Desarrollo y validación preliminar de la sintaxis instruccional Ardilla para Pencak Silat: una prueba de campo pre-postoperacional con un solo grupo que integra multimedia interactiva y retroalimentación biomecánica bidimensional en la formación inicial de docentes de educación física.

Development and Preliminary Validation of the Ardilla Instructional Syntax for Pencak Silat: A One-Group Pre-Post Operational Field Test Integrating Interactive Multimedia and Two-Dimensional Biomechanical Feedback in Pre-Service Physical Education

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Abstract

Introduction: Pencak Silat instruction in higher education remains demonstrative-imitative, creating a gap between motor performance and declarative understanding of movement efficiency among pre-service physical education teachers.
Objective: To develop and preliminarily evaluate the Ardilla instructional syntax (seven phases: Attention, Relevance, Demonstration, Interaction, Learning by Doing, Review, Action Plan) embedding 2D biomechanical feedback within interactive multimedia for Pencak Silat.
Methodology: Using Borg and Gall's (1989) Steps 8–9, the artifact underwent expert validation (two cycles), practicality testing (students n = 100; instructors n = 4), and a one-group pre-test post-test trial (n = 60; 30 males, 30 females; 6 weeks, 12 sessions). Psychomotor competence was assessed via a validated rubric (CVI = 0.91; α = .84; ICC = .96). Biomechanical accuracy (knee, elbow, shoulder, hip, punching) was analyzed via Kinovea in a subsample (n = 20). Paired-samples t-test and Cohen's d<sub> were used.
Results: Expert feasibility post-revision: 90.00–94.00%. Student practicality: 89.96%; instructor practicality: 86.00%. Psychomotor scores improved (M<sub> = 449.30, SD = 24.59 to M<sub> = 467.50, SD = 25.16), t(59) = 6.99, p < .001, d<sub> = 0.90. All five biomechanical indicators improved (p < .001, d<sub> = 0.99–1.79).
Discussion: These findings suggest that the integration of multimedia distribution and biomechanical analysis within an operational education framework results in improved motor learning, considering the components separately.
Conclusion: The Ardilla syntax is feasible and shows promising preliminary effects. Causal inference is precluded by the one-group design. RCTs with retention tests are needed.

Keywords

Ardilla Learning; Interactive; Multimedia Animation; biomechanical Analysis; Pencak Silat; Pre-Service Teacher Education

Resumen

Antecedentes: La enseñanza del Pencak Silat en la educación superior sigue siendo demostrativo-imitativa, creando una brecha entre el rendimiento motor y la comprensión declarativa de la eficiencia del movimiento.
Objetivo: Desarrollar y evaluar preliminarmente la sintaxis instruccional Ardilla (siete fases) que incorpora retroalimentación biomecánica 2D dentro de multimedia interactiva para Pencak Silat.
Método: Siguiendo los Pasos 8–9 de Borg y Gall (1989), el artefacto se sometió a validación por expertos (dos ciclos), pruebas de practicidad (estudiantes n = 100; instructores n = 4) y un ensayo pre-post de un solo grupo (n = 60; 30 hombres, 30 mujeres; 6 semanas, 12 sesiones). La competencia psicomotriz se evaluó con una rúbrica validada (CVI = 0,91; α = ,84; CCI = ,96). La precisión biomecánica se analizó mediante Kinovea en una submuestra (n = 20). Se utilizó la prueba t para muestras pareadas y la d de Cohen.
Resultados: Viabilidad de expertos post-revisión: 90,00–94,00%. Practicidad estudiantes: 89,96%; instructores: 86,00%. Las puntuaciones psicomotrices mejoraron (M<sub> = 449,30, DE = 24,59 a M<sub> = 467,50, DE = 25,16), t(59) = 6,99, p < ,001, d<sub> = 0,90. Los cinco indicadores biomecánicos mejoraron (p < ,001, d<sub> = 0,99–1,79).
Conclusiones: La sintaxis Ardilla es viable y muestra efectos preliminares prometedores. La inferencia causal está impedida por el diseño de un solo grupo. Se necesitan ensayos controlados aleatorizados.

