$).

Data was analyzed using both descriptive and non-parametric inferential statistical procedures. Psychomotor scores across Baseline, Cycle I, and Cycle II were reported as mean (M), standard deviation (SD), median (Mdn), interquartile range (IQR), and classical mastery percentages ($MMC \geq 75$). Because the single-group dataset ($N = 21$) violated normality assumptions (Shapiro-Wilk $p < 0.05$), a non-parametric Repeated Measures Friedman Test ($\alpha = 0.05$) was conducted to examine longitudinal performance gains across the three measurement phases. Post-hoc pairwise comparisons were executed using Wilcoxon Signed-Rank Tests with Bonferroni correction. Practical magnitude of intervention effect was quantified using Cohen's d for paired samples and Normalized Gain (N-Gain) scores.

3. RESULTS AND DISCUSSION

Results

Psychomotor Performance Trajectory Across Action Cycles

Systematic execution of the Jigsaw cooperative model integrated with biomechanical scaffolding produced substantial, progressive improvements in student psychomotor performance across the study phases. Table 2 summarizes the aggregated baseline, Cycle I, and Cycle II performance distributions across cognitive, psychomotor, and affective domains, alongside isolated psychomotor inferential metrics.

Table 2. Summarize the aggregated baseline, Cycle I, and Cycle II performance

Phase / Stage	Cognitive (M±SD)	Psychomotor (M±SD)	Affective (M±SD)	Overall Composite	Mastery % (MMC ≥ 75)
Baseline (pre-action)	51.81 ± 9.62	57.62 ± 5.82	86.67 ± 4.83	65.00 ± 5.21	10% (2/21)
Cycle I post-test	71.24 ± 11.58	74.52 ± 4.20	75.00 ± 5.00	73.43 ± 5.61	38% (8/21)
Cycle II post-test	85.81 ± 6.22	86.43 ± 3.82	78.43 ± 7.21	83.24 ± 2.84	100% (21/21)
Gain (Baseline → C2)	+34.00	+28.81	-8.24	+18.24	+90%
Friedman Test (χ^2)	--	χ^2 (2) = 42.00*	--	--	--
p-value / Effect Size	--	p < 0.001	--	--	N-Gain = 0.68

At baseline, students exhibited severe psychomotor limitations (M = 57.62 ± 5.82), with only 10% achieving the MMC benchmark. The primary deficiencies observed were wrist snapping during serve impact, inability to maintain racket head placement below wrist level, and erratic trajectory height. Following Cycle I, psychomotor scores improved to M = 74.52 ± 4.20, raising mastery to 38%. By Cycle II, following targeted refinements in task-card scaffolding and home-group dyadic peer feedback, psychomotor execution reached M = 86.43 ± 3.82, with 100% of students achieving technical mastery (lowest score = 77, highest score = 92).

Inferential Non-Parametric and Effect Size Analysis

To rigorously evaluate whether observed psychomotor improvements were statistically significant, a Repeated Measures Friedman Test was conducted across Baseline, Cycle I, and Cycle II psychomotor scores. The analysis revealed a statistically significant intervention effect across time, χ^2 (2) = 42.00, p < 0.001, Kendall's W = 1.00, indicating perfect concordant upward rank order across all 21 participants.

Post-hoc pairwise comparisons using Wilcoxon Signed-Rank Tests with Bonferroni correction (adjusted significance threshold α = 0.0167) demonstrated significant performance improvements across all phase transitions:

- Baseline to Cycle I: Z = -4.021, p < 0.001, Cohen's d = 3.32 (large effect size).
- Cycle I to Cycle II: Z = -4.018, p < 0.001, Cohen's d = 2.96 (large effect size).
- Baseline to Cycle II: Z = -4.021, p < 0.001, Cohen's d = 5.86 (extreme effect size).

Overall instructional efficacy was further corroborated by Normalized Gain analysis. The class average N-Gain score for psychomotor performance was g = 0.68 (SD = 0.09), categorized as a strong moderate-to-high instructional gain under Hake's criteria. Individual participant gains ranged from g = 0.52 to g = 0.81, confirming consistent skill acquisition across all learners regardless of baseline motor proficiency.

Contextual Evaluation of Affective Score Dynamics

An examination of multidimensional domain dynamics reveals an interesting affective score pattern across cycles (Baseline M = 86.67; Cycle I M = 75.00; Cycle II M = 78.43). A specific data point in Cycle II involved student EZL, who achieved perfect cognitive (100) and high psychomotor (92) scores but recorded an affective score of 58 (composite score = 83, maintaining MMC mastery). Qualitative field notes clarify that this temporary affective reduction stemmed from heightened task rigor, strict adherence to peer-observation rubric compliance, and peer accountability during dyadic scoring, rather than disengagement. As students transitioned from passive participation (baseline high subjective self-ratings) to rigorous peer evaluation, affective scoring normalized to reflect genuine cooperative responsibility.

