Relationship between content knowledge, pedagogical content knowledge, and throwing performance among primary school students

Relación entre el conocimiento del contenido, el conocimiento pedagógico del contenido y el rendimiento en el lanzamiento entre alumnos de primaria

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Abstract

Introduction: Physical education teacher effectiveness is fundamentally tied to the depth and specialization of content knowledge.
Objective: To examine the influence of teacher content knowledge and developmental stage insights on enacted PCK and subsequent student throwing performance.
Methodology: Two public elementary physical education teachers and 124 boys (Mage=9.42; ± 0.49) corresponding to third and fourth grades in the Iranian educational system) participated in a quasi-experimental design combining a small-N single-case structure at the teacher level with a between-groups comparison at the student level. The study spanned three consecutive phases: design across comparison (standard instruction), professional development (throwing "knowledge packet"), and experimental conditions. Four PCK variables (task representation, demonstration, feedback, modification alignment) and student ball velocity (via Doppler radar) were analyzed using descriptive statistics and independent t-tests.
Results: Teachers' PCK shifted significantly post-intervention, with effect sizes ranging from 1.49 to 7.23. Correct task representations and demonstrations increased from 18% to 95%, while developmentally appropriate feedback rose from 12% to 68%. These upgrades generated significant post-intervention velocity gains in the experimental cohort compared to controls ($t(120) = -4.66$, $p < 0.001$, $d = 0.84$)
Discussion: The results align with broader empirical frameworks regarding the critical role of content-specific pedagogical training in structured educational environments.
Conclusions: Advancing teacher content knowledge and developmental stage mastery directly transforms instructional behaviors, optimizing fundamental motor skill acquisition.

Keywords

Physical education; pedagogical content knowledge; motor development; overhand throwing; teacher professional development.

Resumen

Introducción: La efectividad de los docentes de educación física está vinculada fundamentalmente a la profundidad y especialización de su conocimiento del contenido.
Objetivo: Examinar la influencia del conocimiento del contenido y del desarrollo sobre el CDC ejecutado y el rendimiento del lanzamiento estudiantil.
Metodología: Dos profesores de educación física de escuelas primarias públicas y 124 niños (Medad = 9.42; ± 0.49 años) Los docentes (correspondientes a tercer y cuarto grado en el sistema educativo iraní) participaron en un diseño cuasiexperimental que combinaba una estructura de caso único con una muestra pequeña a nivel docente con una comparación entre grupos a nivel estudiantil. El estudio abarcó tres fases consecutivas: condición de comparación (instrucción estándar), taller de desarrollo profesional ("paquete de conocimiento" del lanzamiento) y condición experimental. Se midieron cuatro variables del CDC (representación de tareas, demostración, retroalimentación y alineación de modificaciones) y la velocidad de la pelota (vía radar Doppler), analizándose mediante estadística descriptiva y pruebas t-para muestras independientes.
Resultados: El CDC docente mejoró notablemente tras la intervención (tamaños de efecto de 1.49 a 7.23). Las representaciones y demostraciones correctas aumentaron del 18% al 95%, y la retroalimentación adecuada creció del 12% al 68%. Estas modificaciones pedagógicas se asociaron con mejoras significativas en el rendimiento estudiantil ($t(120) = -4.66$, $p < 0.001$, $d = 0.84$).
Discusión: Los hallazgos concuerdan con la literatura internacional sobre el impacto del conocimiento especializado en la precisión instruccional y la adquisición motriz infantil.
Conclusiones: La profundización en el conocimiento del contenido y el dominio evolutivo transforma directamente las conductas instructivas, optimizando la adquisición de destrezas motrices fundamentales en contextos centralizados.

Palabras clave

Educación física; conocimiento didáctico del contenido; desarrollo motor; lanzamiento sobre el hombro; desarrollo profesional docente.

Introduction

The mastery of fundamental motor skills (FMS) serves as the indispensable cornerstone of a child's physical development, acting as the prerequisite for a lifetime of physical activity, sport participation, and health-related fitness (C. Il Kim & Lee, 2016). among these skills, the overhand throw is recognized as one of the most complex manipulative motor patterns, necessitating a sophisticated integration of postural control, segmental sequencing, and the application of the kinetic link principle to achieve maximum force and accuracy (KASUYAMA et al., 2016). despite its critical role in the developmental trajectory of children, research consistently indicates that a significant percentage of elementary-aged students do not naturally progress to mature throwing patterns without targeted, high-quality instruction (Martínez-Bello et al., 2025). this failure to reach motor competence often results in a "proficiency barrier," where children lack the necessary skills to engage in more complex sports and games, ultimately leading to a sedentary lifestyle and the associated risks of obesity and metabolic disease (Ezeddine et al., 2025).