Palabras clave

Aprendizaje Ardilla; Interactivo; Animación Multimedia; biomecánico; Pencak Silat

Introduction

The confluence of educational technology, artificial intelligence, and sports science has revolutionized the pedagogical, learning, and scientific assessment of complex motor skills in higher education (Ge & Lai, 2021; Lau et al., 2014). Motion capture analysis, interactive multimedia, and immersive digital environments have become indispensable elements of student-centered pedagogy that demands personalized, adaptive, and inquiry-based learning experiences (Ghanbarzadeh & Ghapanchi, 2020; Reisoğlu et al., 2017; Richards & Taylor, 2015). Recent contributions in Retos have further demonstrated the potential of augmented reality (AR) and artificial intelligence (AI) to improve interactivity in physical education (PE) teaching and teacher training (Antonopoulos, 2024; Omarov et al., 2024; Festiawan et al., 2025; Yu, 2022), while biomechanical analysis has proved indispensable for technique optimization and injury prevention in combat sports (Burke et al., 2017). Within this technological and pedagogical shift, Pencak Silat Indonesian martial art recognized by UNESCO and a compulsory practical course for pre-service physical education teachers serves as an exemplary context for examining the integration of educational technology and biomechanical inquiry in complex motor-skill pedagogy (Hadjarati et al., 2025; Mahardhika et al., 2026).

A preliminary needs analysis, conducted as part of a larger research and development project (Borg & Gall, 1989), reveals a striking pedagogical lag (August, 2022; Aprial et al., 2023). In the target program, of 100 students and four instructors, only 19.6% of students and 25% of instructors used unrelated online video clips as supplementary material, while 80.4% of students and 75% of instructors still relied on printed lecture handouts. All respondents (100%) explicitly requested interactive multimedia animation platforms with integrated biomechanical analysis, and the majority of students (56.5%) and instructors (75%) felt that the current media were inadequate for competency-based skill acquisition. These data suggest three systemic failings of existing instructional media.

First, fragmentation: prior empirical efforts textbooks (Nisa et al., 2025), instructional films (Sasmitha, 2022), generic Android applications (Hasibuan et al., 2024), traditional multimedia modules (Nelson et al., 2025), and isolated training models (Hadiana et al., 2022) have approached exercise structure, media format, or content delivery in isolation, without synergistic integration of biomechanical inquiry and interactive visualization. Second, passivity: the existence of digital artifacts makes learners consumers, not inquirers. Students can watch and practice techniques, but they cannot alter playback speed, pause at biomechanical checkpoints, or compare their own kinematic profiles with a reference model (Nelson et al., 2020; Kurniawan et al., 2024). Third, decontextualization: even when biomechanical data are available, they are presented outside the learning cycle as assessment output rather than within a feedback loop that enables self-directed error correction and reflective practice (Kartini et al., 2018; Ihsan et al., 2024). Learners may replicate movement patterns, yet they often fail to articulate why a specific joint angle or center-of-mass trajectory enhances mechanical efficiency, and they struggle to translate such declarative knowledge into procedural teaching competence.

A significant gap in the tertiary martial-arts pedagogy literature is the scarcity of systematic learning models that integrate interactive animation with real-time, learner-accessible biomechanical feedback (e.g., joint-angle kinematics, force-trajectory visualization). To our knowledge, no operational, seven-phase instructional syntax has been empirically tested with pre-service physical education teachers in a university Pencak Silat program. This gap is especially problematic in university programs that utilize compressed block schedules, where fewer contact hours must be balanced with high-quality, self-directed digital practice that maintains biomechanical integrity.

To address this gap, the Ardilla Learning Model acronym for Attention, Relevance, Demonstration, Interaction, Learning by Doing, Review, Action Plan was developed. Its seven-phase syntax is not an arbitrary sequence but is methodically grounded in established learning sciences (Table 1). Attention and Relevance are aligned with Keller (2016) ARCS motivation model and Mayer's (2024) pre-training principle to prepare the learner's cognitive and motivational channels for complex processing. Demonstration is based on the dual-channel multimedia learning theory (Mayer, 2024; Ge & Lai, 2021), which allocates visual and verbal information to separate cognitive channels to alleviate extraneous load. Interaction and Learning by Doing operationalize constructivist active learning (Lau et al., 2014) and the associative stage of motor learning as described by Grosjean, 2010, where repeated variable practice and immediate feedback consolidate robust motor schemas (Kamibayashi, 2014). The Review integrates (Panadero et al., 2014) model of self-regulated learning with biomechanical feedback through which students view Kinovea-annotated recordings of their own performance, engaging in evidence-based error detection rather than intuitive trial-and-error. Finally, Action Plan applies Schön's (2017) reflective practice to microteaching scenarios, thereby ensuring that declarative biomechanical knowledge is translated into procedural teaching competence. Notably, the Action Plan phase simultaneously constitutes the forethought phase of Zimmerman's next self-regulated learning cycle, creating a recursive loop that sustains autonomous learning beyond the intervention.

This theoretical convergence separates the Ardilla model from prior media artifacts which treated animation and biomechanics as mutually exclusive add-ons. The model aims to move Pencak Silat teaching from repetitive imitation to reflective self-regulation based on evidence by bringing measurable biomechanical questions into an interactive multimedia interface.

