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Review Article

Neuro-Pedagogical Game-Based Learning for Post-Pandemic Executive Function Recovery: BrainGEM Neuro360

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ABSTRACT

The COVID-19 pandemic severely impacted childhood neurodevelopment, with documented executive function levels among primary-aged children dropping below historical developmental norms. Although Game-Based Learning (GBL) is widely recognised for promoting engagement, educators often lack the neuro-pedagogical insights needed to optimise deep learning and prevent cognitive fatigue. This article introduces and theoretically develops BrainGEM Neuro360, a Malaysian-developed framework to bridge practical educational neuroscience and real classroom practice. A structured integrative review of research from 2019 to 2026 is applied, examining how GBL is theorised to engage prefrontal and frontoparietal neural networks and evaluating the framework's alignment with inquiry-based learning, applying the International Baccalaureate Primary Years Programme (IB PYP) as an illustrative context. The four-phase Neuro-Pedagogical Learning Cycle (NPLC) is proposed as a conceptual model for cognitive recovery, learner autonomy, and metacognitive self-regulation, structured within a strategic management ecosystem theorised to give school leaders a data-informed feedback mechanism, pending empirical testing. BrainGEM Neuro360 is offered as a theoretically derived, scalable, culturally responsive governance model for Malaysian and ASEAN school networks, advancing SDG 4 (Quality Education) and establishing a theoretical baseline for subsequent empirical testing.

Keywords: Cognitive flexibility, educational leadership, gamification, neuroeducation, neuroplasticity, SDG 4, self-regulated learning, working memory

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INTRODUCTION

The COVID-19 pandemic disrupted childhood neurodevelopmental trajectories, leaving young learners with documented

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deficits in executive functions: working memory, inhibitory control, and cognitive flexibility (Chichinina & Gavrilova, 2022; Jones et al., 2026). In response, primary educators have increasingly adopted Game-Based Learning (GBL) as a pedagogical approach supporting children's cognitive, social, emotional, and motivational development (Alotaibi, 2024; Qian & Clark, 2016), consistent with neuroplasticity-based accounts of how structured early-childhood pedagogy restores learning capacity (Goldberg, 2022).

Neuroeducation scholars theorise that prefrontal and frontoparietal mechanisms underlying cognitive control, attentional focus, and spatial planning are engaged by adaptive game-based learning across digital and analogue formats (Bavelier & Green, 2019; Diamond, 2013). AI-enabled personalised educational technology further enables real-time calibration of game-based challenges to each student's cognitive profile (Niyazova et al., 2026), informing subsequent hybrid digital-analogue curricular designs.

This research references the International Baccalaureate Primary Years Programme (IB PYP) as a compatible curriculum context, given its inquiry-based, transdisciplinary, student-centric learning model, though the framework proposed here is a broadly applicable neuro-pedagogical system; the IB PYP is illustrative, not constitutive, of its theoretical applicability.

Malaysia and Southeast Asia's national education policies prioritise digital literacy, higher-order thinking, and regional competitiveness (Ministry of Education Malaysia, 2013, 2022), aligning with Sustainable Development Goal (SDG) 4.1 (equitable foundational learning) and SDG 4.7 (critical thinking and global citizenship; United Nations, 2015). Post-pandemic evidence indicates that digital-analogue game-based interventions re-engage students (Nadeem et al., 2023) and that gamified executive-function training correlates with standardised academic achievement (Eng et al., 2024).

This study conceptualises BrainGEM Neuro360, a framework bridging the historically isolated domains of game design, neuroscience, and school management into one operational standard, grounded in a structured integrative literature review (Snyder, 2019; Torraco, 2005) and intended as a theoretical baseline for subsequent empirical data collection (Jaakkola, 2020). The Neuro-Pedagogical Learning Cycle (NPLC) is the framework's core conceptual model, illustrated through application within the IB PYP context.