Within the field of sport pedagogy, the primary mechanism focusses on the physical education (pe) teacher expertise. however, the nature of this expertise is multifaceted. while general pedagogical skills such as classroom management and high levels of student engagement are necessary, they are insufficient for facilitating specific motor skill acquisition (Ward & Ayvazo, 2016). Shulman's seminal work introduced the construct of pedagogical content knowledge (PCK) as the "amalgam" of content and pedagogy that allows a teacher to transform complex subject matter into forms that are accessible and comprehensible to learners (Shulman, 1987). in physical education, PCK is not merely what a teacher knows about a sport, but how that knowledge is enacted during the dynamic, real-time interactions of a lesson. it involves the ability to choose the right analogies, identify subtle student errors, and modify tasks so they are perfectly aligned with a child's current developmental stage (Le Paven Jarno, 2025). the theoretical landscape of teacher knowledge has been further refined by ward and colleagues, who differentiated between common content knowledge (CCK) and specialized content knowledge (SCK). CCK represents the knowledge of rules, techniques, and safety that is shared by practitioners and non-teaching experts alike. SCK, conversely, is the specialized knowledge required uniquely for teaching, such as the ability to recognize developmental sequences and the specific errors students make within those sequences (Chang et al., 2020a).

The conceptual framework for this study is grounded in the belief that teacher effectiveness in physical education is a function of the depth and organization of the teacher's knowledge base (Harris, 2025). at the heart of this model is the interaction between three primary domains: content knowledge, knowledge of the learner, and pedagogical expertise (Zhang et al., 2024). when these domains intersect, they produce enacted PCK, which manifests as four observable teacher behaviors: task representation, task demonstration, feedback, and task modification.in this study's theoretical model, CCK and SCK act as the input variables that inform the teacher's comprehension of the overhand throw. CCK provides the baseline understanding of "what" to throw (e.g., the target, the rules of the activity), while SCK provides the "how" and "why" of throwing instruction (e.g., identifying humeral lag or the importance of a contralateral step) (Fu et al., 2022a). when these knowledge bases are enhanced through professional development, they are expected to shift the teacher's instruction from "immature" PCK-characterized by generic feedback and non-specific tasks-to "mature" PCK (Noelva, 2023). mature PCK is evidenced by instruction that is developmentally appropriate, where the teacher provides specific, congruent feedback that matches the student's current motor stage and adapts tasks to provide the optimal level of challenge. despite the intuitive logic of this framework, there is a noted scarcity of empirical research exploring the direct relationship between improvements in teacher ck (specifically CCK and SCK) and the subsequent effect on enacted PCK and student learning outcomes in the context of individual fundamental motor skills (Ward & Ayvazo, 2016).

While foundational research by (Chang et al., 2020b), established the efficacy of specialized content knowledge (SCK) workshops within Western educational paradigms, a critical geographic and structural gap persists regarding their cross-cultural transferability. The present investigation addresses this theoretical void by operationalizing the SCK model within the public elementary school system of Tehran, Iran. Governed by a centralized, state-mandated curriculum and strict gender segregation, the Iranian educational infrastructure provides a highly controlled naturalistic laboratory to isolate the effects of teacher-level knowledge enhancement while expanding pedagogical content knowledge models beyond Western, co-educational settings. most prior research has focused on team sports or general educational settings, leaving a gap in our understanding of how teacher knowledge influences the acquisition of discrete skills like throwing in early childhood (Fu et al., 2022a).

To examine how educator expertise influences the acquisition of discrete fundamental motor skills, this study utilizes a targeted "knowledge packet" focused on the overhand throw. This research by utilizing a "knowledge packet" (Ladrón-de-Guevara et al., 2021) designed to enhance teachers' SCK of overhand throwing, this study seeks to elucidate the causal chain between teacher expertise and student motor competence. the overhand throw provides an ideal subject for this inquiry because its developmental stages are well-documented, allowing for precise measurement of both instructional alignment and performance outcomes through ball velocity. Grounded in this experimental framework, the study evaluates two primary hypotheses. First, it is hypothesized that implementing the SCK intervention within a centralized curriculum will precipitate significant, observable functional transitions in educator behaviors, characterized by increased frequencies of accurate task representation, precise physical demonstration, and developmentally appropriate feedback compared to baseline instruction. Second, it is hypothesized that students receiving instruction aligned with this enhanced pedagogical framework will exhibit statistically significant elevations in peak throwing velocity relative to control cohorts, with these biomechanical adaptations demonstrating temporal stability during retention evaluations. Ultimately, this research elucidates the causal chain linking teacher professional development to student motor competence across diverse administrative and cultural contexts.

Method

The study was conducted within two mid-sized, public elementary schools situated in suburban districts of Tehran, Iran. two physical education teachers (one male, one female) were randomly selected for participation. selection criteria included a minimum of five years of teaching experience and a current schedule involving multiple sections of first and second-grade physical education, which facilitated the implementation of both comparison and experimental conditions within each teacher's professional environment. prior to the study, both teachers reported high levels of general pedagogical confidence but noted a lack of specialized training in biomechanical error detection and developmental motor sequences.

Participants

The male primary school students 124 (M_{age}=9.42; ± 0.49), including 71 third-graders and 53 -fourth-graders, participated in the study. students were recruited from 12 total classes (six per teacher). within each teacher's schedule, classes were randomly assigned at the classroom level to either the comparison condition (n=63; one 3st grade, one 4nd grade) or the experimental condition (n=61; one 3st grade, one 4nd grade). The student sample was intentionally restricted to an exclusively male demographic to proactively control for the extensive morphological and kinematic gender dimorphism consistently observed in early childhood overhand throwing trajectories. this randomization strategy was employed to prevent cross-contamination of instructional strategies between classes during the baseline phase. informed consent was obtained from teachers and parents, and student assent was secured in accordance with university institutional review board (IRB) protocols and school district guidelines. the ethics review board of Farhangian university, Iran approved the present study with the code of ir.cfu.rec.1403.002. also, written informed consent was obtained from the children's parents.

