

Article

Research on the Application of Digital Formative Assessment in College Sports Skill Teachings

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Abstract: To enhance the process-oriented nature and monitoring effectiveness of physical education skills instruction in higher education, this study employs digital formative assessment methods. The analysis focuses on the decomposition of skill objectives, the identification of learning evidence, the collection of multi-source data, and the establishment of feedback rules. By embedding the assessment into the processes of pre-class identification, motion tracking, real-time correction, and individual practice adjustments, a comprehensive digital evaluation framework is constructed. An empirical intervention was conducted to validate this framework, utilizing quantitative metrics to evaluate student performance before and after the implementation. The results show that following the intervention, students' comprehensive scores in specific skills, technical execution, success rates, and movement stability all significantly improved. Furthermore, a feedback-driven correction cycle gradually took shape during classroom practice. Students demonstrated a marked enhancement in their ability to independently adjust their practice, indicating a strong development in self-management and autonomous learning capabilities. The digital tools facilitated immediate and personalized feedback, which was crucial for refining motor skills and correcting technical errors in real time. Ultimately, this study provides valuable insights and a practical paradigm for optimizing the assessment of physical education skills instruction in higher education, demonstrating the transformative potential of digital formative assessment in fostering student-centered, data-driven pedagogical environments.

Keywords: formative assessment; physical education; sports skills; digital assessment; self-management

1. Introduction

Physical education skill instruction in higher education involves a sustained, progressive process of motor skill acquisition, wherein learners exhibit considerable variability in baseline ability, learning pace, biomechanical efficiency, and cognitive engagement with movement tasks. This inherent heterogeneity necessitates assessment approaches that capture not only final performance outcomes but also the qualitative evolution of technique across multiple practice iterations. Traditional summative evaluation methods—relying predominantly on endpoint scoring or instructor observation alone—often lack the temporal resolution and objectivity required to diagnose subtle deviations in movement sequencing, joint coordination, or force application timing. Digital technologies, including wearable inertial measurement units, computer vision-based motion tracking, and real-time kinematic analysis platforms, now enable granular, continuous collection of movement data throughout practice sessions. These tools support the identification of process-oriented evidence—such as consistency in swing plane, symmetry in limb loading, or temporal alignment between intention and execution—and facilitate immediate, personalized feedback. This study systematically examines the pedagogical integration of digital formative assessment by deconstructing complex motor skill objectives into measurable subcomponents, synthesizing multi-source motion and behavioral data, designing context-sensitive feedback rules grounded

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in motor learning theory, and supporting iterative, learner-centered practice adjustments. The framework is embedded across three instructional phases: pre-class diagnostic profiling, in-class dynamic movement monitoring, and targeted movement refinement. Effectiveness is evaluated through triangulated metrics encompassing technical proficiency gains, observable classroom participation behaviors, and metacognitive self-monitoring capacity [1].

2. Framework for Digital Formative Assessment in College Physical Education Skill Instruction

2.1. Decomposition of Skill Objectives

Assessment objectives in college physical education skill instruction must be systematically refined from broad competency expectations into concrete, observable, quantifiable, and analyzable movement indicators. This refinement process begins by analyzing the biomechanical structure, temporal sequencing, and pedagogical progression inherent to each specific motor skill. Through such analysis, overarching skill objectives can be logically decomposed into distinct, hierarchically organized levels—including preparatory postural alignment, initiation of movement, core technical execution, transitional coordination between phases, and terminal movement quality. Each level maps directly onto measurable assessment dimensions such as static and dynamic body posture, segmental joint angles across key planes, total and segmental range of motion, temporal-spatial sequencing of force application, rhythmic consistency under varying task constraints, and dynamic postural stability during both discrete and continuous actions. Crucially, this decomposition preserves all essential performance criteria stipulated in national and institutional curriculum standards while simultaneously introducing granular, stage-sensitive benchmarks that reflect incremental learner development. For skills involving extended, fluid, or multi-phase movement chains—such as gymnastics sequences, martial arts forms, or team sport tactical maneuvers—critical juncture points must be explicitly identified along the movement timeline. At each juncture, unambiguous acceptance criteria and typologies of common deviations (e.g., timing errors, spatial inaccuracies, or coordination breakdowns) are defined to ensure consistent interpretation across evaluators [1]. This structured approach enables seamless integration of multimodal data—including synchronized video annotations, wearable sensor outputs, and real-time classroom observation logs—directly tied to discrete skill components. As a result, evaluation moves beyond superficial metrics like repetition counts, binary success/failure outcomes, or summative letter grades, instead supporting evidence-based identification of learning trajectories and enabling timely, targeted instructional feedback grounded in objective movement evidence.