Existing frameworks address these domains only in isolation: cognitive-training programmes (Birtwistle et al., 2025) improve executive function but are not embedded in classroom pedagogy or school-management architecture; inquiry-based curricula such as the IB PYP (International Baccalaureate Organization [IBO], 2018) provide pedagogical structure without neurodevelopmental grounding; and school-leadership models (e.g., Fullan, 2014; Spillane, 2006) offer governance architecture while treating the

classroom itself as a black box. BrainGEM Neuro360's specific contribution, the Neuro-Pedagogical Learning Cycle (NPLC), translates neurodevelopmental constructs into classroom-observable pedagogical moves nested inside a school-management architecture, running the same conceptual vocabulary from learner to institution. This integrative connection, rather than any single-domain finding, is the paper's central contribution; RQ1 (the NPLC's neurodevelopmental basis) is accordingly its primary scholarly contribution, with RQ2-RQ4 as applications to curriculum, equity, and leadership.

Problem Statement and Research Gaps

Primary school systems experience a compounding developmental crisis, despite positive empirical data on neuro-pedagogy in digital-analogue game-based learning environments. A study by Jones et al. (2026) shows that the executive functioning (EF) growth among young learners dropped approximately 0.5 standard deviations below historical developmental norms, as evidenced by a longitudinal cohort of 3,107 children aged 3 to 11 with similar patterns across socioeconomic groups. Chichinina and Gavrilova (2022) specifically document smaller gains in working memory and cognitive flexibility among 5- to 6-year-olds during lockdown.

Independent corroboration comes from Wright et al. (2026), who used direct behavioural EF assessment (N = 667) and found 11-12 months of lost growth during closures, with recovery at only 65-74% of the pre-closure rate. The broader evidence base is more mixed, however: a 16-country meta-analysis of 22,348 preschoolers (Alcon et al., 2024) found only small effects, and Rivera-Urbina et al. (2025) found no significant pre–post difference on most adolescent EF measures. This literature is therefore treated as an emerging, still-consolidating evidence base, more consistent for primary-school-aged children (Jones et al., 2026; Wright et al., 2026) than for preschoolers or adolescents, and claims here are bounded accordingly, kept analytically separate from the longer-standing GBL and cognitive-training literature (Birtwistle et al., 2025; Gkintoni et al., 2026) addressed in the Neurocognitive Foundations section.

The data reveal a fundamental mismatch between how children's brains recover and how traditional, factory-model primary schooling delivers its curriculum, a poor fit for children still working through acute post-pandemic cognitive overload, and the starting point for the neuro-pedagogical framework proposed here, offered as a theoretical proposition requiring empirical validation, not an established effect.

First, in the absence of a practical implementation model, inadequate institutional policy support (Ministry of Education Malaysia, 2013) and limited teacher professional development erode rather than structure the practicability of neurological game-based learning in real classrooms (Plass et al., 2015). In-depth studies on curricular design, school management, and leadership support are essential to developing SDG-aligned educational strategies (Ramachandaran et al., 2025). This

disconnection reflects the isolation between these domains in the current literature: GBL research focuses on motivation and engagement without an established link to measurable neurological growth (Plass et al., 2015), while neuroeducational literature reviews focus on theoretical insights, largely ignoring their practical application in actionable, classroom-ready, game-based curricular design.

Second, even where brain-informed programmes reach the classroom, school management lacks a structured roadmap for implementation, leaving principals and administrators without structural support to scale, evaluate, and sustain these innovations.

Third, research remains at an early stage in confirming an educational model that addresses post-pandemic EF recovery in a culturally specific way within Malaysia and the wider Association of Southeast Asian Nations (ASEAN) region.

The framework is urgently needed to address these gaps, given the risk that unmitigated cognitive deficits erode the nation's capacity to generate competitive talent. The proposed NPLC maps a pathway integrating neuroscience into daily classroom practice via structured digital-analogue gameplay translating onto observable, behaviour-based neurodevelopmental indicators, embedded within a strategic management model equipping school leaders to counteract the documented 0.5 *SD* shortfall in executive function growth and drive cognitive recovery.

Theoretical Axioms and Key Definitions

Before presenting the framework's components, this section states BrainGEM Neuro360's foundational theoretical axioms explicitly, defines its key recurring term ("neuro-pedagogical insights"), and clarifies what, specifically, is proposed as new relative to the existing theories it draws on. This responds directly to the concern that bringing neuroscience, pedagogy, game-based learning, leadership, and technology into proximity does not by itself constitute a new theoretical contribution unless their interaction is specified.