Procedure

This investigation utilized a within-subjects, quasi-experimental design involving a three-phase intervention protocol. this design is particularly effective in naturalistic educational settings as it allows for the simultaneous control of individual teacher variability (e.g., personality, management style) and class-level baseline characteristics. by comparing phase 1 (baseline) to phase 3 (experimental) within the same teachers, any observed shifts in pedagogical behaviour can be more confidently attributed to the phase 2 content intervention.

Phases of the study

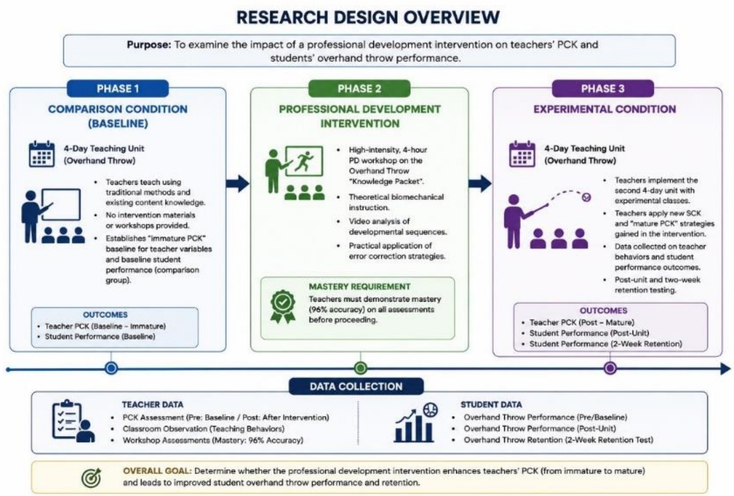
The study was structured into three sequential operational phases (see figure 1):

Phase 1: comparison condition (baseline): teachers were instructed to teach a standard four-day unit on the overhand throw using their traditional teaching methods and existing content knowledge. no intervention materials or workshops were provided during this phase. this established the "immature PCK" baseline for teacher variables and the baseline performance for students in the comparison group.

Phase 2: professional development intervention: teachers participated in a high-intensity; four-hour professional development (PD) workshop cantered on the overhand throw "knowledge packet". the workshop involved theoretical biomechanical instruction, video analysis of developmental sequences, and practical application of error correction strategies. teachers were required to demonstrate mastery (96% accuracy) across several assessments before proceeding to the next phase.

Phase 3: experimental condition: following the workshop, teachers implemented a second four-day throwing unit with the classes assigned to the experimental condition. during this phase, teachers applied the new SCK and "mature PCK" strategies gained in the intervention. data were collected on teacher behaviours and student performance outcomes, including post-unit and two-week retention testing.

Figure 1. A diagram of research design**.**



Independent variable

The primary independent variable was the implementation of the overhand throwing "knowledge packet" and its associated professional development workshop. To ensure absolute methodological rigor and construct validity, the content validation of the knowledge packet was executed via a modified two-round Delphi methodology utilizing an independent panel of five international academic experts in sport pedagogy, motor development, and kinesiology. The expert panel evaluated the packet components for developmental accuracy, biomechanical precision, and pedagogical relevance. The Content Validity Index (CVI) was computed for each individual item (I-CVI) and for the overall scale (S-CVI). (Roberton & Konczak, 2001;Ward & Ayvazo, 2016). the packet focused on several key domains:

1. Biomechanical fundamentals: detailed descriptions of the biomechanical mechanics of a mature thrower, emphasizing the kinetic link principle where energy is transferred from the feet through the trunk to the arm. this training highlighted that elite performance is characterized by sequential joint rotations, starting from the lower extremities, transitioning through the pelvis and trunk, and accelerating the distal humerus and forearm.
2. Developmental sequences: teachers were trained to utilize the component approach developed by Robert on and Halverson. rather than categorizing a throw as a singular, global pattern, teachers learned to analyse five independent body components (trunk, humerus, forearm, stepping, and backswing) and categorize them into validated developmental levels.

- Trunk action: coded from level 1 (no trunk action or simple forward-flexion in the sagittal plane) to level 2 (upper trunk rotation or block/unitary rotation) and level 3 (differentiated rotation, where the pelvis rotates forward prior to the upper trunk and spine).
- Humours action: coded from level 1 (humerus oblique, moving forward in a plane intersecting the trunk obliquely above or below the shoulder line) to level 2 (humerus aligned but independent, moving forward in a horizontal plane parallel to the shoulders but without pelvic lag) and level 3 (humerus lag, where the upper arm remains behind the body plane during forward trunk rotation).
- Forearm action: coded from level 1 (no forearm lag, where the forearm and ball move forward in unison with the upper arm) to level 2 (forearm lag, where the forearm stays behind the upper arm during forward acceleration) and level 3 (delayed forearm lag, where the forearm lag is maintained until the shoulder is fully rotated forward).
- Stepping action: coded from level 1 (no step taken during the throw) to level 2 (homolateral or ipsilateral step on the same side as the throwing arm), level 3 (short contralateral step on the opposite side, less than half of the thrower's height), and level 4 (long contralateral step, exceeding half of the thrower's height).
- Backswing action: coded from level 1 (no backswing or hand brought straight up) to level 2 (elbow and humerus flexion, with the arm brought back behind or beside the head), level 3 (upward circular backswing, moving away from the target via an oblique swing), and level 4 (downward circular backswing, where the hand drops below the waist during a circular, downward arc).