Discussion

The primary objective of this study was to evaluate the effectiveness of the Jigsaw cooperative learning model integrated with biomechanical task-card scaffolding in refining backhand short serve execution in badminton. The empirical findings demonstrate significant, progressive improvements in student psychomotor performance, increasing from a 10% baseline mastery to 100% classical mastery by Cycle II, accompanied by a highly significant inferential effect (Friedman $\chi^2 = 42.00$, $p < 0.001$; N-Gain = 0.68). These findings affirm that structured peer-dependence strategies can serve as a potent pedagogical alternative in physical education, bridging collaborative cognition with motor skill mastery.

Biomechanical Mechanisms of Skill Acquisition in Jigsaw Syntax

The successful acquisition of fine motor precision in the backhand short serve can be explained through the biomechanical deconstruction embedded within the Jigsaw expert groups. The backhand short serve is a highly constrained kinetic movement requiring precise spatial-temporal control. In direct instruction, students often struggle to process simultaneous feedback regarding grip, backswing, contact point, and follow-through. By isolating these four kinetic components across Jigsaw expert groups, cognitive load was significantly reduced. Expert students mastered a single movement phase before teaching it to home-group peers, operationalizing Sweller's Cognitive Load Theory within motor learning (Sepp et al., 2019).

Crucially, the inclusion of the 'Instructor Quality Control Phase' resolved the fundamental pedagogical risk of novice-to-novice error transmission (Costouros, 2020; Darabi et al., 2025). Verifying expert execution prior to home-group peer tutoring ensured that peer instructors served as accurate movement models. During home-group dyadic practice, the use of visual Task Cards enabled peers to deliver real-time kinesthetic feedback ('keep racket head below wrist', 'shorten backswing'). This real-time external feedback loop accelerated the refinement of internal motor programs, reinforcing findings by Yang et al. (2021) and Khataybeh et al. (2024) regarding cooperative motor feedback.

Methodological Integrity and Critical Analysis of the 100% Mastery Ceiling

The observed progression from 38% mastery in Cycle I to 100% mastery in Cycle II warrants critical examination regarding action research dynamics. While a 100% classical mastery rate might initially suggest a potential ceiling effect or evaluator leniency, rigorous methodological controls were implemented to safeguard objectiveness. The psychomotor rubric demonstrated strong content validity (Aiken's V = 0.88) and high inter-rater agreement between independent assessors (Cohen's κ = 0.85). The sharp gain in Cycle II is attributable to targeted cycle reflections: Cycle I identified peer-tutoring pacing and rubric misinterpretation as key bottlenecks. Re-organizing execution-observation dyads and enforcing structured 10-trial practice blocks in Cycle II provided the repetition density necessary for neuromuscular consolidation.

Nevertheless, researchers must interpret action research ceiling results within context. The standard Minimum Mastery Criterion (MMC = 75) represents an educational threshold for basic proficiency rather than elite athletic mastery. Achieving 100% MMC compliance indicates that all vocational students successfully executed fundamental biomechanical mechanics under controlled practice conditions. These results align with findings by Amri (2025) and Irham et al. (2024), who reported rapid mastery acceleration (reaching 86.7%–87%) when cooperative structures were optimized in physical education settings.

Social Interdependence Theory and Anxiety Reduction

The social dynamics observed during Jigsaw interventions strongly support Deutsch's Social Interdependence Theory, as adapted by Roseth et al. (2019). Traditional physical education assessments often induce execution anxiety, particularly among students with lower baseline motor competence (Huhtiniemi et al., 2022). By shifting from individual performance isolation to cooperative dyadic accountability, execution anxiety was reduced. Peer-tutoring created a supportive psychological climate where errors were treated as diagnostic feedback rather than failures. This positive affective environment enhanced student self-efficacy and practice persistence, directly translating into refined neuromuscular control (Turan et al., 2023; Boke et al., 2025).

4. CONCLUSION

This study demonstrates that integrating the Jigsaw cooperative learning model with a three-tier biomechanical scaffolding protocol significantly enhances learning outcomes for the badminton backhand short serve among vocational high school students. The intervention achieved a progressive transition from a 10% baseline mastery (M = 57.62) to 38% in Cycle I (M = 74.52), culminating in 100% classical mastery in Cycle II (M = 86.43; Friedman χ^2 = 42.00, $p < 0.001$; N-Gain = 0.68). The combination of modular movement deconstruction, instructor quality control, and dyadic peer feedback successfully resolved the challenge of applying cognitive cooperative models to fine motor skill acquisition.

The main theoretical contribution of this study lies in establishing a structured framework for adapting cooperative learning syntax to psychomotor domain instruction. By introducing teacher-led quality control and visual task cards into Jigsaw expert structures, this research proves that peer-tutoring can effectively deliver accurate kinesthetic feedback without transmitting movement errors. For physical education practitioners, this study provides an actionable, evidence-based strategy for managing large physical education classes while maintaining individualized movement coaching.

Several empirical limitations must be acknowledged. First, the study utilized a single-group action research design with a small sample size (N = 21) from a single vocational school, limiting external generalizability. Second, the evaluation focused on controlled skill execution rather than longitudinal retention or dynamic match-play performance. Future research should employ quasi-experimental randomized controlled trials (RCTs) with larger sample sizes, incorporate retention post-tests (e.g., 4 weeks post-intervention), and utilize high-speed kinematic video analysis to objectively track biomechanical angles and shuttlecock trajectory parameters.

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