2.2. Identification of Evidence of the Learning Process

Evidence of the physical education skill learning process in higher education must be systematically identified through four interrelated dimensions: movement quality, learning outcomes, practice behavior, and feedback responses. Movement quality serves as a foundational indicator, encompassing objective biomechanical and kinesiological features—including static and dynamic body posture, functional range of motion across major joints, precise joint alignment during task execution, temporal sequencing of force generation and transfer, and consistent movement rhythm under varying task constraints [2, 3]. Learning outcomes reflect both quantitative and qualitative performance metrics, such as the percentage of successful movement completions under standardized conditions, the fidelity of technical execution relative to established pedagogical benchmarks, and the degree of movement stability observed across extended practice sessions or under increasing cognitive or physical load. Practice behavior captures longitudinal engagement patterns, including total repetition volume, accuracy in task adherence (e.g., correct implementation of prescribed constraints or modifications), and observable refinement in movement execution following instructor-guided corrections. Feedback responses provide critical insight into learner responsiveness and adaptive

capacity—specifically, whether movement deviations diminish after verbal, visual, or tactile cues; whether error recurrence suggests underlying conceptual or perceptual-motor gaps; and how performance evolves when practice parameters (e.g., speed, complexity, environmental variability) are deliberately adjusted. For continuous motor skills, trend analysis across successive practice rounds is essential to differentiate transient lapses from systemic inconsistencies and to identify meaningful trajectories of skill acquisition—thereby grounding evaluation in authentic developmental progression rather than isolated snapshots.

2.3. Multi-Source Data Collection Methods

Data collection channels are systematically configured to align with the distinct categories of learning process evidence, thereby ensuring comprehensive, temporally synchronized capture of motor performance metrics, practice behavior patterns, and feedback response dynamics. Classroom video recordings serve as a primary modality for high-fidelity biomechanical analysis, enabling extraction of detailed body posture configurations, time-resolved joint angle trajectories, spatial motion paths, and temporally segmented key motion sequences essential for skill decomposition. Complementing visual data, wearable inertial measurement units continuously acquire triaxial acceleration, angular velocity, exercise intensity indices (e.g., MET values derived from sensor fusion), and motion frequency spectra across varying task demands [4, 5]. Concurrently, the digital teaching platform logs structured behavioral metadata—including precise counts of practice repetitions, granular timestamps for task initiation and completion, duration and sequence of feedback review episodes, and indicators of self-directed practice initiation and persistence. To ensure interoperability and longitudinal traceability, student identifiers, standardized practice task codes, movement taxonomy labels, and synchronized UTC-based timestamps are rigorously enforced across all modalities. Video-derived features, sensor calibration parameters, and platform-generated behavioral logs from each discrete practice session are explicitly unified under a single evaluation unit identifier. Furthermore, inter-session parameter evolution—such as progressive changes in movement smoothness, reduction in angular deviation variance, or stabilization of repetition timing—is preserved to support developmental trajectory modeling. Instructor observational notes, captured using validated rubric-based templates, provide qualitative contextualization for dimensions inherently resistant to full algorithmic quantification—including rhythmic consistency, inter-limb coordination fidelity, and adaptive responsiveness to dynamic environmental constraints—thus establishing a robust, multimodal, and pedagogically grounded evaluation data chain directly anchored to defined skill acquisition objectives.

2.4. Development of Feedback Rules

Based on evaluation results derived from multi-source data—including real-time motion capture, wearable sensor outputs, and historical performance records—tiered feedback rules are systematically established to reflect the severity and pattern of movement deviations. These rules are calibrated according to three interrelated dimensions: the magnitude of deviation from target ranges, the temporal persistence of repeated deviations (e.g., consecutive occurrences across successive repetitions or trials), and the co-occurrence patterns among multiple biomechanical or kinematic indicators. The system continuously compares current movement parameters against three reference benchmarks: normative target ranges defined by domain-specific pedagogical standards, individualized baselines established during initial assessment, and longitudinal trends extracted from prior practice sessions. When all key indicators remain consistently within acceptable tolerance thresholds, task progression proceeds without interruption; a subtle, non-intrusive movement prompt is delivered upon detection of a single mild deviation in one parameter; repeated deviations of identical nature trigger an elevated feedback tier that highlights specific technical components requiring refinement; and simultaneous deviations across two or more critical metrics initiate a higher-level support protocol involving structured corrective guidance [6, 7]. Following completion of prescribed