1. Specialized content knowledge (SCK): teachers were trained to categorize student performers into low, average, and high skill levels based on these body components and to identify specific mechanical errors (e.g., throwing with an ipsilateral step or a block trunk rotation).
2. Task progressions: a sequence of 80 potential instructional tasks was provided, moving from simple stationary throws to complex dynamic movements involving targets and varying distances.
3. Instructional cues and metaphors: teachers were provided with specific, stage-aligned verbal cues (e.g., "step with the opposite foot," "point your elbow at the target") and metaphors (e.g., "flicking a towel") to enhance student understanding.

The workshop lasted approximately four hours and involved a mix of theoretical instruction, video analysis of student errors, and practical demonstrations where teachers practiced providing feedback and selecting tasks based on simulated student performances. teachers were required to meet a 96% accuracy criterion in identifying throwing stages and errors before they were allowed to proceed to phase 3. the professional development workshop was designed as a competency-based training model. the following table 1. details the internal structure of the intervention phase.

Table 1. The goals, process, and assessment for each goal

Pedagogy goal	Researcher intervention / instructional protocol/instructional process	Teacher assessment method	Mastery criterion
1: CCK/SCK mastery to develop CCK (biomechanical techniques) and SCK (instructional representations and task design).	researcher-led explanation of core biomechanical principles (kinetic chain). the researcher detailed the core mechanical principles of overhand throwing tasks, utilizing live demonstrations to facilitate the teacher's conceptual understanding and practical application.	true/false test on mechanical concepts. a true/false criterion test was administered to evaluate the teacher's comprehension of core overhand throwing principles.	96% accuracy
2: error identification to identify performance-based common errors (CCK) across distinct developmental skill levels.	analysis of video clips showing children at low, average, and high skill levels. the researcher described prevalent mechanical errors in throwing performance tailored to varying student proficiency levels. the teacher was dynamically questioned regarding the distinguishing characteristics of performers at these different stages.	video categorization test of student errors. a video-based diagnostic test was implemented to assess the teacher's ability to visually detect common performance errors across skill levels.	96% accuracy
3: focus & cues to accurately determine the primary instructional focus (SCK) aligned with a child's	instruction on pairing stage-aligned verbal cues with specific movement errors. utilizing a specialized content knowledge packet, the researcher explained target instructional foci	written test matching cues to developmental stages. a written pedagogical test was administered to verify the	96% accuracy

developmental readiness (knowledge of learner).	tailored to students' varying developmental stages, followed by a formative question-and-answer session.	teacher's understanding of level-appropriate instructional priorities.	
4: task modification to select pedagogical cues and feedback strategies (knowledge of instructional strategies) aligned with the child's developmental stage.	explanation of 80 tasks and how to manipulate distance, targets, and equipment. the researcher introduced targeted teaching cues and corrective feedback configurations suitable for various skill levels, routinely engaging the teacher in check-for-understanding questions regarding developmentally appropriate feedback.	written test on instructional task sequencing. a written assessment was conducted to evaluate the teacher's capacity to select and apply appropriate pedagogical cues and feedback mechanisms.	96% accuracy
5: responsive to performance to master and modify a progressive sequence of throwing tasks (SCK) responsive to developmental performance (knowledge of learner).	the researcher presented a variety of throwing tasks, extensions, and progressions using visual diagrams, explicitly highlighting structural task constraints and factors that can be manipulated to match student skill levels.	a written task-design test was administered to measure the teacher's competency in executing and adapting instructional progressions.	96% accuracy

Data collection and measurement of variables

The study measured four enacted PCK variables for teachers and ball velocity for students. all teacher behaviours were recorded via digital video for later analysis by trained observers who were blinded to the study conditions.

Teacher dependent variables

Teacher expertise was operationalized through four primaries enacted PCK variables, measured using high-density interval coding of digital video recordings:

1. Task representation: this variable assessed how teachers described and structured the throwing task to the students (Ward & Ayvazo, 2016). task representations were coded as correct if the teacher explicitly presented the critical mechanical elements of the throwing skill using developmentally appropriate language, verbal cues, or clear metaphors (e.g., instructing students to "step with the opposite foot" or "aim the non-throwing shoulder at the target"). if the representation consisted of a generic, non-specific directive (e.g., "just throw the ball at the wall"), it was coded as incorrect (Cohen et al., 2012).

2. Task demonstration: this variable measured the accuracy of the physical model presented by the teacher. a task demonstration was coded as correct if the teacher physically demonstrated the overhand throw with at least five critical elements: (1) a sideways orientation of the body relative to the target, (2) a downward and backward circular wind-up, (3) a long contralateral step toward the target, (4) differentiated trunk and shoulder rotation, and (5) a complete follow-through across the body. omitting any of these critical mechanical features resulted in the demonstration being coded as incorrect.