Therefore, the current research is intended to preliminarily evaluate the finalized Ardilla Learning Model through an operational field test. Specifically, it addresses: (a) the expert-rated feasibility of the integrated multimedia–biomechanical architecture, (b) student and instructor perceptions of practicality in authentic classroom contexts, and (c) preliminary evidence of effectiveness on psychomotor competence within a one-group pre-test post-test design. It is important to note that this manuscript reports Steps 8–9 (operational field testing and final product revision) of a larger R&D project grounded in Borg and Gall (1989). The product-development phases (needs analysis, prototype design, iterative alpha testing, and expert-directed revision) were completed between August 2022 and May 2023, resulting in the stable artifact evaluated herein. This re-positioning is consistent with the convention in educational technology research of separating product development reporting from effectiveness validation (Richey & Klein, 2014), and ensures that the present article is read as a rigorous operational field test, not a comprehensive R&D monograph.

Table 1. Theoretical anchoring of Ardilla Learning Syntax

Phase	Theoretical Foundation	Pedagogical Function
Attention	Keller's (2010) ARCS model; Mayer's (2024) pre-training principle	Engage motivation and prime cognitive channels for incoming procedural information
Relevance	Keller's (2010) ARCS relevance	Establish meaningful connections between Pencak Silat technique and prior pedagogical knowledge
Demonstration	Dual-channel multimedia learning (Mayer, 2024; Ge & Lai, 2021)	Distribute visual and verbal processing to minimize extraneous cognitive load
Interaction	Constructivist active learning (Lau et al., 2014)	Enable learner control over pacing, angle, and replay to foster inquiry
Learning by Doing	Fitts & Posner's (1967) associative stage; deliberate practice (Ericsson & Harwell, 2019)	Consolidate motor schemas through repeated, variable physical rehearsal
Review	Self-regulated learning (Zimmerman, 2000); biomechanical feedback	Support evidence-based self-correction via annotated kinematic comparison
Action Plan	Schön's (2017) reflective practice; Zimmerman (2000) forethought cycle	Translate declarative biomechanical knowledge into procedural teaching competence; initiate next SRL cycle

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Method

The systematic ten-step framework by Borg and Gall (1989), selected for its rigorous validation architecture and proven suitability for producing educational technology products of controlled quality in higher education settings, served as the foundation for the quantitative research and development (R&D) design used in this study. In addition to creating a new learning model the Ardilla Learning Model (Attention, Relevance, Demonstration, Interaction, Learning by Doing, Review, Action Plan) the scope of this one-group pre-test post-test operational field test aims to empirically confirm the feasibility, utility, and effectiveness of the model within the physical education setting in Indonesia. The need to ensure that the final multimedia artifacts are theoretically valid and empirically justifiable before being widely disseminated justifies this two-phase method, which combines product development with effectiveness testing.

Methodological Scope and Positioning

This manuscript reports Steps 8–9 (operational field testing and final product revision) of a larger educational design research project grounded in Borg and Gall's (1989) ten-step research and development framework. Phases 1 through 7 were completed from August 2022 to May 2023 (needs analysis, literature synthesis, prototype design, multimedia production, iterative expert validation, and product revision), resulting in a stable Ardilla multimedia artifact. This article addresses the operational field testing and final revision phases, following the convention in educational technology research of separating reporting on product development from reporting on validation of effectiveness (Richey & Klein, 2014). There is sufficient development context to understand the work in isolation, but for those interested in finer design decisions (e.g., storyboard wireframes or alpha-testing logs), the dissertation source is recommended.

The study employs a one-group pre-test post-test design for preliminary effectiveness identification. The Ardilla model was implemented in an intact, obligatory university course; it would have been pedagogically and ethically unacceptable to deny the intervention to a control group because of the curricular obligation to teach Pencak Silat. Thus, the study deliberately limits causal inference and is presented as an operational field test rather than as a definitive efficacy trial.

Participants and Sampling

The target population was 100 undergraduate students (five intact classes, n = 20 each) who took the third-semester mandatory course of Pencak Silat in the Physical Education, Health, and Recreation (PJKR) program at a state university in Indonesia. The practicality assessment was conducted by four Pencak Silat instructors as observer-respondents.

For the effectiveness phase, all 60 students who completed both pre-test and post-test assessments were included in the analysis. These 60 students were selected from the larger pool of 100 through stratified random sampling to ensure equal representation of ability levels and classes. Pre-test technical scores for all 100 students were ranked into low, medium, and high tertiles, and students from each tertile in each class stratum were selected randomly, resulting in 60 participants (30 males, 30 females; M = 20.4 years, SD = 1.1) who participated in psychomotor assessment. A stratified random subsample of 20 students from these 60 was selected for intensive biomechanical video annotation due to resource constraints (approximately 15 minutes per student per session).