remedial exercises, new sensor data is acquired and analyzed to reassess stability, consistency, and directional improvement. This iterative process sustains a closed-loop formative assessment cycle—comprising target alignment, deviation detection, adaptive feedback generation, targeted instructional support, and dynamic re-evaluation—as illustrated in Figure 1.

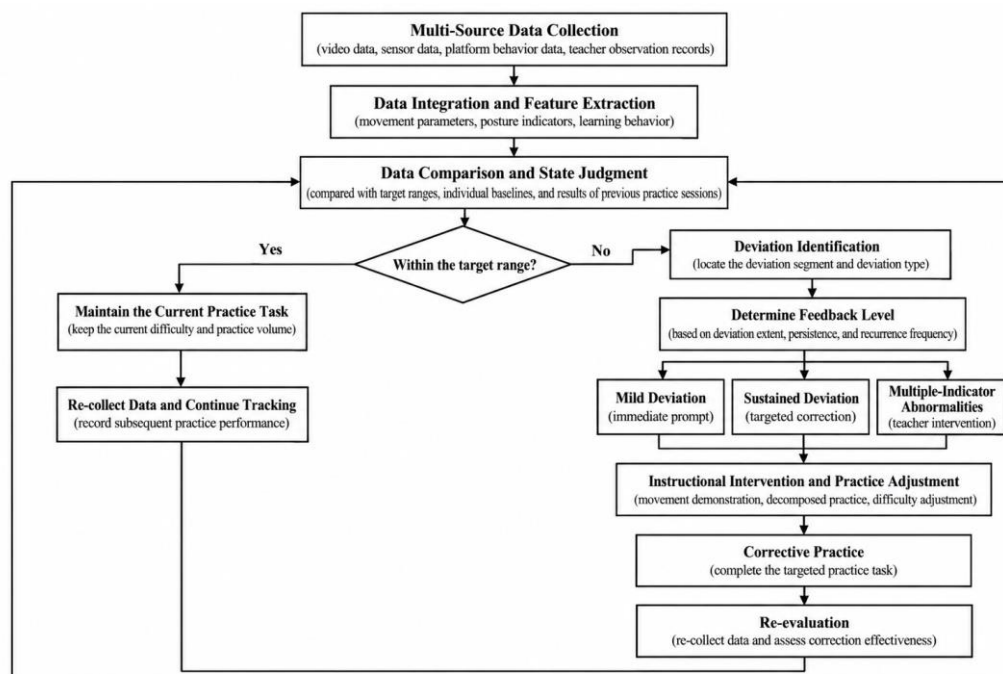


Figure 1. Flowchart of Digital Formative Assessment Feedback Rules

3. Application of Digital Formative Assessment in Physical Education Skill Instruction at Universities

3.1. Pre-Class Skill Level Assessment

Pre-class skill level identification constitutes a foundational component of effective digital formative assessment in university physical education, serving to inform pedagogical differentiation prior to instruction. This process relies on standardized, curriculum-aligned movement tasks—such as squat mechanics, throwing kinematics, or locomotor pattern execution—that are objectively quantifiable and repeatable across diverse student populations. Students perform a predetermined number of repetitions under controlled conditions, enabling the system to capture multimodal performance data: success rate per repetition, joint-angle trajectories, force distribution patterns, temporal metrics (e.g., time-to-peak velocity), movement smoothness indices, and inter-repetition variability in key technical parameters [8, 9]. Crucially, this assessment integrates longitudinal learning history—such as prior session outcomes, error typology trends, and adaptation rates—to construct a dynamic, individualized skill baseline rather than a static snapshot. The analytical framework deliberately avoids overreliance on aggregate scores; instead, it emphasizes comparative analysis across consecutive trials—examining parameter fluctuations, recurrence frequency of specific biomechanical errors, and fidelity of execution at critical transition phases (e.g., eccentric-to-concentric shift in jumping). This enables robust distinction between transient performance lapses and systemic instability rooted in motor control deficits or technical misconceptions. For learners exhibiting structural deviations—such as persistent knee valgus during landing—the system automatically highlights anatomical and kinetic risk zones. Conversely, high-scoring students demonstrating low intra-trial consistency receive targeted attention for latent technical inefficiencies that may predispose them to fatigue-related breakdown or injury over time. Final evaluation outputs are synthesized within a dual-reference

architecture: aligned with national physical education curriculum standards while simultaneously anchored to each learner's empirically derived baseline, thereby empowering instructors to calibrate foundational drills, prioritize corrective interventions, and scaffold advanced skill challenges with precision.