Foundational Axioms

Axiom 1 (Behavioural inference). Because direct neuroimaging is not feasible in routine classroom practice, neurodevelopmental constructs (e.g., inhibitory control, working memory) are treated in this framework as inferable from structured, observable learning behaviours, not as claims requiring or implying direct neural measurement. This axiom is what licenses the NPLC's classroom-observable indicators (Table 2) as a legitimate proxy system, while also bounding what the framework can claim: behavioural inference is a weaker evidentiary basis than direct measurement, and NPLC indicators should be read accordingly.

Axiom 2 (Cycle dependency). The four NPLC phases (stimulus activation, cognitive resonance, feedback and adaptation, metacognitive reflection) are theorised as sequentially interdependent

rather than as four independent techniques that could be adopted piecemeal: each phase is proposed to condition the pedagogical opportunity available in the next (e.g., attentional engagement in Phase 1 is treated as a precondition for the pattern-recognition demands of Phase 2). This is the axiom that distinguishes the NPLC from a menu of unconnected GBL techniques and is itself a testable proposition; later empirical work could examine whether phases delivered out of sequence, or in isolation, produce weaker outcomes than the full cycle.

Axiom 3 (Nested scale-linkage). Classroom-level pedagogical practice (the NPLC) and institutional-level governance (RQ4 and Figure 4) are theorised as operating on the same underlying constructs: the same behavioural indicators that inform a teacher's in-classroom adaptation are proposed to be the ones that aggregate into the school-level data a leader would use to evaluate and scale the approach. This is the axiom that connects the classroom and leadership dimensions of the framework; without it, the leadership material would simply be existing leadership theory applied alongside an unrelated pedagogical model, rather than integrated with it.

These three axioms interact as follows: Axiom 1 sets the evidentiary basis on which Axiom 2's phase sequence is theorised, and Axiom 3 extends that basis upward into the institutional layer. BrainGEM Neuro360's distinct theoretical claim is therefore not any single construct (EF, GBL, and distributed leadership are each already well established) but this three-axiom architecture connecting a behaviourally inferred, sequentially dependent classroom cycle to a governance layer built on the same inferential logic. The Neurocognitive Foundations and Implication of the Study sections apply this architecture and should be read as applications of these axioms, not independent contributions.

Defining "Neuro-Pedagogical Insights"

The term "neuro-pedagogical insights," used throughout, refers specifically to classroom-actionable instructional principles derived from behaviourally inferred neurodevelopmental constructs under Axiom 1, e.g., translating "working memory load" into "sequence game challenges in small, immediately reinforced steps." It is distinct from (a) raw neuroscience findings, not classroom-actionable without translation; (b) generic pedagogical best practice, not necessarily grounded in a neurodevelopmental construct; and (c) learner cognitive profiling, which this paper does not undertake.

Research Questions and Objectives

The four research questions form the foundational basis for this study:

- **RQ1 (The Science):** How does GBL mechanistically activate children's post-pandemic recovery of executive functions (working memory, inhibitory control, cognitive flexibility)?
- **RQ2 (The Curriculum):** How does BrainGEM Neuro360 align with the active inquiry architecture of the IB PYP,

and what does this suggest about transferability across curricula?

- **RQ3 (The Equity Impact):** How does integrating GBL within a structured neuro-pedagogical model contribute to SDG 4 (equitable, inclusive, quality education)?
- **RQ4 (The Leadership):** What leadership architecture enables administrators to deploy, evaluate, and sustain these innovations?

Correspondingly, this study aims to:

- **The Science:** Examine how structured GBL supports post-pandemic EF recovery and identify the game-design principles driving these effects;
- **The Curriculum:** Analyse BrainGEM Neuro360's alignment with inquiry-based curricula such as the IB PYP and develop the NPLC as a transferable classroom framework;
- **The Equity Impact:** Articulate the framework's contribution to SDG 4, showing how brain-informed pedagogies can close regional cognitive disparities and foster inclusion; and
- **The Leadership:** Propose a strategic leadership model giving administrators evidence-based feedback loops for sustainable institutional innovation.

These are not equally weighted: RQ1 establishes the NPLC's neurodevelopmental basis and is this paper's primary contribution; RQ2-RQ4 examine how that core model extends to curriculum, equity, and leadership, and are read as applications of RQ1 rather than independent claims.