Intervention Fidelity and Instructor Role

The six-week intervention involved 12 face-to-face sessions (90 min each, twice weekly) led by one Pencak Silat instructor (15 years of experience, black belt grade) who completed a 4-hour Ardilla training workshop on platform navigation, Kinovea calibration, and phase syntax, supplemented by ongoing technical support via a dedicated WhatsApp group and weekly 30-minute troubleshooting meetings. Implementation fidelity was tracked using a 15-item checklist (e.g., "Did students access the biomechanical checkpoint overlay during the Review phase?"; "Did the instructor ask students to compare the Kinovea angle data with the reference lines?"). After each session, the instructor completed a fidelity log; mean adherence was 95.0% (Very High Fidelity; range across phases: 92.8%–97.8%).

Instrument

Expert validation questionnaires. Three domain-specific questionnaires were given to external validators: (1) material expert (Pencak Silat pedagogy); (2) media expert (educational technology); and (3) biomechanics expert (sports kinematics). Each instrument contained 10 to 16 items using 4- or 5-point Likert scales (1 = strongly disagree, 4 or 5 = strongly agree) assessing biomechanical fidelity, alignment with learning objectives, visual design, content accuracy, and navigation.

Student and instructor practicality surveys. A 10-item student response survey (4-point Likert scale) measured perceived appeal, clarity, autonomy support, and knowledge acquisition. A corresponding 10-item instructor questionnaire measured classroom integration, motivational potential, and pedagogical flexibility.

Pencak Silat Techniques Rubric. Six basic techniques (stances, ready stance, blocking, evasion, striking, and kicking) were evaluated against four performance indicators (initial posture, execution, final posture, and stability) using a validated rubric. Scores ranged from 1 (one descriptor correct) up to 4 (all four descriptors correct). The rubric was further aggregated across six sub-components per technique, yielding a composite range of 400–539 points in practice.

Biomechanical analysis protocol. High-definition digital cameras (Sony FDR-AX43, 60 fps) were positioned in the frontal and sagittal planes, calibrated with a 2-meter reference frame. Students performed 6 basic techniques in random order. Video files were analyzed frame-by-frame using Kinovea (v.0.9.5). The dependent variables were: (1) knee joint angle accuracy, (2) elbow joint angle accuracy, (3) shoulder girdle alignment accuracy, (4) hip angle (sagittal-plane pelvic tilt during stance transitions), and (5) punching technique accuracy, expressed as percentage agreement with consensus expert-ideal reference angles based on expert-validated Kinovea annotation protocols.

Biomechanical Reference Standards. The optimal reference angles for each biomechanical variable were established through a two-stage consensus process. First, three certified national Pencak Silat coaches (≥ 10 years coaching experience) and one sports biomechanist independently annotated the consensus expert-ideal execution of each technique from a reference video library of 30 elite performers. Second, a Delphi panel was conducted to resolve discrepancies and establish consensus thresholds. These reference angles were then validated through pilot testing with 30 students outside the main study sample, achieving an inter-rater agreement of ICC = .96. The reference standards were embedded into the Kinovea overlay system as color-coded target zones (green = optimal ± 5°, yellow = acceptable ± 10°, red = suboptimal > 10° deviation).

Instrument Validity, Reliability, and Inter-Rater Agreement

The technique rubric for Pencak Silat was validated by three external Pencak Silat coaches (content validity index, CVI = 0.91) and pilot tested with 30 students who were not part of the study sample. Internal consistency was $\alpha = .84$. Inter-rater reliability was established by two independent raters (a Pencak Silat coach and a biomechanist) scoring 20% of the video recordings (n = 12 pre-test, n = 12 post-test). The intraclass correlation coefficient (ICC) for absolute agreement was .96 (95% CI [.89, .97]), indicating excellent reliability (Ten Hove et al., 2022).

Ethical Considerations and Data Protection

The study was approved by the Institutional Ethics Committee (Protocol No. 50/7/UN33.6.1/LL/2025). Written informed consent was obtained from all participants. Video recordings were stored on an encrypted server with access only by the university research team. All biomechanical outputs used for instructional feedback had faces blurred and participant identifiers were replaced with alphanumeric codes to ensure anonymity.

Data analysis

We used descriptive and inferential statistics. Percentage adequacy was calculated by $P = (f/n) \times 100\%$ and interpreted as: 81–100% (very feasible/acceptable), 61–80% (feasible/acceptable), 41–60% (fairly acceptable), 21–40% (less acceptable), and 0–20% (unacceptable). The instrument validity was tested with Pearson's item-total correlations with critical r-values at $\alpha = .05$. Reliability was assessed with Cronbach's alpha, where coefficients ≥ .80 were rated as high, ≥ .70 as acceptable, and < .60 as insufficient.