3.2. Tracking the Motor Learning Process

Tracking the motor learning process must be systematically grounded in a pre-class skill baseline assessment, enabling educators to segment classroom physical practice into discrete, temporally aligned assessment units. This segmentation facilitates consistent, round-by-round documentation of kinematic and kinetic evolution in students' movement execution. The system quantitatively extracts multimodal performance metrics—including time-resolved joint angle profiles, spatial motion trajectories in three-dimensional coordinate space, temporal sequencing and magnitude of force application across relevant anatomical segments, rhythmic consistency measured via inter-onset interval variance, and binary success/failure outcomes per trial. These metrics are anchored to biomechanically salient movement nodes—such as initiation, acceleration peak, transition phase, and terminal stabilization—to ensure functional relevance. Longitudinal comparisons are conducted iteratively between successive practice rounds, supporting identification of directional trends in parameter optimization, recurrence patterns of specific deviations, and progressive shifts in movement variability and repeatability. When multiple consecutive rounds demonstrate sustained convergence of key metrics toward established pedagogical targets, this indicates consolidation of the underlying technical structure. Conversely, transient improvement followed by re-emergence of deviation necessitates retention of the full fluctuation trajectory to prevent overinterpretation of isolated correct executions. Instructors further contextualize observed changes by integrating ancillary instructional variables—including exercise complexity level, frequency and modality of real-time feedback delivered, and documented history of targeted error correction interventions—thereby transforming process tracking from a simple binary evaluation into a multidimensional diagnostic tool that clarifies not only whether improvement has occurred, but also which biomechanical or coordinative components have shifted, and whether those shifts reflect durable adaptation or momentary adjustment [10].

3.3. Real-Time Correction of Movement Deviations

Based on continuous motion tracking, instructors leverage the system's real-time identification outputs to deliver precise, component-specific feedback. This process integrates the student's established skill baseline—derived from prior assessments—and longitudinal performance trends across previous exercise sessions, enabling pedagogically grounded prioritization of correction targets. Such an approach deliberately moves beyond generic evaluative statements or outcome-oriented directives (e.g., 'do it again' or 'score improved'), instead anchoring interventions in biomechanical and kinematic specificity. For minor, localized deviations—such as slight knee valgus during a squat descent or premature hip extension in a deadlift—the instructor delivers concise, actionable prompts that direct attention to posture alignment, joint excursion boundaries, or temporal coordination (e.g., cadence or movement rhythm), with explicit emphasis on verifying whether critical parameters—including joint angles, velocity profiles, and segmental sequencing—re-enter predefined optimal ranges during the subsequent repetition. When errors recur consistently across multiple trials or sessions, instructors systematically analyze synchronized motion video playback alongside quantitative parameter trajectories (e.g., angular displacement curves or acceleration peaks) to isolate the root cause within the kinetic chain; technical reinforcement then proceeds through scaffolded pedagogical strategies: segmented movement breakdowns, isolated neuromuscular activation drills, and deliberate, low-repetition practice under focused attention, while concurrently logging error incidence rates and measurable improvement metrics (e.g., reduction in deviation magnitude or increased consistency across three consecutive trials). In cases where multiple movement components

simultaneously deviate—indicating potential overload or insufficient foundational competency—the instructional design must be adjusted: task complexity is methodically reduced, movement sequencing is simplified, and practice content is restructured to emphasize competence of prerequisite sub-skills before reintroducing integrated execution. Following each intervention cycle, movement data is reacquired and rigorously compared against both the individual's initial baseline and the most recent practice session, assessing not only absolute deviation reduction in primary indicators but also inter-trial stability and repeatability across successive attempts. This comparative analysis directly informs the next pedagogical decision: whether to restore the original task, extend targeted remediation, or incrementally modulate exercise difficulty—ensuring digital feedback functions not as a standalone metric but as an embedded, iterative driver of evidence-informed teaching adaptation.