Neurocognitive Foundations and Post-Pandemic Context

This review distinguishes three related but non-synonymous constructs: GBL, a complete game used as the instructional vehicle (Plass et al., 2015); gamification, discrete game-like elements layered onto a non-game activity (Deterding et al., 2011); and cognitive training, structured executive-function practice without narrative framing (Birtwistle et al., 2025). BrainGEM Neuro360 draws on all three, but the NPLC itself is a GBL model. This distinction matters because the strength of evidence differs markedly across the three and claims from one should not be read as applying automatically to the others.

Neurodevelopment refers to the progressive consolidation of neural networks underlying a child's executive function, memory, and attention (Diamond, 2013), driven by experience-dependent stimuli and iterative feedback (Goldberg, 2022; Hebb, 1949; Kolb & Gibb, 2014). Structured GBL taps into this biological engine by pairing cognitive milestones with feedback-rich mechanisms; immediate game-based feedback is theorised to engage dopamine-linked motivational circuitry (Howard-Jones et al., 2016), a psychological mechanism supported by educational research but not directly measured here, treated as a theoretical proposition rather than a demonstrated effect.

This is central to post-pandemic cognitive recovery: children's working memory and mental agility fell below pre-pandemic norms (Chichinina & Gavrilova, 2022; Jones et al., 2026), and structured cognitive training

showed modest but significant EF gains (g = 0.23), strongest for younger children (57-study meta-analysis; Birtwistle et al., 2025). Gkintoni et al. (2026), reviewing 94 studies, show that educational technology centred on neuroplasticity principles supports real-time motivational engagement.

This model pairs neuroplasticity theory with established constructivist theory (Piaget, 1952; Vygotsky, 1978), underpinning the cyclical engagement-exploration-feedback-reflection progression formalised as the four-phase NPLC (described below), grounded in real classroom behaviour rather than clinical neuroimaging data (Howard-Jones, 2014; Tokuhama-Espinosa, 2018), minimising neuromyth risk and translating neuroscientific theory into measurable classroom strategies (Figure 1).

This translation is not uncontested: Bowers (2016) argues educational neuroscience rarely yields teaching methods that behavioural and psychological research could not already provide, since classroom-relevant capacities are more reliably characterised through observable performance than through neural measurement. BrainGEM Neuro360's Axiom 1 (Theoretical Axioms and Key Definitions section) is framed as a direct response to this critique: neurodevelopmental constructs are treated as inferable from structured, observable learning behaviours precisely because, consistent with Bowers's argument, behavioural inference, not neuroimaging, is what a classroom-actionable framework can credibly claim.

Effective GBL is theorised to cultivate self-directed learners, supporting schema formation through scaffolding and adaptive difficulty (Hamari et al., 2016; Mayer, 2019). The NPLC operationalises goal-setting and immediate feedback loops theorised to support attention control, cognitive flexibility, and planning; self-reflection is proposed to support neural consolidation and cognitive recovery, though this pathway is not directly measured here.

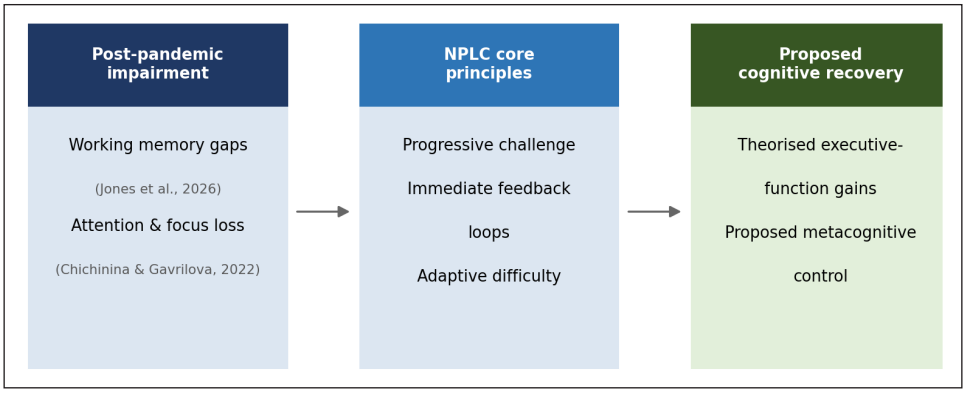

Figure 1. The scientific foundation of post-pandemic cognitive impairment and the BrainGEM Neuro360 recovery pathway: Advancing cognitive recovery in young children through the Neuro-Pedagogical Learning Cycle (NPLC)
Source: Authors' conceptual synthesis based on the reviewed literature

This aligns with the IB PYP's emphasis on student agency, transdisciplinary inquiry, and self-regulation (IBO, 2018).

