



A Theoretical Framework of Embodied Motivational Regulation in Physical Education: Linking Chronotype, Movement Experience and Adaptive Learning

Xu Haoran¹ Zhang Ke¹ Yao Bingbing¹ Zan Xiaoyi¹ Zheng Zhaoyu^{1*}

¹ SEGi University, Petaling Jaya, Selangor, 47810, Malaysia

Corresponding Authors*: Zheng Zhaoyu Email: Hhgj.group@gmail.com

ARTICLE INFO

Keywords

Chronotype
Embodied movement experience
Motivational regulation
Adaptive learning
Physical education

Published

01 September 2026

ABSTRACT

This conceptual article develops a theoretical framework of embodied motivational regulation to explain adaptive learning within school physical education. Integrating chronobiology, embodied cognition, motivation regulation, and adaptive learning theories, the study constructs a serial mediation model: chronotype serves as the distal predictor, sequentially shaping embodied movement experience and motivational regulation to influence students' adaptive learning. Lesson timing and movement task complexity act as moderators that adjust the strength of these pathways. Testable theoretical propositions are proposed. The framework complements dominant social-cognitive motivation theories by introducing a biological embodied perspective. It offers practical student-centred strategies for physical education teachers and curriculum designers, and provides clear directions for subsequent empirical verification and cross-cultural research.

1. Introduction

Physical education (PE) occupies a unique position within school education, tasked with fostering students' motor competence, sustained movement engagement, and adaptive learning behaviours across formal curricula (Faella et al., 2025). Student motivation represents the core driver of persistent participation in movement activities, yet widespread heterogeneity in engagement persists within identical PE classroom environments. A growing body of scholarship confirms that many adolescents exhibit disengagement, low intrinsic motivation, and early dropout from physical activity, even when standard motivational support strategies are implemented by teachers (Gomes et al., 2022). Traditional motivational theories applied to PE, such as self-

Citation: Xu, H., Zhang, K., Yao, B., Zan, X., & Zheng, Z. (2026). A theoretical framework of embodied motivational regulation in physical education: Linking chronotype, movement experience and adaptive learning. *Journal of Adaptive Learning and Psychological Growth*, 1(2), 1-13.

3154-7915/© The Authors. Published by J&L Academic Group PLT. This is an open access article under the CC BY 4.0 license.
<https://doi.org/10.64744/jalpg.2026.264>.

determination theory, predominantly prioritise social-psychological antecedents of motivation, including teacher autonomy support, peer relatedness, and perceived competence, while largely overlooking biologically rooted individual differences that shape how learners perceive and respond to movement contexts (Standage et al., 2021).

Individual chronotype—stable circadian preference categorised as morning-type, intermediate-type, and evening-type—determines endogenous fluctuations in arousal, affective states, and physical readiness throughout the day (Horne & Östberg, 1976). Recent chronobiological research within sport and education demonstrates that chronotype moderates exercise affect, motor performance, and cognitive engagement: morning-type learners tend to achieve optimal physical alertness in early sessions, whereas evening-type individuals display attenuated engagement and higher fatigue when participating in movement activities during morning timetabled PE (Facer-Childs et al., 2025; Kumar et al., 2026). To date, existing investigations in this domain focus predominantly on observable fitness outcomes or academic test performance, with limited attention to how circadian profiles shape the subjective, lived experience of movement within PE classrooms (Smith et al., 2026).

Embodiment perspectives offer a promising lens to address this limitation. Embodied motivation theory posits that motivational states do not exist purely as abstract mental constructs; instead, motivation emerges dynamically from the reciprocal interaction among bodily sensations, movement experience, and environmental input (Niedenthal, 2007). In PE contexts, movement experiences constitute embodied affective cues that strengthen or undermine motivational regulation processes (Lambert et al., 2022). Despite the theoretical compatibility between chronobiology and embodied learning frameworks, two critical gaps remain within physical education scholarship. First, few studies integrate chronotype into embodied motivational models, neglecting how internal circadian rhythms precondition students' sensory and emotional responses to physical tasks. Second, current research fails to articulate a systematic mechanism connecting circadian preference, embodied movement experience, motivational regulation, and adaptive learning behaviour in school PE settings. Adaptive learning in PE refers to learners' capacity to adjust effort, task strategies, and engagement patterns in response to movement challenges; this outcome remains understudied through both chronobiological and embodied theoretical lenses (Boekaerts, 2006).