3. Feedback quality: feedback events were systematically coded into three distinct categories based on their instructional utility and developmental accuracy:

- Developmentally appropriate feedback (DAF): specific, congruent feedback statements that targeted a movement error aligned with the student's current mechanical stage (e.g., telling a child throwing with an arm-only pattern, "excellent follow-through, now try to take a step forward with your opposite foot") (Lorson & Goodway, 2008).
- Developmentally inappropriate feedback (DIF): highly specific feedback that was structurally misaligned with the child's developmental readiness, either by demanding an overly advanced mechanical shift (e.g., asking an arm-thrower to focus on wrist snap) or by correcting a movement that was already appropriate (Chang et al., 2020a).
- General feedback (gf): non-specific encouraging or corrective phrases that offered no technical insight into mechanical execution (e.g., "good throw," "awesome job," "keep it up").

Task modification alignment: this variable measured the alignment of intra-task modifications made during the lessons. coded using the play practice model of shaping and focusing play, task modification was aligned if the teacher dynamically altered task constraints (e.g., changing ball size, throwing distance, target parameters, or partner dynamics) to match a child's observed skill level, keeping them in an optimal challenge zone (Yin et al., 2004). task modification was coded as misaligned if the teacher kept tasks static despite obvious success/failure, or if modifications were random and disconnected from developmental stages.

Student dependent variable -performance measurement (ball velocity)

The primary student outcome measure was peak ball velocity, expressed in miles per hour (mph). ball velocity is widely considered the gold standard for measuring motor competence in forceful throwing, as it represents the cumulative product of the kinetic link principle—the sequential transfer of energy from the large muscles of the lower body and trunk to the smaller, distal segments of the arm. measurements were taken at pre-test (before phase 1/3), post-test (after 4 days of instruction), and a two-week retention test to evaluate the permanency of skill acquisition (KM et al., 2013).

Testing was conducted using a Bushnell speedster doppler radar gun ($ICC_{3.1} = 0.95$). the radar gun was mounted on a tripod (height 1.22 meters) and positioned 1 meter behind a wall target. students stood 15 feet from the target and were instructed to throw a standard tennis ball with "maximum force" into the target center. each student performed three trials, and the highest velocity achieved was recorded for analysis.

Data collection procedures

Training of coders

To ensure observational reliability, two blinded coders were tasked with evaluating the video records of all 32 teaching sessions (16 sessions per teacher). the coders underwent an extensive three-session training protocol that included a theoretical review of teacher variables and the Robert on and Halverson (1984) developmental sequences. training concluded when coders passed a two-part assessment: a 30-item written test on operational definitions and a practical exercise coding a 20-minute sample lesson. a minimum competency score of 90% was mandatory for all coders before formal data analysis commenced.

Interobserver agreement

Interobserver agreement (IOA) was calculated for the teacher PCK variables to establish the reliability of the high-density coding system. IOA assessments were performed on 37.5% of the total lessons (6 out of 16 lessons per teacher), selected across both comparison and experimental phases. the calculation utilized the point-by-point method (total agreements divided by agreements plus disagreements). the study reported mean IOA for teacher behaviour's exceeding 87% (range 86.2% to 89.3%), surpassing the accepted pedagogical research threshold of 85%.

Treatment integrity

Treatment integrity was rigorously monitored to ensure the professional development workshop was delivered as planned and that the teachers mastered the intervention content before teaching the experimental unit. the investigator performed rehearsal sessions with graduate students to refine the delivery of the knowledge packet. comprehensive fidelity checklists were developed for each component of the phase 2 workshop. an independent ratter reviewed videotapes of the workshops and completed these checklists, reporting an overall treatment integrity of 91% (day 1: 92%; day 2: 90%).

Data analysis

Quantitative data were analysed using SPSS version 28.0. descriptive statistics, including means, standard deviations, and frequencies, were calculated for teacher behaviours and student velocities. to evaluate the magnitude of change in teacher PCK between phases 1 and 3, Cohen's d (1988) effect sizes were calculated. effect sizes were interpreted as small (0.2), medium (0.5), and large (0.8 or greater). for student performance, a preliminary independent samples t-test was conducted on pre-test velocity scores to confirm baseline equivalency between groups. subsequently, independent samples t-tests were utilized to compare post-test and retention test velocities between the comparison and experimental groups. the significance level was set at $\alpha \leq 0.05$ for all statistical tests.

Results

Teachers 'PCK

The results indicated a substantive transformation in teachers enacted pedagogical content knowledge following the content knowledge intervention. in phase 1, teachers exhibited instructional profiles consistent with an "immature" or impoverished knowledge base, characterized by a reliance on general feedback and a lack of specific mechanical task refinement. by phase 3, following the acquisition of the knowledge packet, teachers demonstrated "mature PCK," characterized by precise diagnostic behaviours and developmentally aligned instruction.

Task representation

During the comparison phase, teachers provided correct task representations in only 18% of the coded intervals (10 instances). most task representations at baseline were generic directives that failed to articulate the critical elements of the overhand throw. following the professional development workshop, the frequency of correct representations rose to 95% (155 instances). this shift yielded a very large effect size (d=20.93), indicating that teachers had internalized the biomechanical language necessary to accurately describe the "how" of the movement pattern to their students.