The assumptions for parametric testing were verified. Normality was evaluated by Lilliefors test ($L = 0.1283, p > .05$; $L = 0.1594, p > .05$), showing normal distributions. A paired-sample t-test was performed to evaluate pre-post differences. Cohen's d<sub> was computed as the mean of the paired differences divided by the standard deviation of the paired differences (M<sub> / SD<sub>; Lakens, 2015). All analyses were conducted with SPSS (version 22.0).

Results

Results are reported in four domains in chronological order: expert feasibility, iterative development trail, instructional practicality and preliminary effectiveness for psychomotor and biomechanical competence.

Expert Validator Profiles

(1) A professor of Pencak Silat pedagogy with 18 years' experience of teaching and 12 national coaching certifications; (2) A professor of educational technology with a specialization in multimedia learning and instructional design; and (3) A sports biomechanist with doctoral-level experience in martial arts kinematics (taekwondo and judo) and 10 years' experience of motion-analysis. The three expert validators were outside of the development team.

Iterative Revision Trail

Table 2 presents the specific weaknesses identified in Cycle 1 and the concrete changes implemented before Cycle 2.

Table 2. Revision Trail: Expert Validation Cycles

Expert Domain	Cycle 1 Feedback (Weakness)	Concrete Revision Action	Cycle 2 Score (%)
Materials	Technical explanations insufficient for university level; lacking pedagogical alignment with Bloom's taxonomy	Added biomechanical rationale paragraphs for each technique; aligned learning objectives with Bloom's taxonomy; added higher-order thinking questions	94.00
Media	Navigation buttons lack contrast; video buffering delays; UI not intuitive for first-time users	Redesigned UI with high-contrast palette per WCAG 2.1 AA standards; compressed video files using H.264 codec; added progress tracker and breadcrumb navigation	93.75
Biomechanics	Joint angle reference lines too small; overlap with limb segments; 2D tracking lacks depth cues; no calibration wizard	Enlarged overlays by 150%; added color-coded flexion/extension zones (green/yellow/red); added step-by-step calibration wizard with 2-meter reference frame	90.00

The scores of the expert validation for two iterative refinement cycles are shown in Table 2. Cycle 1 materials experts rated the model at 84.00%, media experts at 82.50%, and biomechanics experts at 80.00%, with all ratings falling within the "very feasible" range (≥ 81%). Materials, media, and biomechanics were reviewed, resulting in Cycle 2 ratings of 94.00%, 93.75%, and 90.00%, respectively. These results reaffirm the integrated architecture of the interactive multimedia animation and biomechanical analysis conforms to the quality standards required for physical education at the university level.

Table 3. Results of Expert Validation in Two Development Cycles

Expert Domain	Cycle 1 Score (%)	Category	Cycle 2 Score (%)	Category
Materials	84.00	Very feasible	94.00	Very feasible
Media	82.50	Very feasible	93.75	Very feasible
Biomechanics	80.00	Very feasible	90.00	Very feasible

Note. Phase 2 involved expert-led revisions of the product. Percentage thresholds: 81–100% very feasible; 61–80% feasible.

Real Classroom Applications Practicality

User acceptance data are shown in Table 4. In the small-scale trial (n = 40), the model was rated at 88.35% and in the large-scale trial (n = 100), the model was rated at 89.96%, which is in the "very acceptable" category. In the large-scale trial, the instructor evaluations were 86.00% (very acceptable) compared to 73.50% (acceptable) in the small-scale trial. The relatively low instructor score at the start suggests a learning curve with technology-supported pedagogy, consistent with the Technology Acceptance Model (Davis, 1989; Li et al., 2024). The increase indicates that confidence and competency grew with gradual exposure and interface improvements.

Table 4. Practicality Ratings of Students and Teachers

User Group	n	Small-Scale Trial (%)	Category	Large-Scale Trial (%)	Category
Students	40 / 100	88.35	Very feasible	89.96	Very feasible
Instructors	4	73.50	Feasible	86.00	Very feasible

Note. Student instrument: 10 items, 4-point Likert scale. Instructor instrument: 10 items, 4-point Likert scale.