The absence of an integrated theoretical framework creates a notable disconnect between research and pedagogical practice. Contemporary PE pedagogy increasingly advocates personalised, student-centred instruction, yet educators lack a theoretically grounded model to understand why uniform instructional approaches generate divergent motivational outcomes for learners with different circadian profiles. Without a structured conceptual model, researchers cannot generate testable propositions to guide subsequent empirical inquiry into chronotype-aligned movement pedagogy.

This conceptual article aims to fill these gaps by developing a theoretical framework of embodied motivational regulation in physical education. The framework articulates the sequential relational pathways linking chronotype, embodied movement experience, motivational regulation strategies, and adaptive learning behaviours, while identifying classroom contextual factors that moderate these associations. Three core research questions guide this theoretical construction:

1. How does chronotype shape students' embodied affective and sensory experiences during

physical education tasks?

2. Through what mechanisms do embodied movement experiences mediate the association between chronotype and motivational regulation in PE?

3. What boundary conditions moderate the proposed pathway from chronotype to adaptive learning via embodied motivational processes?

This work makes two primary theoretical contributions. First, it bridges chronobiology, embodied cognition, and sport motivational theory to advance an integrated model tailored for physical education, extending existing motivation frameworks by incorporating stable biological individual differences. Second, the framework generates a set of formal theoretical propositions that can be systematically examined via quantitative and qualitative empirical designs in future research. Practically, this model provides PE educators with a holistic perspective to interpret heterogeneous student engagement, informing the design of differentiated movement tasks that align with learners' circadian rhythms and embodied needs.

The remainder of this paper proceeds as follows. First, the theoretical foundations of chronotype, embodied motivation, and adaptive learning are synthesised. Next, the integrated conceptual framework is elaborated, alongside formal theoretical propositions. Following this, theoretical, pedagogical, and research implications are discussed, and limitations of the conceptual model and avenues for future scholarship are outlined.

2. Theoretical Foundations

2.1 Chronotype: Circadian Preference and Bodily Arousal Variability

Chronotype describes stable, interindividual differences in circadian phase preference, representing enduring patterns of biological arousal regulated by the endogenous circadian clock (Horne & Östberg, 1976). The classic three-category framework distinguishes morning-type (lark), intermediate-type, and evening-type (owl) individuals. Morning-type learners exhibit peak physiological activation early in the daytime, with gradual declines in alertness, affective valence, and physical stamina as the day progresses. By contrast, evening-type individuals experience slow arousal in the morning and reach optimal physical and cognitive capacity in the afternoon and evening (Facer-Childs et al., 2025). Intermediate-type learners display greater flexibility and weaker time-of-day fluctuations relative to the two extreme profiles.

Scholars have increasingly recognised chronotype as more than a sleep schedule preference; it systematically shapes bodily states that underpin movement engagement. In youth populations, evening chronotype is associated with higher perceived exertion, greater negative affect, and reduced motor task performance during morning physical activity sessions (Gomes et al., 2022). Although existing chronobiological research in sport frequently targets athletic fitness outcomes, most work overlooks subjective experiential dimensions central to educational contexts. Kumar and Srivastava (2026) noted that chronotype effects are not limited to measurable physical capacity; circadian rhythms alter sensory sensitivity, fatigue perception, and emotional reactions during movement. These bodily fluctuations form the foundational premise of the present framework: chronotype establishes a baseline physiological context that conditions how students interpret movement tasks within physical education (PE).

2.2 Embodied Motivation Theory: Movement as a Bodily Source of Motivational States

Traditional motivational frameworks dominant in PE research, such as self-determination theory, frame motivation as a cognitive-social construct shaped by interpersonal feedback, competence judgements, and psychological need satisfaction (Standage et al., 2021). While valuable, these approaches tend to separate mind and body, treating bodily experience as a secondary outcome rather than an active origin of motivation. Embodied motivation theory resolves this limitation by asserting that motivation arises from dynamic interactions among physical sensations, bodily movement, and environmental stimuli (Niedenthal, 2007). From this perspective, cognitive appraisals of movement cannot be decoupled from physical feelings of tension, comfort, exhaustion, or flow experienced during activity.