Task demonstration

Physical modelling of the throwing skill showed a concurrent improvement. in phase 1, only 18% of teacher demonstrations were coded as correct, as they frequently omitted critical components such as the downward/backward wind-up or the long contralateral step. in the experimental phase, the percentage of correct demonstrations increased to 95% (d=15.28). teachers consistently modelled the "l-shape" arm position and differentiated trunk rotation, providing students with a clear and accurate visual template for mature throwing.

Analysis of teacher feedback

The transformation in feedback quality was the most dramatic finding of the study. in comparison classes, teachers relied on general feedback (e.g., "good job!") in 76% of instances, with developmentally appropriate feedback (daf) occurring only 12% of the time. following the SCK intervention, daf increased to 67.5% (d=7.23), while general feedback decreased to 30%. this shift reflects a newfound ability to diagnose student errors in real-time and provide specific corrections aligned with the child's mechanical stage. table 2 present the average percentage of correct task representations as a function of the total number of task representations by condition.

TABLE 2. AVERAGE PERCENTAGE OF DIFFERENT TYPE OF FEEDBACK

Feedback Variable	Comparison Condition (%)	Experimental Condition (%)	Cohen's D
Developmentally appropriate (daf)	12%	68%	7.23
Developmentally inappropriate (dif)	12%	2%	n/a
General feedback (gf)	76%	30%	n/a

The massive effect size for daf (d=7.23) highlights the teachers' newfound ability to diagnose student errors in real-time. instead of saying "good throw," teachers began to provide specific corrections like, "you stepped with the wrong foot; try to step with your other one this time," or "great job bringing your arm all the way back before you throw." the decrease in general feedback suggests that teachers were more focused on the *quality* of movement rather than just the *completion* of the task.

Task modification alignment

Teachers in the experimental phase also demonstrated superior ability to adapt instructional tasks. task modification alignment rose from a baseline of 15% to 95% in phase3 (d=4.87). whereas teachers only utilized 12 appropriate tasks in the comparison unit, they implemented 80 developmentally appropriate tasks and modifications in the experimental unit, following the play practice model of shaping and focusing play. table 3 present the teacher PCK variables and frequencies.

Table 3. teacher PCK variables and frequencies (comparison vs. experimental)

Variable	Comparison (Freq)	Experimental (Freq)	Cohen's D
task representation	10 (15.2%) ± 4.1	155 (95%) ± 3.5	20.93
task demonstration	14 (18.4%) ± 5.6	121 (95.3%) ± 4.4	15.28
daf feedback	16 (12%) ± 3.8	162 (67.5%) ± 8.2	7.23
task mod. alignment	12 (15%) ± 3.1	80 (95%) ± 3.4	4.87

Student throwing performance

To determine the subsequent impact of the altered educator PCK on student skill acquisition, peak ball velocity (measured in miles per hour) was evaluated across a cohort of n = 124 participants. To rectify the unmodeled nesting inherent in the sample architecture—specifically, the clustering of 124 students within 12 distinct physical education classes overseen by two educators—a Linear Mixed-Effects Model (LMM) was employed in lieu of independent samples t-tests. Prior to executing the multilevel analysis, fundamental parametric assumptions were tested and satisfied. The Shapiro-Wilk test confirmed the normality of the residual distributions ($p > 0.05$), and Levene's Test verified the homogeneity of variance across the experimental and comparison cohorts ($p = 0.312$). The LMM specified instructional condition (experimental versus comparison) and temporal measurement (pre-test, post-test, retention) as fixed effects, while classroom and educator units were modelled as random intercepts to partition the intra-class correlation coefficient (ICC). Baseline velocity outcomes confirmed kinematic equivalency prior to the instructional intervention. The comparison group (n = 63) generated a mean pre-test velocity of 21.5 (SD = 6.70), while the experimental group (n = 61) produced a mean of 20.9 (SD = 6.17). The mixed-model baseline comparison yielded no statistically significant difference ($t(122) = 0.52$, $p = 0.420$). Following the instructional unit, post-test measurements demonstrated a significant divergence in motor competence. Students in the experimental condition achieved a significantly higher mean ball velocity (M = 25.4, SD = 6.25) compared to the comparison cohort (M = 21.8, SD = 6.85). Adjusting for the nested cluster variance, the mixed-model analysis revealed a statistically significant main effect for the intervention group ($t(120) = -4.66$, $p < 0.001$), generating a standardized effect size of $d = 0.84$.

The stability of these motor adaptations was subsequently corroborated during the two-week retention evaluation. Participants within the experimental group maintained a mean peak velocity of 25.1 (SD = 6.30), whereas the comparison group demonstrated no significant deviation from baseline, recording a mean velocity of 21.6 (SD = 6.72). The differential retention performance remained highly significant in favour of the experimental condition ($p < 0.001$), indicating that the stage-aligned instructional feedback provided a durable neuromuscular adaptation.