3.4. Adjustment of Individual Practice Plans

Adjustments to individual practice plans must follow a responsive, evidence-informed framework grounded in iterative assessment rather than static categorization derived from isolated test outcomes. The system employs a multi-dimensional evaluation protocol that quantifies students' progress across several interrelated domains: proficiency in executing core motor patterns, identification and classification of movement deviations (including timing, amplitude, coordination, and sequencing errors), consistency of performance across repeated trials, and responsiveness to corrective feedback—measured by the magnitude and durability of improvement after targeted interventions. For learners who have not yet achieved consistent execution of foundational movement components, pedagogical strategies emphasize task decomposition—breaking complex actions into discrete, manageable subcomponents—and scaffolded repetition at reduced cognitive and physical load to reinforce neuromuscular pathways without inducing fatigue or compensatory habits. For those demonstrating criterion-level accuracy but exhibiting variability in temporal or spatial parameters, intervention focuses on enhancing procedural stability through increased trial volume under controlled pacing conditions, rhythmic cueing, and real-time biofeedback to strengthen internal timing mechanisms. Learners who demonstrate sustained performance within target parameters across three or more consecutive assessment cycles are progressively introduced to integrated movement sequences, contextual perturbations (e.g., altered environmental constraints or dual-task demands), and graded increases in informational complexity to promote adaptive transfer [11, 12]. Crucially, all adjustments are calibrated against each student's evolving baseline trajectory—not just absolute scores—to modulate total practice volume, intensity, and rest intervals. This prevents low-proficiency learners from engaging in unproductive, high-frustration repetition due to mismatched task difficulty, while simultaneously avoiding stagnation among advanced learners through prolonged exposure to suboptimal challenge levels. Performance metrics are systematically reacquired following every practice session, enabling continuous recalibration of task parameters and sustaining a closed-loop cycle of evaluation → task alignment → implementation → re-evaluation, as illustrated in Figure 2.