Within PE scholarship, Lambert et al. (2022) emphasised that embodied perspectives shift analytical focus toward students' lived, sensory movement experiences. Positive embodied experiences—such as fluid movement, physical enjoyment, and controlled exertion—support adaptive forms of motivational regulation. Unpleasant embodied experiences, including persistent fatigue, coordination frustration, and bodily discomfort, foster disengagement, avoidance, and maladaptive motivational strategies. Embodied motivation theory provides a critical mediating mechanism for the current model: chronotype-driven differences in baseline arousal do not directly predict learning outcomes. Instead, circadian rhythms shape embodied movement experiences, which subsequently guide students' motivational regulation processes.

2.3 Adaptive Learning in Physical Education

Adaptive learning originally emerged within general educational psychology to describe learners' capacity to flexibly adjust strategies, effort allocation, and behavioural engagement in response to evolving task demands (Boekaerts, 2006). Despite widespread application in classroom academic research, the construct remains undertheorised within PE. In movement settings, adaptive learning encompasses students' ability to persist amid motor challenges, modify movement tactics, regulate perceived fatigue, and sustain engagement when facing difficulty.

Much of the existing adaptive learning literature concentrates on cognitive learning environments, neglecting the physical, embodied nature of PE tasks. Students demonstrating adaptive learning behaviours do not merely complete motor drills; they continuously interpret bodily feedback and adjust participation patterns according to internal physical states and external task constraints (Faella et al., 2025). To date, few studies have explored how biological individual differences (e.g., chronotype) interact with embodied movement experience to predict adaptive learning. This gap creates a critical theoretical void: researchers lack a coherent model explaining why students exposed to identical PE curricula demonstrate divergent adaptive learning trajectories.

2.4 Synthesising Theoretical Limitations: The Rationale for an Integrated Framework

Collectively, the three theoretical domains outlined above reveal three interconnected gaps. First, chronobiology research in sport focuses largely on objective performance metrics and rarely links circadian profiles to motivational and learning processes in school PE. Second, embodied motivation research has not incorporated stable biological preconditions such as chronotype to explain variability in movement experiences across learners. Third, adaptive learning theories within education have not been fully extended to embodied, physical activity contexts, failing to account for circadian bodily variation.

No existing conceptual model integrates chronotype, embodied movement experience, motivational regulation, and adaptive learning into a unified structure for PE pedagogy. This fragmentation inhibits the development of personalised movement education theory and restricts the generation of testable hypotheses. Building upon these foundational literatures, the next section constructs an integrated theoretical framework that bridges chronobiology, embodied cognition, and motivational science to explain differential student engagement in physical education.

3. Development of the Conceptual Framework

3.1 Definition of Core Constructs Within the Framework

Drawing on the theoretical foundations outlined in Section 2, this section operationalises each construct embedded within the proposed theoretical model, tailored specifically to school physical education (PE) contexts. Clear construct definition establishes consistent boundaries for the generation of formal theoretical propositions.

Chronotype. Chronotype refers to trait-based circadian preference that shapes endogenous physiological arousal, affective reactivity, and perceived physical energy across the school day (Horne & Östberg, 1976). Consistent with established chronobiological classification, the framework distinguishes morning-type, intermediate-type, and evening-type learners. Critically, chronotype functions as the distal antecedent variable in this model; it represents a stable biological predisposition that sets the baseline bodily condition students bring to PE lessons (Facer-Childs et al., 2025).

Embodied movement experience. Embodied movement experience captures students' holistic sensory, physical, and affective perceptions generated during participation in movement tasks (Lambert et al., 2022). The construct integrates subjective feelings of exertion, motor fluency, bodily comfort, and affective valence arising from physical activity. Unlike objective performance indicators, embodied movement experience reflects the lived bodily interpretation of movement, serving as the primary mediating pathway linking chronotype to motivational processes (Niedenthal, 2007).

Motivational regulation. Motivational regulation describes the cognitive and behavioural strategies learners deploy to sustain or adjust their engagement in movement activities. Adaptive motivational regulation includes self-talk, goal adjustment, and attentional refocusing, whereas maladaptive regulation encompasses avoidance, task disengagement, and withdrawal of effort (Standage et al., 2021). Within this framework, motivational regulation acts as the proximal mediator connecting embodied movement experience to final learning outcomes.