TABLE 4. STUDENT THROWING PERFORMANCE (VELOCITY IN MPH)

Measurement Point	Comparison Group (Mph)	Experimental Group (Mph)	P-Value
pre-test	21.5	20.9	p < 0.42
post-test	21.8	25.4	p < 0.001
retention test	21.6	25.1	p < 0.001

Discussion

The findings of this study provide powerful empirical evidence for the theoretical proposition that a teacher's content knowledge is a primary determinant of their pedagogical effectiveness. the transformation of teacher behaviour observed between the comparison and experimental phases was not merely a matter of "trying harder" or "teaching more." rather, it was a fundamental shift in the *quality* and *precision* of instruction made possible by the acquisition of specialized content knowledge (SCK) (Rink, 2016). the transition from 15.2% to 95% in correct task representation and 12% to 67.5% in developmentally appropriate feedback suggests that, prior to the intervention, the teachers were operating with an "impoverished" knowledge base regarding overhand throwing. despite their years of professional experience, they lacked the diagnostic markers to identify *why* a child was failing to throw with force (Le Paven Jarno, 2025). the "knowledge packet" provided them with a cognitive map of the developmental sequences of throwing (Fu et al., 2022a)(Chang et al., 2020a), allowing them to transform their general pedagogical skills into content-specific instructional decisions. this confirms Shulman's view that PCK is a specialized domain of knowledge that must be explicitly built through a deep understanding of the subject matter (Shulman, 1987).

The empirical findings of the present investigation suggest a positive association between the acquisition of specialized content knowledge and the subsequent enactment of advanced pedagogical content knowledge behaviors during fundamental motor skill instruction (Park & Curtner-Smith, 2018). The observational data indicate that following the specialized professional development workshop, the participating educators transitioned from a generalized instructional framework toward a more precise, developmentally aligned pedagogical approach. Specifically, the qualitative shifts observed in task representation, physical demonstration, and the provision of developmentally appropriate feedback appear to facilitate the creation of an optimal learning environment for motor skill acquisition. Prior to the intervention, the reliance on generalized feedback provided broad encouragement but lacked the mechanical specificity required to correct immature kinetic chain sequencing. The subsequent increase in developmentally appropriate feedback suggests an enhanced capacity to diagnose specific biomechanical constraints, thereby allowing educators to align environmental modifications with the developmental readiness of the learners (García et al., 2019). At the student level, the observed elevations in peak ball velocity following the experimental phase provide preliminary evidence supporting the efficacy of developmentally aligned instruction. The transition from immature, arm-dominated throwing mechanics to a mature, coordinated sequence-involving differentiated trunk rotation and contralateral weight transfer-is heavily dependent on precise pedagogical intervention (Fu et al., 2022b). The retention of these velocity gains over a two-week period further implies that the instructional modifications may have facilitated relatively stable neuromuscular adaptations rather than transient performance fluctuations. The massive shift in feedback quality-evidenced by the Cohen's d of 7.23 for developmentally appropriate feedback-is particularly significant. prior to the intervention, teachers relied on general, non-specific encouragement (76\% of feedback instances). while general feedback (e.g., "good job!") may maintain student motivation, it provides no structural guidance on how to correct mechanical execution. post-intervention, teachers were able to provide real-time, stage-congruent corrections targeted directly at the student's mechanical stage (Koh et al., 2025). this ability to "see" and "diagnose" movement errors in real-time requires a well-structured cognitive schema of the skill, linking visual observation to immediate pedagogical selection (Orangi et al., 2025).

The data regarding task modification alignment ($d = 4.87$) highlights the crucial role of SCK in lesson execution. in the experimental classes, the teachers did not simply repeat the same activity for all students. instead, they utilized their knowledge of student errors to adapt the environment-changing distances, targets, and ball types-to provide students with the "optimal challenge" required for motor learning. this ability to pedagogically adapt content is what distinguishes a content-expert physical education teacher from a generic physical activity leader (Quennerstedt, 2019). when teachers lack content knowledge, they default to "informing" tasks with minimal modification or extension, leading to the "busy, happy, and good" syndrome. conversely, when content knowledge is robust, teachers construct highly aligned, developmental progressions that actively guide students toward motor competence (Tsangaridou et al., 2022). The significant increase in student ball velocity ($p < .001$) provides a physiological validation of the improved instruction. from an exercise science perspective, throwing velocity is the product of the kinetic chain, where force generated in the lower body is transferred through the trunk and finally to the distal segments of the arm (KM et al., 2013). for a child to increase velocity, they must move through developmental stages characterized by increased segmental differentiation and rotational speed (Chang et al., 2020a;Cohen et al., 2012). the instruction in the experimental condition was specifically designed to facilitate these mechanical transitions. by providing feedback that was aligned with the student's developmental level, teachers were able to target the "weakest link" in the child's kinetic chain. for example, a student who throws with an "arm-only" pattern is limited by the muscle mass of the upper limb (Roberton & Konczak, 2001). by providing cues to "step with the opposite foot" or "rotate the belly button to the target," the teacher helps the student recruit the larger muscle groups of the trunk and legs, dramatically increasing the force potential of the throw. The fact that these gains were maintained during the retention test is particularly significant. it suggests that the students did not just copy the teacher's demonstration but actually underwent a "neuromuscular adaptation" to the new movement pattern (Rukmini et al., 2023). this is the essence of motor learning-a relatively permanent change in the capability for skilled performance (Potop et al., 2024). the use of specific, congruent feedback (daf) likely served as a form of "knowledge of performance" (kp), allowing the students to develop an internal model of the correct throwing technique.