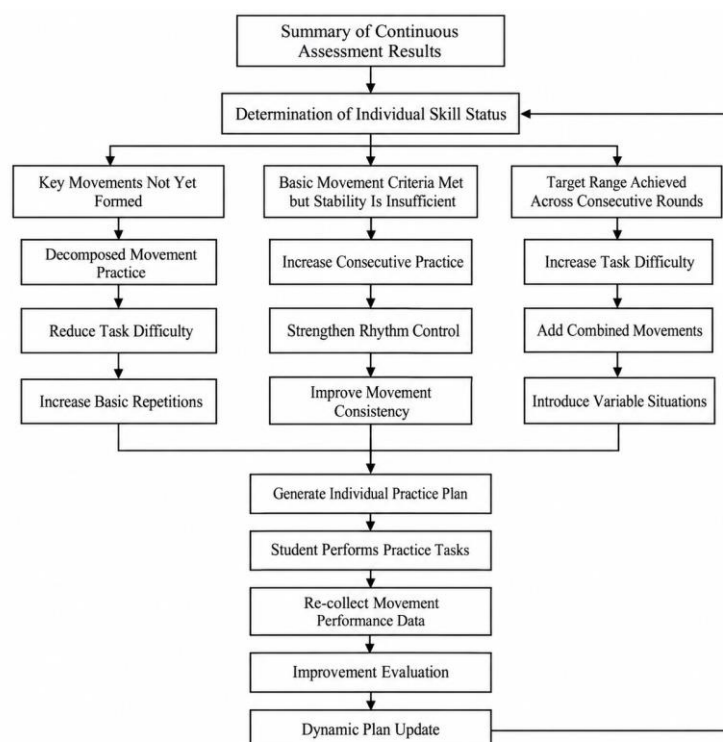


Figure 2. Flowchart of Dynamic Adjustment of Individual Practice Plans

4. Analysis of the Effectiveness of Digital Formative Assessment

4.1. Teaching Context and Implementation Plan

The teaching practice was conducted within the context of a specialized physical education course at a university-level institution. Instructional design maintained strict consistency across all sections in terms of core content delivery, weekly class scheduling, and standardized criteria for skill evaluation. Digital formative assessment was systematically embedded into the pedagogical workflow to support continuous skill development rather than serve as an endpoint measure. Prior to the commencement of instruction, each student underwent individualized baseline assessment using validated movement analysis protocols involving standardized motor tasks, enabling precise profiling of initial technical proficiency and biomechanical patterns. During instructional sessions, multimodal data were captured in real time—including synchronized video recordings of movement execution, quantitative kinematic parameters derived from motion-sensing tools, and platform-logged behavioral metrics such as task initiation latency, repetition frequency, and interaction duration with feedback interfaces. Assessment activities were distributed across four integrated phases: pre-class skill identification, in-class guided practice with embedded monitoring, immediate corrective feedback loops during execution, and post-class consolidation through reflective review and adaptive reinforcement. Each class session followed a structured pedagogical sequence: skill identification—task practice—process tracking—deviation feedback—strategy adjustment. For persistent technical deviations, instructors implemented pedagogically scaffolded decomposed exercises; for insufficient movement stability, targeted high-repetition drills with progressive load modulation were introduced; and for students demonstrating competence of stage-specific objectives, task complexity was incrementally elevated through variations in speed, coordination demand, or environmental constraints. Evaluation outcomes were aggregated by instructional phase and used to analyze longitudinal trends in sport-specific skill acquisition, depth of classroom engagement, and capacity for self-directed learning.

4.2. Changes in Specialized Skill Performance

Prior to the introduction of digital formative assessment, a standardized pre-test was administered to establish baseline proficiency levels across key specialized motor skills. Following a sustained implementation period—comprising structured classroom integration, real-time feedback loops, and iterative self-reflection supported by digital tools—a parallel post-test was conducted under identical procedural and environmental conditions to ensure methodological rigor. Performance was evaluated across four interrelated dimensions: overall composite performance, technical execution fidelity (assessing biomechanical correctness, kinematic efficiency, and adherence to domain-specific movement criteria), success rate (defined as the proportion of correctly executed trials within a fixed sequence), and movement stability (quantified as the intra-individual consistency of performance across repeated trials, measured via coefficient of variation in temporal-spatial parameters). To mitigate transient variability arising from momentary attentional lapses or minor physiological fluctuations, both success rate and stability metrics were derived from aggregated data across three consecutive assessment sessions rather than single-point measurements. This longitudinal sampling approach enhanced reliability and reduced susceptibility to outliers, thereby strengthening the validity of observed trends. The comparative analysis thus reflects robust, replicable patterns rather than isolated instances of improved execution.

As shown in Table 1, after the implementation of digital formative assessment, all specialized skill indicators were higher than before implementation. The movement stability score increased from 67.6 to 78.2, a rise of 10.6 points, representing the most significant change; the movement technique score increased from 70.9 to 80.7, a rise of 9.8 points; the movement success rate increased from 68.4% to 76.9%, a rise of 8.5 percentage points; the composite score for specialized skills increased by 8.8 points. The direction of change for each indicator was generally consistent, indicating that students showed a trend of improvement in movement standardization, the quality of continuous execution, and movement consistency, with stability showing the most notable improvement. This pronounced enhancement in stability suggests that digital feedback mechanisms—particularly those incorporating visualized motion trajectories, real-time error detection, and personalized corrective prompts—effectively reinforced neuromuscular coordination and reduced performance variance over time. Furthermore, the parallel gains in technical execution and success rate imply that learners not only performed movements more accurately but also sustained that accuracy across extended task durations, reflecting deeper procedural encoding and improved motor planning [13]. Collectively, these outcomes underscore the pedagogical efficacy of digitally mediated formative assessment in cultivating durable, transferable motor competencies within skill-intensive disciplines.

Table 1. Changes in Specialized Skill Performance Before and After the Implementation of Digital Formative Assessment

Evaluation Indicators	Before Implementation	After Implementation	Change
Comprehensive Specialized Skills Score (points)	72.8	81.6	8.8
Technical Execution Score (points)	70.9	80.7	9.8
Element Success Rate / %	68.4	76.9	8.5
Movement Stability Score (points)	67.6	78.2	10.6