AI-driven systems support active classroom design through adaptive tools and real-time feedback aligned with each child's cognitive profile (Mohd Amin et al., 2025; Niyazova et al., 2026), integrating self-regulated learning with metacognitive control (Junaštíková, 2024). This inclusive, personalised approach is intended to honour learner diversity across cultural and cognitive spectrums, advancing SDG 4 (Quality Education) in the classroom (Ramachandaran et al., 2025).

The Neuro-Pedagogical Learning Cycle (NPLC)

BrainGEM Neuro360 turns this theory into action via the Neuro-Pedagogical Learning Cycle (NPLC), a four-phase model built to answer RQ1 and RQ2 (Figure 2).

- **Phase 1:** Stimulus Activation (Attentional Readiness): sparks classroom engagement using multisensory game challenges adapted to student ability. Rooted in neuroconstructivist principles (Karmiloff-Smith, 2009), it targets the pandemic-linked executive function deficits noted above (Chichinina & Gavrilova, 2022; Jones et al., 2026) as a design intention, not a demonstrated remediation effect.
- **Phase 2:** Cognitive Resonance (Pattern Recognition): prefrontal and fronto-parietal networks are theorised to be engaged through structured, active problem-solving, mirroring Kolb's (1984) classic experiential learning cycle, with adaptive game environments calibrating challenge to each child's live skill level (Gkintoni et al., 2026).

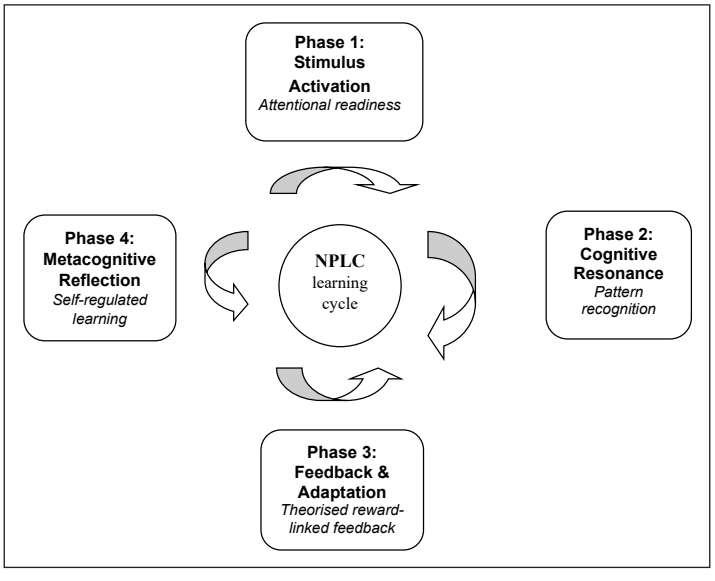

Figure 2. The four-phase Neuro-Pedagogical Learning Cycle (NPLC)
Source: Authors' conceptual synthesis based on the reviewed literature

- **Phase 3:** Feedback and Adaptation (Theorised Reward-Linked Reinforcement): newly formed neural pathways are theorised to be reinforced through immediate, game-driven feedback and student-led inquiry (IBO, 2018), engaging dopamine-linked reward processes associated in the literature with persistence and self-correction (Nadeem et al., 2023), a theoretical proposition, not directly measured here.
- Phase 4: Metacognitive Reflection (Self-Regulated Learning): helps children pause and articulate how they learned, matching established models of self-regulated reflection (Junaštíková, 2024; Zimmerman & Schunk, 2011) and supporting UN SDG 4.1.

Systemic Leadership and Innovation Governance

The NPLC bridges neuroscience and daily school management. Structured GBL correlates with sharpened spatial planning (Diamond, 2013), emotional engagement (Howard-Jones et al., 2016), and social skills (Gentile et al., 2009); AI-driven systems embedded within GBL give administrators real-time engagement analytics to scaffold curricular design and respond to individual learners' cognitive profiles.

The NPLC is mapped into a strategic management model giving administrators a roadmap to deploy, track, and scale the integration of neuroscience, pedagogy, and institutional management school-wide, reframing neuroscience from an abstract concept into an operational, strategic leadership tool, sustaining alignment with national and regional education policies across Malaysia and the ASEAN region (Ministry of Education Malaysia, 2013, 2022).