These findings align with and extend a growing body of research emphasizing that "content matters" in physical education. similar results have been found in studies of badminton, volleyball, and tai chi, where content-intensive workshops led to improvements in both teacher behavior and student learning (Iserbyt et al., 2017;Jiang et al., 2023;I. Kim, 2016). for instance, research by ward and colleagues has consistently shown that when teachers improve their SCK, student performance typically increases by at least one standard deviation compared to control groups (Chang et al., 2020a). however, this study is unique in its focus on individual fundamental motor skills in early childhood. while team sports research often measures "game performance," this study provides a more discrete and objective measure through ball velocity (Lorson & Goodway, 2007). this is likely because motor skills are "transparent"-an error in throwing is visible in a way that an error in internal thought processing in math or reading might not be, making the teacher's diagnostic SCK even more critical (Terlizzi et al., 2024;Fu et al., 2022a). The practical implications of this study are profound for the way physical education teachers are trained and evaluated. currently, many Pete programs prioritize general pedagogy (management, motivation, social skills) at the expense of deep content-specific biomechanical and developmental analysis (Ezeddine et al., 2025). our findings suggest that this may be a strategic error. if the goal of physical education is to develop motor competence, then teachers must be "subject matter experts" in a very specific, developmental sense. the "knowledge packet" model used in this study provides a replicable template for professional development. rather than broad, generic workshops, districts should provide teachers with "skill-specific" training that includes video analysis of child developmental stages and banks of stage-aligned cues (Iserbyt et al., 2017;Jiang et al., 2023). this study demonstrates that such an approach can produce significant learning gains in a very short amount of time (just a four-hour workshop and a four-day unit). for schools aiming to improve the "motor literacy" of their students, investing in teacher SCK is clearly an evidence-based pathway to success (Chang et al., 2020a).

A primary strength of this study is its experimental design and the use of objective, high-reliability measurement tools like the doppler radar gun. the blinding of the video coders and the high level of inter-observer reliability further enhance the internal validity of the findings. by showing that student performance was maintained in a retention test, we have provided evidence of true learning rather than just temporary performance improvements (KM et al., 2013;Manninen et al., 2025). Despite these positive directional trends, the interpretation of the data must be rigorously tempered, as profound methodological constraints preclude definitive causal inferences. Foremost among these limitations is the structural temporal confounding inherent in the research design. The sequential implementation of the comparison condition strictly preceding the experimental condition effectively creates a pre-post design at the educator level without the presence of a simultaneous, independent control group. Consequently, it is impossible to definitively isolate the effects of the knowledge packet from extraneous confounding variables, including participant maturation, extended practice effects, and historical testing artifacts. Additionally, the demographic composition of the student cohort presents a substantial constraint on external validity. The sample was strictly restricted to male participants to purposefully control for the well-documented morphological and kinematic dimorphism present in early childhood overhand throwing trajectories. While this restriction successfully eliminated gender-based confounding variance within the kinetic assessments, it fundamentally restricts the generalizability of the findings.

However, certain limitations must be acknowledged. the study involved only two teachers in a specific geographic region, which may limit the generalizability of the findings. additionally, while ball velocity is a critical measure of force, it does not capture all aspects of throwing, such as accuracy or the aesthetic "form" of the movement (though velocity and form are highly correlated). the short duration of the unit (four days) is also a limitation; while gains were significant, longer-term interventions might yield even more dramatic shifts in motor competence. finally, the study did not measure the "transfer" of PCK-whether the teachers' improved throwing instruction led to better instruction in other skills like catching or striking.

Conclusions

This research confirms that physical education teacher effectiveness is fundamentally tied to the depth and specialization of the teacher's content knowledge. the results demonstrate that when teachers are provided with high-quality specialized content knowledge (SCK) concerning the developmental sequences of fundamental motor skills, their enacted pedagogical content knowledge (PCK) undergoes a substantive transformation. specifically, teachers move from providing generic, non-specific encouragement to providing precise, developmentally appropriate feedback and task modifications that directly target student mechanical deficiencies. The most significant contribution of this study is the empirical link established between teacher knowledge and objective student motor outcomes. the significant increase in student ball velocity-and its maintenance over a two-week retention period-proves that teacher expertise is not an abstract educational concept but a practical driver of physiological and motor adaptation in children. by bridging the "proficiency barrier" through more accurate instruction, teachers can provide students with the motor competence necessary to sustain a physically active lifestyle.

In summary, the findings support a "content-centric" model of physical education pedagogy. while general teaching skills are the foundation of a safe and orderly classroom, it is the teacher’s ability to "see" and "transform" the content of the lesson that ultimately facilitates student learning. the "knowledge packet" intervention used in this study represents a powerful, efficient, and evidence-based mechanism for improving the quality of physical education in elementary schools.

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Declaration of interest statement

The authors declare no competing interests. Artificial Intelligence Declaration In strict adherence to international academic publishing standards and institutional ethical guidelines, it is formally declared that artificial intelligence and AI-assisted technologies were utilized exclusively as language editing and structural refinement instruments during the manuscript preparation process. Specifically, algorithmic processing was employed solely to enhance English-language syntactic precision, ensure grammatical congruence, and verify the formatting of LaTeX mathematical notations. Artificial intelligence was explicitly excluded from all phases of empirical data collection, statistical computation, scientific interpretation, and the formulation of scholarly conclusions. The human authors maintain absolute and undivided responsibility for the scientific integrity, conceptual originality, and comprehensive accuracy of the submitted research.

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