Effectiveness on Psychomotor Competency

Descriptive and inferential statistics for the operational field test ($n = 60$) are presented in Table 5. Pre-test mean technical score was 449.30 ($SD = 24.59$, range = [400, 501]). Post-test mean was 467.50 ($SD = 25.16$, range = [429, 539]). The mean paired difference was 18.20 points ($SD = 20.17$). Normality was confirmed (Lilliefors $L = 0.1283$, $p > .05$; $L = 0.1594$, $p > .05$). The paired t-test displayed $t(59) = 6.99$, $p < .001$, two-tailed, with a critical value of 2.001. The 95% confidence interval of the difference of mean was [12.99, 23.41]. Cohen's d<sub> was computed as 0.90, reflecting a large effect size (Lakens, 2015).

Table 5. Motor Competence and Inferential Statistics at Pre-test and Post-test

Variable	n	M	SD	t	p	Cohen's d	95% CI	Interpretation
Pre-test	60	449.30	24.59	6.99	< .001	0.90	[12.99, 23.41]	Significant; large effect
Post-test	60	467.50	25.16					
Paired difference	60	18.20	20.17					

Note. Critical $t(59) = 2.001$ (two-tailed, $\alpha = .05$). Lilliefors normality Normality assumptions were met assumptions were met.

Biomechanical Outcomes

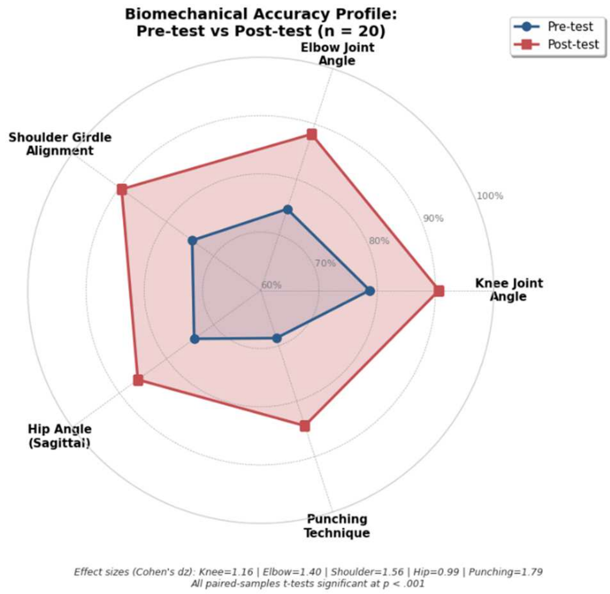
Table 6 shows the biomechanical indicators for the subsample ($n = 20$) derived from Kinovea. All variables showed statistically significant improvements from pre-test to post-test (all $p < .001$). The accuracy of the knee joint angle increased from 78.70% ($SD = 5.23$) to 90.60% ($SD = 8.73$), indicating an improvement in lower extremity positioning during stances and weight transfer. Elbow joint angle accuracy increased from 74.67% ($SD = 6.43$) to 88.19% ($SD = 11.83$), indicating improved arm extension mechanics. The shoulder girdle alignment accuracy improved from 74.56% ($SD = 7.82$) to 89.53% ($SD = 11.60$), demonstrating improved upper torso positioning. Hip angle (sagittal-plane pelvic tilt) showed better pelvic control, from 74.14% ($SD = 5.77$) to 86.09% ($SD = 11.77$). The most pronounced improvement was in punching technique accuracy, where the percentage increased from 68.63% ($SD = 8.28$) to 84.45% ($SD = 10.94$), emphasizing the effectiveness of the model in optimizing the biomechanical chain involved in strike execution. All effect sizes were large (Cohen's d<sub> range: 0.994–1.790), suggesting that the observed improvements were not only statistically significant but also educationally meaningful.

Table 6. Biomechanical Parameters Before and After Intervention (n = 20)

Biomechanical Variable	Pre-test M (SD)	Post-test M (SD)	Mean Difference	Cohen's d	Interpretation
Knee Joint Angle Accuracy	78.70 (5.23)	90.60 (8.73)	11.90	1.164	Large improvement
Elbow Joint Angle Accuracy	74.67 (6.43)	88.19 (11.83)	13.52	1.395	Large improvement
Shoulder Alignment Accuracy	74.56 (7.82)	89.53 (11.60)	14.97	1.562	Large improvement
Hip Stability Angle	74.14 (5.77)	86.09 (11.77)	11.95	0.994	Large improvement
Punching Technique Accuracy	68.63 (8.28)	84.45 (10.94)	15.82	1.790	Large improvement

Note. All values reported as percentage accuracy (%). Measured with frame-by-frame Kinovea v.0.9.5 analysis. All paired-samples t-tests were significant at $p < .001$.