METHODOLOGY

Research Design and Justification

This study employs an integrative review methodology (Snyder, 2019; Torraco, 2005), synthesising existing literature across different domains (Jaakkola, 2020) to offer a theory-building contribution. It functions strictly as a framework-origination paper without empirical field data; its propositions are theoretically developed from this cross-domain review, establishing a strategic baseline for subsequent empirical data collection.

A structured integrative review was chosen to integrate diverse theories and evidence across domains historically independent of one another: educational neuroscience, GBL pedagogy, and school management. An integrative review and a PRISMA-guided (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) search-and-screening process are not mutually exclusive: PRISMA is primarily a reporting standard for transparency, and this study borrows PRISMA-style transparency for the search, screening, and inclusion process reported in the following subsections and Figure 3. What distinguishes this study from a PRISMA-based systematic review or meta-analysis is not structured search reporting, but the analytic goal: rather than statistically pooling effect sizes within one narrow domain, the review synthesises

qualitatively across domains for which no single body of homogeneous, poolable studies exists (Jaakkola, 2020).

Search Strategy and Database Protocols

A structured search was executed across Scopus, Web of Science, ERIC, and PsycINFO, enriched by targeted Google Scholar searches for forward citation tracking and backward citation scanning. The protocol consolidated three concept clusters via Boolean operators and database-specific filters (search-to-synthesis roadmap in Figure 3): Cluster 1 (Intervention) covered game-based learning, gamification mechanics, and hybrid digital-analogue learning; cross-referenced with Cluster 2 (Neurology: executive function, neurodevelopment, neuroplasticity) and Cluster 3 (Pedagogy and System: inquiry-based pedagogy, brain-informed leadership, curriculum governance).

Priority was given to post-pandemic peer-reviewed empirical studies, meta-analyses, and systematic reviews published in 2019-2026. Seminal theoretical literature (Diamond, 2013; Hebb, 1949; Piaget, 1952; Vygotsky, 1978) was included despite falling outside this range, given its role in the framework's conceptual foundation.

This search-and-screening process (Figure 3) was a qualitative, criteria-based funnel rather than a fully logged bibliometric count: records were narrowed through the criteria above to a final corpus of 53 sources. Consistent with this paper's conceptual status, stage-by-stage counts were not systematically logged, to avoid implying a precision the process did not have; a fully logged, PRISMA-compliant protocol is planned for the subsequent empirical validation phase.

Screening and Thematic Synthesis

Screening applied defined inclusion criteria: clear methodological or theoretical grounding; a focus on early/primary childhood (ages 3-12); and direct alignment with at least one domain. Non-peer-reviewed papers, studies lacking clear empirical or scientific grounding, and studies incompatible with school-based learning were excluded. Policy and curricular documents (Malaysian/ASEAN ministry guidelines, UN SDG frameworks, IB PYP materials) were used for primary-source context rather than treated as raw empirical metrics.

The corpus combines four source types: primary empirical studies, meta-analyses/systematic reviews, theoretical literature, and policy documents, not equally weighted. Primary studies (Eng et al., 2024; Wright et al., 2026) are most heavily caveated as single-study findings; meta-analyses/systematic reviews (Birtwistle et al., 2025; Gkintoni et al., 2026) are prioritised as a stronger, aggregated basis; seminal theoretical literature (Diamond, 2013; Piaget, 1952; Vygotsky, 1978) justifies conceptual architecture rather than serving as evidence of effect (Axiom 1); and policy documents (IBO, 2018; Ministry of Education Malaysia, 2013, 2022) establish contextual alignment only. The Conceptual Synthesis section makes this distinction explicit, separating what is