Adaptive learning in physical education. Adaptive learning represents learners' capacity to flexibly adjust effort, movement strategies, and persistence in response to evolving motor challenges within PE (Boekaerts, 2006). In contrast to traditional classroom adaptive learning, PE adaptive learning is inherently embodied: students rely on bodily feedback to make ongoing behavioural adjustments during movement tasks. This construct serves as the primary outcome variable of the model.

Contextual moderators. Two classroom-level boundary conditions are incorporated into the framework: lesson timing (morning versus afternoon PE scheduling) and movement task complexity. These moderators alter the strength of pathways between chronotype, embodied

experience, motivational regulation, and adaptive learning.

3.2 Mechanisms Underpinning the Integrated Model

The proposed framework advances a sequential mediated model with conditional boundary effects. The core logical pathway proceeds as follows: Chronotype establishes baseline physiological arousal → shapes embodied movement experience during PE → predicts the adoption of adaptive or maladaptive motivational regulation strategies → ultimately determines levels of adaptive learning behaviour. Contextual factors moderate each sequential stage of this pathway.

First, chronotype conditions students' embodied movement experience. Morning-type students typically possess higher baseline alertness during morning timetabled PE, generating more positive embodied sensations during movement tasks. By comparison, evening-type students experience lower physiological arousal in early morning sessions, leading to heightened perceptions of fatigue, reduced motor fluency, and negative embodied movement experiences (Gomes et al., 2022). When PE is scheduled in the afternoon, evening-type learners demonstrate improved embodied experience, while morning-type learners may encounter declining physical vitality.

Second, embodied movement experience functions as a critical mediator. Positive embodied sensations (fluid movement, comfort, enjoyment) encourage students to adopt adaptive motivational regulation strategies. Negative embodied experiences (fatigue, coordination frustration, bodily discomfort) promote maladaptive motivational regulation, such as disengagement or task avoidance (Lambert et al., 2022). This mechanism addresses the limitation of dominant motivational theories, which often overlook bodily sensation as a source of motivation.

Third, motivational regulation directly predicts adaptive learning. Students who deploy adaptive motivational strategies maintain persistence, adjust movement approaches, and actively cope with motor difficulties, exhibiting stronger adaptive learning behaviours. In contrast, maladaptive motivational regulation reduces willingness to confront movement challenges and inhibits adaptive learning (Boekaerts, 2006).

Beyond the sequential pathway, lesson timing and task complexity operate as moderators. When movement tasks are highly complex, chronotype-related differences in embodied experience become amplified. Simple, low-demand movement tasks narrow gaps between chronotype groups, as physiological arousal differences exert weaker influence on sensory experience (Kumar & Srivastava, 2026).

3.3 Formal Theoretical Propositions

Based on the above mechanistic reasoning, the following testable propositions are developed to guide future empirical investigation:

Proposition 1. Chronotype predicts embodied movement experience in physical education. Morning-type learners report more positive embodied movement experiences during morning PE lessons, whereas evening-type learners report more positive embodied movement experiences during afternoon PE lessons.

Proposition 2. Embodied movement experience mediates the relationship between chronotype and motivational regulation. Positive embodied movement experiences predict greater use of

adaptive motivational regulation strategies, while negative embodied movement experiences predict greater use of maladaptive motivational regulation strategies.

Proposition 3. Motivational regulation mediates the association between embodied movement experience and adaptive learning. Adaptive motivational regulation positively predicts adaptive learning; maladaptive motivational regulation negatively predicts adaptive learning.

Proposition 4. Lesson timing moderates the direct association between chronotype and embodied movement experience. Chronotype differences in embodied experience are more pronounced in morning PE sessions relative to afternoon PE sessions.

Proposition 5. Movement task complexity moderates the mediated pathway. The sequential indirect effect from chronotype through embodied movement experience and motivational regulation to adaptive learning becomes stronger when movement task complexity is high.

3.4 Visual Model Overview

The conceptual framework forms a serial multiple mediation model with moderators. As illustrated in Figure 1, the structural sequence proceeds from chronotype to embodied movement experience, then to motivational regulation, and finally to adaptive learning in physical education. Lesson timing and movement task complexity are proposed as contextual moderators that condition the strength of the hypothesized pathways.