Figure 2. Biomechanical Parameters Before and After Intervention



Operationalization of the Learning Syntax

Figure 1 illustrates the multimedia biomechanical interface mapped to the seven-phase syntax of Ardilla. The sequence starts with Attention, where learners are engaged with historical animation clips and movement previews, and concludes with Action Plan, where students develop tailored training plans and microteaching scenarios. Specific biomechanical checkpoints are embedded in each phase in the Kinovea analytics layer, including: force direction vectors, joint angle reference lines, and balance metrics.

Figure 2. The Seven-Phase Ardilla Learning Model Syntax Integrated with Multimedia Animation and Biomechanical Analysis

Discussion

The results of this study indicate that the Ardilla Learning Model is a theoretically grounded, practically feasible, and empirically promising prototype for Pencak Silat education in pre-service physical education programs. This model is conceptualized as a methodical integration of interactive multimedia animation and biomechanical analysis within a seven-phase pedagogical framework. High user acceptance rates (students 89.96%, instructors 86.00%), strong convergence of expert validation indices (content 94.00%, media 93.75%, biomechanics 90.00%), and a statistically significant pre-post improvement ($t(59) = 6.99$, $p < .001$, Cohen's d<sub> = 0.90) indicate that this model is associated with improved psychomotor competence within the tested context.

Alternative Explanations for Improvement

The pre-post gains are statistically robust, but the one-group design does not allow us to attribute these gains solely to the Ardilla intervention. Several alternative explanations must be considered. First, practice and testing effects: the 6-week duration included 12 supervised sessions. Participants may have improved simply because of the amount of practice and increased familiarity with the assessment rubric, regardless of the multimedia biomechanical layer. Second, instructor attention: the instructor's enthusiasm for the novel technology may have provided motivational and corrective support beyond typical instruction (the Hawthorne effect). Third, maturation: young adults enrolled in physical education programs naturally undergo neuromuscular development that may partially explain the skill gains over six weeks. Fourth, regression to the mean: if the stratified sample included students with temporarily low baseline performance, statistical expectation is that they would spontaneously improve towards their true mean ability. These alternatives do not negate the model's potential but point to the need for future randomized controlled trials with blinded assessors and active control groups (e.g., conventional instruction with equal practice time).

Addressing Heterogeneous Results

Not all feasibility indices were equally strong. The Cycle 1 instructor practicality score was relatively low (73.50%, "acceptable" rather than "very feasible"), indicating that instructors unfamiliar with motion-analysis software need significant scaffolding. This finding aligns with the Technology Acceptance Model (Davis, 1989; Li et al., 2024), which posits that perceived ease of use and perceived usefulness determine technology adoption trajectories among educators. Similarly, the lowest score (80.00%) was given by the biomechanics expert in Phase 1, which indicated initial skepticism regarding the accuracy of 2D video-based angle tracking compared to 3D motion-capture systems. What is instructive about these lower initial scores is that the model's success depends on instructor digital literacy and rigorous calibration protocols. The increase to 86.00% (instructors) and 90.00% (biomechanics) in Cycle 2 confirms that targeted revisions and short training can overcome these barriers, but they also warn against assuming frictionless scalability.

Theoretical Interpretation

Within the constraints of a one-group pre-post design, the Ardilla model shows promise for supporting cognitive-motor learning restructuring in martial arts pedagogy. As proposed by the cognitive theory of multimedia learning (Mayer, 2024; Ge & Lai, 2021), meaningful learning takes place when students actively select, organize, and integrate verbal and visual information through dual cognitive channels. This principle is instantiated in the Ardilla syntax: Attention and Relevance activate processing capacity; Demonstration utilizes multi-angled narrated animated videos on multiple channels to reduce extraneous load; Interaction and Learning by Doing promote active schema construction through variable practice (Fitts & Posner, 1967; Kamibayashi, 2014). The Review phase, along with the Kinovea-annotated self-assessment, corresponds to Zimmerman's (2000) self-regulated learning cycle specifically the self-reflection phase, where learners compare their performance to internal standards. Making biomechanical error detection tangible (e.g., "my knee flexion is 142°, whereas the reference is 130°") allows students to move from intuitive trial-and-error to evidence-based self-correction, in agreement with Schön's (2017) reflective practitioner model. The Action Plan phase then serves as the forethought phase for the subsequent learning cycle, creating a recursive self-regulation loop.

The large effect size (d<sub> = 0.90) for psychomotor improvement, combined with even larger effect sizes for biomechanical indicators (d<sub> range: 0.994–1.790), suggests that the integration of measurable biomechanical inquiry into an interactive multimedia interface is associated with educationally meaningful changes. However, without a control group receiving equivalent practice time without the multimedia-biomechanical layer, it is impossible to isolate the unique contribution of the Ardilla syntax. This is consistent with the deliberate practice framework (Ericsson & Harwell, 2019), which posits that improvement in complex skills requires not just repetition, but repetition with immediate, specific feedback on errors. The Ardilla model operationalizes this by providing biomechanical feedback that is both immediate (during the Review phase) and specific (angle deviations from reference standards).