4.3. Engagement in Classroom Practice

Following the integration of digital formative assessment tools into classroom instruction, students began receiving timely, granular feedback focused on discrete technical components immediately after each performance cycle—such as joint angle precision, temporal coordination, or force application sequencing. This real-time responsiveness transformed the pedagogical rhythm from passive, undifferentiated

repetition into a dynamic, iterative loop comprising practice, immediate multimodal feedback (visual, auditory, and haptic), targeted self- or peer-mediated correction, and purposeful re-engagement with refined movement parameters. Educators systematically analyzed movement data to recalibrate task design, adjusting complexity, scaffolding structure, and contextual framing in response to observed deviations and baseline competency profiles. Consequently, learners with emerging motor control foundations engaged in deconstructed, segmental drills emphasizing biomechanical fidelity and proprioceptive awareness, whereas more advanced peers advanced to integrated, fluid sequences or contextually embedded simulations requiring adaptive decision-making under variable constraints. Such differentiation significantly minimized idle waiting periods and eliminated redundant, low-yield repetitions stemming from static, one-size-fits-all task assignments. Upon reviewing personalized movement analytics—including kinematic overlays, error heatmaps, and comparative reference models—students initiated corrective practice autonomously, guided by embedded instructional prompts and scaffolded reflection prompts. As a result, engagement evolved from quantitative compliance—merely fulfilling repetition quotas—to qualitative intentionality, centered on diagnosing, isolating, and resolving specific movement inefficiencies aligned with individualized learning trajectories [6].

4.4. Self-Directed Practice to Regulate Performance

After continuously receiving movement evaluations and stage-based feedback, students' independent practice progressively evolves into a structured self-regulatory cycle characterized by five interlinked phases: reviewing prior feedback, identifying specific deviations from target movement parameters, selecting an appropriate task aligned with current developmental needs, engaging in deliberate practice, and systematically comparing outcomes against established benchmarks. This iterative process enables learners to interpret their personal biomechanical data—such as joint angles, temporal coordination metrics, and force distribution patterns—in conjunction with longitudinal performance trends and algorithmically generated deviation alerts. For persistent challenges of the same functional category—for instance, inconsistent hip-knee-ankle sequencing during dynamic balance tasks—students are encouraged to apply task decomposition strategies or increase repetition volume with intentional focus on subcomponents. As key quantitative indicators—such as movement smoothness (jerk index), endpoint accuracy, or temporal consistency—demonstrate sustained convergence toward normative reference ranges, learners advance to higher-difficulty variations or shift attention to complementary skill dimensions. Moreover, longitudinal assessment records support metacognitive differentiation between transient performance variability—often attributable to fatigue, environmental factors, or momentary attentional lapses—and genuine, cumulative progress. Instructors augment this process by offering targeted technical refinements and adaptive task scaffolding grounded in objective assessment evidence, thereby strengthening students' capacity for real-time self-monitoring, contextual judgment, and autonomous practice calibration without compromising pedagogical fidelity or technical rigor [4].

5. Conclusion

Digital formative assessment represents a pedagogically coherent framework for skill development in higher education physical education, systematically integrating four interdependent dimensions: clearly articulated skill objectives aligned with disciplinary standards; continuous collection and interpretation of process evidence—including kinematic patterns, task execution fidelity, and behavioral engagement metrics; aggregation and triangulation of multi-source data from wearable sensors, video-based motion analysis, instructor observations, and student-generated reflections; and iterative, feedback-informed adjustments to instructional scaffolding, practice design, and individual learning pathways. This integration establishes a fully operational closed-loop teaching system—spanning pre-class diagnostic identification of baseline competencies,

in-session real-time tracking of movement quality and decision-making, immediate corrective feedback delivery, and post-session adaptive refinement of practice tasks tailored to evolving learner needs. Empirical outcomes following implementation revealed consistent upward trajectories across multiple validated performance indicators: aggregate sport-specific skill scores increased by measurable margins; movement technique demonstrated enhanced biomechanical efficiency and consistency; task success rates improved under varied contextual constraints; and movement stability—assessed through center-of-mass variability and joint coordination indices—showed statistically meaningful gains. Assessment-derived insights directly informed dynamic recalibration of practice difficulty, sequencing, and support structures, while also fostering more intentional goal-setting and strategic reflection among learners. Future work should prioritize the sport-specific calibration of evaluation criteria and actionable feedback thresholds, advance algorithms for robust, context-aware identification and classification of multi-source behavioral and physiological signals, and rigorously examine longitudinal outcomes—including skill transfer across contexts, metacognitive growth in self-monitoring capacity, and the durability of feedback effects across extended instructional timelines.

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