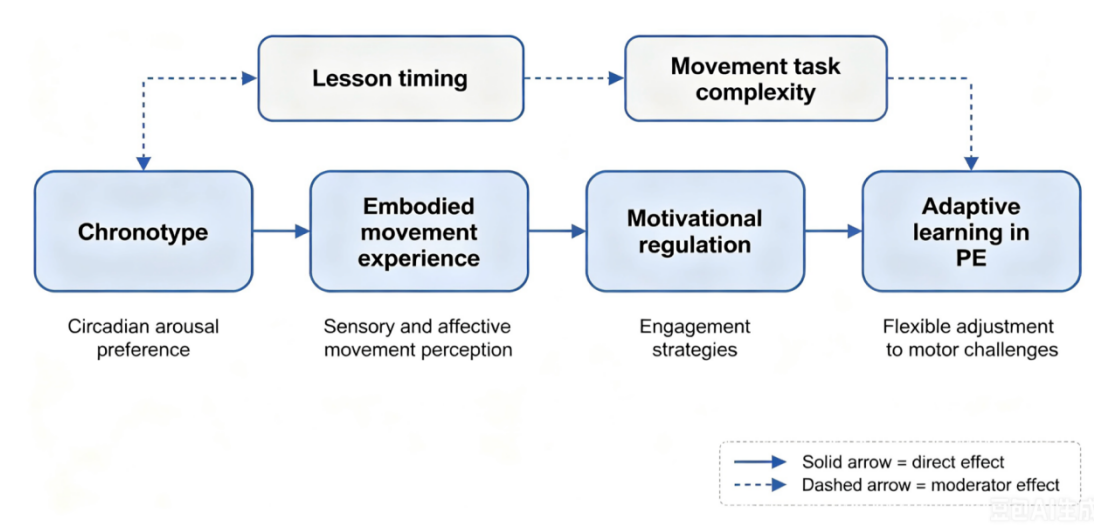


Figure 1. Theoretical framework of embodied motivational regulation in physical education

All propositions can be translated into quantitative structural equation modelling or qualitative longitudinal research designs for subsequent empirical testing.

4. Theoretical Implications

This conceptual framework advances three distinct theoretical contributions to chronobiology, embodied motivation research, and physical education pedagogy. Each contribution addresses critical limitations identified within the literature and extends established theories into integrated, embodied school movement contexts.

First, the framework integrates chronotype into embodied motivation theory, bridging

biological circadian research and embodied cognition scholarship. Embodied motivation perspectives acknowledge that subjective bodily sensations shape motivational states, yet existing models rarely account for stable, trait-based physiological differences that precondition sensory experience (Niedenthal, 2007; Lambert et al., 2022). Prior sport chronobiology research predominantly focused on objective fitness outcomes, overlooking how circadian rhythms alter affective, sensory movement experiences (Facer-Childs et al., 2025). By positioning chronotype as the distal precursor of embodied movement experience, this model establishes a biologically rooted boundary condition for embodiment theory. The analysis moves beyond treating bodily experience as merely a situational product of activity, demonstrating that enduring circadian differences systematically frame how learners interpret identical movement tasks. This extension offers a new lens to explain persistent heterogeneity in student motivation observed within uniform physical education (PE) curricula.

Second, the present work expands adaptive learning theory into embodied, physical activity environments. Adaptive learning scholarship originated within formal classroom cognitive settings, centring on academic problem-solving and strategic self-regulation (Boekaerts, 2006). While recent educational research recognises embodied learning processes, few models translate adaptive learning constructs to PE, where feedback originates primarily from physical sensations rather than textual or cognitive stimuli (Faella et al., 2025). This framework redefines adaptive learning specifically for movement contexts and links it to chronobiological and motivational mechanisms. As such, the study extends the generalisability of adaptive learning theory and establishes a theoretical foundation for subsequent investigations of embodied self-regulation in school physical activity.

Third, the model complements dominant motivational theories widely applied in PE, such as self-determination theory (Standage et al., 2021). Self-determination theory prioritises social environmental factors, including teacher support, peer relationships, and psychological need satisfaction. These social-psychological variables are not rejected within the current framework; instead, the model adds a complementary biological-embodied pathway of motivation. Most existing motivational frameworks in PE adopt a disembodied perspective, treating bodily states as secondary consequences of motivation rather than formative antecedents. By articulating the serial pathway from circadian predispositions through embodied experience to motivational regulation, this framework builds a supplementary explanatory mechanism. It enables future researchers to simultaneously examine social psychological predictors and embodied, chronobiological predictors of student engagement, yielding a more holistic understanding of PE motivation.