Recent advances in AR and AI-based exercise monitoring for teacher training (Omarov et al., 2024; Shekerbekova et al., 2025) and biomechanics analysis in combat sports (Burke et al., 2017) confirm the broader feasibility of technology-enhanced physical education. However, the Ardilla model is distinguished by the inclusion of biomechanical inquiry as part of the instructional syntax rather than as an external layer of assessment (Kartini et al., 2018; Ihsan et al., 2024). This integration allows biomechanics to be an accessible, reflective language for preservice teachers to use in their own classrooms, rather than an esoteric specialized field.

Practical Implementation Requirements and Barriers

For those who wish to adopt the Ardilla model, the following minimum requirements are recommended: (a) Hardware: two HD cameras (minimum 60 fps), a laptop with 8 GB RAM, and the open-source software Kinovea; (b) Instructor preparation: 4–6 hour training block on multimedia navigation, Kinovea calibration, and rubric scoring, plus ongoing technical support; (c) Scheduling: blended format (two 90-minute face-to-face sessions per week plus one self-directed Ardilla module) to overcome compressed block-schedule limitations; (d) Space: indoor training space with consistent lighting to ensure motion-capture fidelity. Expected hurdles include instructor resistance to technology (particularly veteran coaches), time commitment to video annotation (about 15 minutes per student per session), and internet reliability for uploading videos during the Review phase. Institutions should find ways to overcome these barriers through incremental roll-out, peer mentoring, and technical support desks.

Limitations

Several factors limit the generalizability of this study. First, the one-group pre-post design without a control group means that causal inference is not possible; the observed gains may be ascribed to practice, testing, or instructor effects rather than to the Ardilla model per se. Second, although the sample size for pre-post analysis was adequate (n = 60), the biomechanical video annotation was limited to a subsample (n = 20) due to time constraints. Third, the intervention was short (six weeks), and no retention test was administered to assess the stability of skill gains after the intervention. Fourth, biomechanical reporting was limited to 2D video analysis; 3D motion capture or force-plate data would provide more robust validation of joint kinetics and ground reaction forces. Fifth, it was not possible to blind the assessors because the same students were observed by the raters in face-to-face sessions, which may result in performance bias. Sixth, the study was conducted in the Indonesian higher education context only, and the transferability of the findings to other national systems may be affected by cultural and curricular differences. Seventh, no gender-disaggregated analysis was performed despite a balanced sample (30 males, 30 females), leaving open the question of whether biomechanical improvements are equivalent across sexes. These limitations imply that the Ardilla model is a rigorously developed prototype worthy of experimental confirmation, rather than an evidence-based intervention ready for unconditioned adoption.

Conclusions

In this operational field test, the Ardilla Learning Model (a seven-phase instructional syntax: Attention, Relevance, Demonstration, Interaction, Learning by Doing, Review, Action Plan) has been preliminarily evaluated by integrating interactive multimedia animations and biomechanical analysis in a systematic way for the purpose of teaching Pencak Silat at the university level. Convergent evidence from instructor and student practicality testing (~86–90% acceptance), expert validation (>90% feasibility), and a one-group pre-test post-test trial ($t(59) = 6.99$, $p < .001$, Cohen's d<sub> = 0.90) supports the model's preliminary pedagogical validity and its association with improved psychomotor competence in the context tested.

The main contribution of this work is a shift from isolated digital artifacts to a coherent theory-driven educational ecosystem. The Ardilla model provides a framework for shifting martial arts learning from imitative repetition to reflective and evidence-based self-regulation by incorporating measurable biomechanical investigations into an interactive multimedia interface. This equips future physical education teachers with the advanced motor skills and digital scientific literacy increasingly required by 21st-century curricula. However, causal claims are mitigated by the lack of a control group and the single-institution design. Future research should employ randomized controlled trials with active control groups, retention measures, gender-disaggregated analyses, and replication across multiple sites to determine if the observed effects are robust and generalizable across diverse educational contexts. This approach provides a scalable means for technology-enhanced physical education in advanced and developing higher education settings and can be directly replicated in many other domains of complex motor skills.

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Conflict of Interest

The author declares that the work presented in this study was not influenced by any competing financial interests or known personal relationships. No specific grants from the government, private sector, or funding organizations were received for this research, which was conducted as part of the requirements for a doctoral dissertation. No third-party commercial entities were involved in the conception, implementation, analysis, or publication of the research findings; the authors themselves are solely responsible for the composition and content of this work.

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