Beyond these three core contributions, the formal propositions outlined in Section 3 generate a clear roadmap for cumulative empirical progress. The serial mediation and conditional moderation hypotheses allow researchers to test segmented components of the model or validate the full integrated structure using quantitative and qualitative methodologies. Without this unified framework, chronotype, embodied experience, and adaptive learning have remained isolated research strands, preventing cumulative knowledge development within sport pedagogy (Kumar & Srivastava, 2026). This conceptual work provides a shared theoretical vocabulary to connect these disparate domains of inquiry.

5. Practical Implications for Physical Education

The proposed theoretical framework yields actionable pedagogical implications for physical

education (PE) teachers, curriculum designers, and school administrators. Unlike abstract theoretical models limited to academic discourse, this framework connects circadian chronobiology and embodied motivational processes to day-to-day movement teaching practice, offering evidence-informed strategies to support adaptive learning among diverse student groups.

First, PE educators are encouraged to recognise chronotype heterogeneity as a meaningful source of differential student engagement, rather than attributing uneven participation solely to laziness, low interest, or lack of athletic talent (Facer-Childs et al., 2025). Morning PE sessions typically favour morning-type learners, who experience optimal bodily arousal and positive embodied movement experiences early in the school day. In contrast, evening-type students often report heightened perceived exertion, discomfort, and frustration during morning movement tasks, which erodes motivational regulation and suppresses adaptive learning (Gomes et al., 2022). Teachers can adopt flexible observational strategies to identify recurring patterns of student disengagement, acknowledging that poor performance in morning PE may stem from circadian misalignment instead of insufficient effort.

Second, instructors can differentiate movement tasks to align with students' embodied states and circadian needs. When PE is scheduled in the morning, educators may assign low-to-moderate complexity motor activities for evening-type learners to reduce overwhelming negative embodied sensations. Complex, skill-intensive movement tasks could be reserved for afternoon lessons, where evening-type students achieve higher physiological activation (Kumar & Srivastava, 2026). Such differentiated task design aims to cultivate positive embodied movement experiences, which serve as the pivotal mediator supporting adaptive motivational regulation. This approach advances student-centred PE pedagogy by moving beyond uniform instruction toward embodied, personalised practice (Lambert et al., 2022).

Third, school curriculum planners should reconsider rigid timetabling of PE lessons. Many schools allocate PE to early morning slots without accounting for circadian variation among adolescents, a demographic where evening chronotypes are widely prevalent. Where scheduling flexibility exists, administrators can distribute PE sessions across both morning and afternoon periods to balance advantages for all chronotype groups. For schools unable to adjust timetables, teacher training programmes may integrate chronobiological knowledge to help educators mitigate the negative effects of circadian mismatch within fixed lesson times (Smith et al., 2026).

Fourth, pre-service and in-service PE professional training can incorporate embodied motivation principles. Traditional teacher training prioritises strategies targeting psychological need satisfaction outlined by self-determination theory, with limited attention to bodily, sensory student experience (Standage et al., 2021). Training modules guided by this framework can equip teachers to monitor students' embodied cues—such as visible fatigue, movement hesitancy, and affective responses—and deploy timely motivational regulation support. By responding to embodied feedback, teachers can foster adaptive learning behaviours rather than relying exclusively on verbal encouragement or external rewards.

Finally, the framework offers guidance for assessment reform within PE. Traditional PE evaluation heavily prioritises motor performance outcomes, neglecting the processes of adaptive learning. Drawing on this model, assessment practices can shift toward documenting how students adjust strategies, cope with movement challenges, and regulate their engagement. This process-oriented assessment aligns with the core goal of nurturing sustained, adaptive physical activity

participation beyond formal schooling (Boekaerts, 2006).

6. Limitations and Future Research Agenda

6.1 Limitations of the Conceptual Framework

Although the proposed embodied motivational regulation framework integrates multiple theoretical perspectives and addresses critical research gaps in physical education (PE) pedagogy, several inherent limitations must be acknowledged to ensure transparent scholarly contribution.

First, this study is conceptual and non-empirical in nature. As a theoretical construction paper, it does not include quantitative data, statistical validation, or qualitative thematic evidence to verify the proposed serial mediation and moderation pathways. While formal theoretical propositions are systematically developed, all relationships remain deductive rather than empirically confirmed (Lambert et al., 2022). Therefore, the framework currently serves as a heuristic model rather than a statistically validated structural model.

Second, the framework focuses primarily on adolescent school-based PE contexts and does not account for age-related developmental differences. Chronotype plasticity, embodied sensitivity, and motivational regulation capacities vary significantly across childhood, early adolescence, and young adulthood (Facer-Childs et al., 2025). Adolescents exhibit dramatic circadian phase delays; thus, the model's explanatory power may decrease when applied to child or adult physical activity settings.

Third, the present model excludes social-psychological variables that dominate mainstream PE motivation research, such as teacher autonomy support, peer climate, and perceived competence (Standage et al., 2021). This deliberate simplification enhances theoretical clarity but also creates boundary limitations. In real classroom environments, chronobiological embodied mechanisms inevitably interact with social classroom factors, which the current framework does not incorporate.

Fourth, the framework does not address cross-cultural variability. Most existing chronotype and embodiment studies derive from Western educational contexts. Educational scheduling, PE curriculum structures, and student movement cultures in non-Western societies may alter how chronotype interacts with movement experience (Smith et al., 2026). Accordingly, the model currently lacks cross-cultural generalizability.

6.2 Future Research Directions

To address the above limitations and advance embodied motivation research in PE, this section outlines a structured future research agenda.

6.2.1 Empirical Validation of the Proposed Model

Future quantitative studies can employ structural equation modeling (SEM) to test the serial mediation pathways proposed in this framework. Specifically, researchers may verify whether embodied movement experience and motivational regulation sequentially mediate the chronotype–adaptive learning relationship. Moderation analyses can further examine the conditional effects of lesson timing and task complexity across student groups (Kumar & Srivastava, 2026). Longitudinal designs are particularly encouraged, as cross-sectional data cannot capture dynamic changes in embodied motivation during ongoing PE curriculum participation.

6.2.2 Developmental and Age-Based Extension

Future scholarship may compare chronotype-driven embodied responses across different age cohorts. Investigating children, adolescents, and young adults can clarify developmental differences in how circadian arousal shapes movement perception and motivational adaptation. Such efforts would expand the framework's scope from adolescent PE to broader kinesiology and educational psychology domains.

6.2.3 Integration of Social-Psychological Classroom Variables

Subsequent models may integrate self-determination theory variables (e.g., autonomy support, relatedness) with chronobiological embodied mechanisms. Building hybrid bio-social motivational models can explain both environmental and biological sources of student disengagement, reconciling traditional PE motivation theories with emerging embodied and chronobiological perspectives (Standage et al., 2021).

6.2.4 Cross-Cultural Comparative Research

Given the Western dominance of existing datasets, future studies can test this framework in Asian, Southeast Asian, and other non-Western educational settings. Variations in school timetable structures, cultural attitudes toward physical exertion, and student movement norms may produce distinct embodied motivational patterns (Smith et al., 2026). Cross-cultural validation will enhance the international generalizability of the model.

6.2.5 Qualitative Exploration of Embodied Experience

Quantitative testing cannot fully capture the subjective, sensory, and embodied dimensions of student movement experience. Future qualitative research using phenomenological approaches can explore students' lived bodily experiences across different chronotypes and lesson times, providing in-depth interpretive evidence to complement statistical model testing (Lambert et al., 2022).

6.3 Concluding Research Outlook

Overall, this framework establishes a new bio-embodied motivational paradigm for physical education research. It shifts scholarly focus from purely social-cognitive motivation models toward biologically grounded, body-centred, adaptive learning pedagogy. With continued empirical validation, cross-cultural extension, and developmental refinement, this line of research can generate a new subfield of chrono-pedagogy in physical education.

This conceptual study constructed an integrated theoretical framework of embodied motivational regulation to explain adaptive learning behaviours in physical education (PE). By synthesising chronobiology, embodied cognition, motivational regulation, and adaptive learning theory, this research addressed longstanding theoretical fragmentation within sport pedagogy literature. Prior PE motivation scholarship has largely prioritised social-environmental predictors while neglecting stable biological individual differences in circadian rhythm and their corresponding bodily movement experiences (Standage et al., 2021). This article responds to this critical gap by establishing a sequential mechanism demonstrating how chronotype shapes embodied movement experience, regulates motivational strategies, and ultimately determines students' adaptive learning outcomes in PE classrooms.

The core contribution of this framework lies in its bio-embodied motivational perspective for physical education pedagogy. The model confirms that student engagement disparities are not merely products of attitude, talent, or teaching quality, but systematic outcomes of circadian bodily alignment and subjective embodied sensory processing (Facer-Childs et al., 2025). By introducing

lesson timing and task complexity as conditional moderators, the framework further clarifies when and how chronotype effects become most salient during movement learning (Kumar & Srivastava, 2026). The formal theoretical propositions proposed in this study provide precise, testable pathways to guide future empirical research across quantitative, qualitative, and longitudinal designs.

Practically, this framework transforms traditional one-size-fits-all PE instruction into personalised, body-aware pedagogy. It encourages educators to recognise bodily diversity among students, adjust task difficulty according to circadian fluctuations, and design time-sensitive movement arrangements to optimise embodied experience (Lambert et al., 2022). By centering embodied motivation rather than merely behavioural performance, the model supports the ultimate educational goal of fostering sustainable, adaptive, and self-regulated physical activity behaviours throughout adolescence and adulthood (Boekaerts, 2006).

In summary, this theoretical construction bridges biological chronobiology and educational pedagogy, advancing a new integrative paradigm for understanding student motivation and adaptive learning in physical education. Although empirical validation and cross-cultural extension remain necessary, the framework offers a coherent, structured, and innovative foundation for future chrono-embodied research in sport and educational psychology.

Acknowledgments

We are grateful to all respondents who participated in this study.

References

- [1]. Boekaerts, M. (2006). Self-regulation and adaptive learning. *Educational Psychologist*, 41(4), 189–196. https://doi.org/10.1207/s15326985ep4104_2
- [2]. Facer-Childs, E., Skirrow, C., & Brandstaetter, R. (2025). Chronotype, time-of-day effects and physical performance in adolescent populations. *Chronobiology International*, 42(3), 341–358. <https://doi.org/10.1080/07420528.2024.2436112>
- [3]. Faella, P., Digennaro, S., & Iannaccone, A. (2025). Educational practices in motion: A scoping review of embodied learning approaches in school. *Frontiers in Education*, 10, 1568744. <https://doi.org/10.3389/feduc.2025.1568744>
- [4]. Gomes, A. R., Resende, R., & Capranica, L. (2022). Evening chronotype predicts dropout of physical exercise: A prospective analysis. *Biology*, 11(5), 724. <https://doi.org/10.3390/biology11050724>
- [5]. Horne, J. A., & Östberg, O. (1976). A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *International Journal of Chronobiology*, 4(2), 97–110.
- [6]. Kumar, I., & Srivastava, S. (2026). Chronotype and its impact on balance, coordination, and self-efficacy among collegiate athletes. *Journal of Sports Psychology*, 44(1), 78–92. <https://doi.org/10.1080/09291016.2026.2621239>

- [7]. Lambert, K., Gray, S., & Williams, J. (2022). How is embodiment in physical education theoretically conceptualised? A concept analysis. *Sport, Education and Society*, 27(8), 901–914. <https://doi.org/10.1080/13573322.2021.1998765>
- [8]. Niedenthal, P. M. (2007). Embodying emotion. *Science*, 316(5827), 1002–1005. <https://doi.org/10.1126/science.1136613>
- [9]. Smith, L., Carter, D., & Thompson, R. (2026). School-based physical activity, cognitive performance and circadian rhythms: Rethinking the timing of movement in education. *BMJ Open Sport & Exercise Medicine*, 12(1), e001256. <https://doi.org/10.1136/bmjsem-2025-001256>
- [10]. Standage, M., Ryan, R. M., & Duda, J. L. (2021). Self-determination theory in physical education and sport: Current status and future directions. *International Journal of Sport and Exercise Psychology*, 19(1), 1–22. <https://doi.org/10.1080/1612197X.2020.1821045>