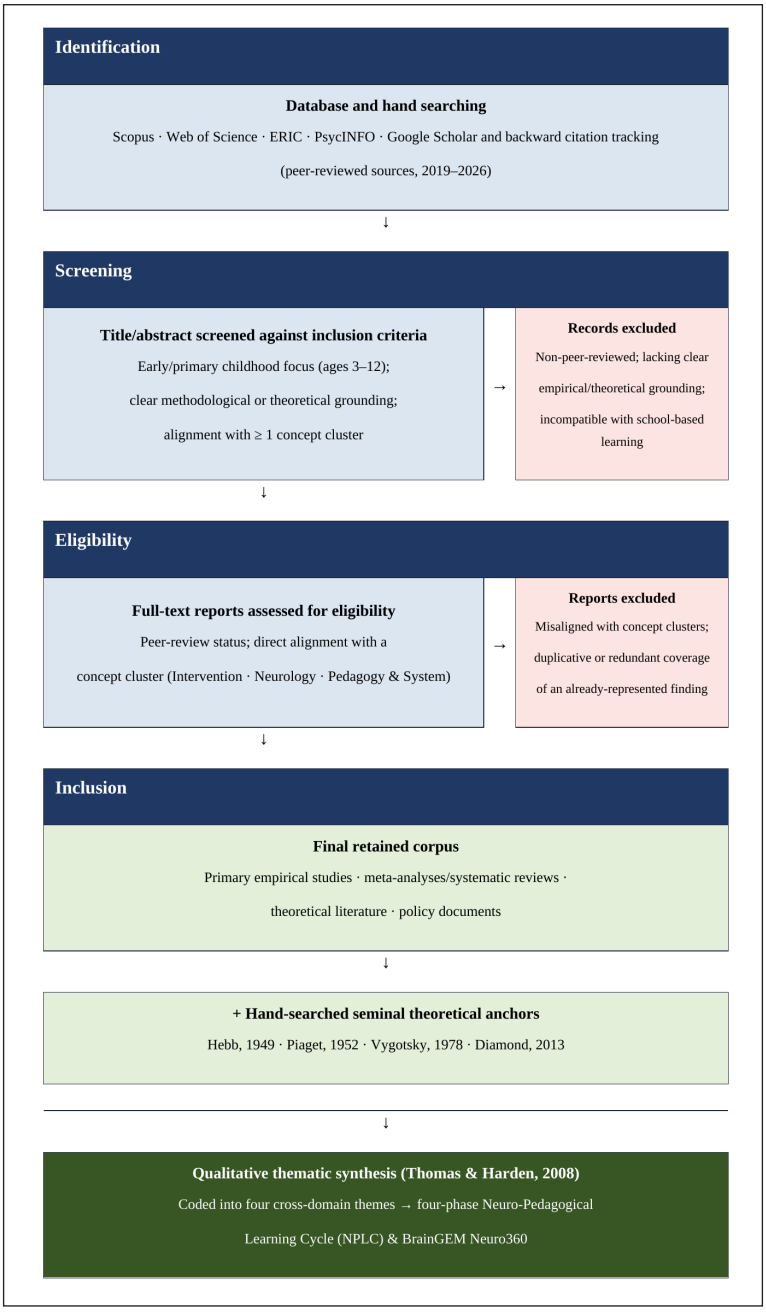

Figure 3. Qualitative search, screening, and synthesis funnel for the integrative review
Note. Consistent with this paper's status as a conceptual, framework-origination review, this diagram represents the qualitative, criteria-based logic of the search-and-screening process rather than a numerically logged PRISMA count; stage-by-stage record counts were not systematically retained during the original search and are not reported here to avoid implying a precision the process did not have. A fully logged, PRISMA-compliant protocol is planned for the subsequent empirical validation phase
Source: Authors' conceptual synthesis based on the reviewed literature

empirically established from BrainGEM's own theoretical proposition.

The finalised corpus of 53 sources was evaluated using qualitative thematic synthesis (Thomas & Harden, 2008). Recurring constructs were coded into cross-domain themes: neurodevelopmental activation, active inquiry pedagogy, feedback and metacognition, and institutional leadership, directly shaping the four-phase NPLC and the framework's broader operational architecture.

Coding Process and Reflexivity

Coding combined deductive and inductive logic: three deductive starter categories were set from the search strategy's concept clusters (Search Strategy and Database Protocols section), within which recurring constructs were grouped inductively into the four themes in Table 3, shaping the NPLC phases, e.g., feedback/error-correction sources informed "feedback and metacognition" (Phase 3), while multisensory-stimuli sources informed "neurodevelopmental activation" (Phase 1). As a conceptual synthesis rather than a formally logged qualitative study, this did not follow a documented line-by-line coding protocol; a structured, documented protocol is planned for the subsequeny empirical validation phase.

This synthesis was conducted solely by the first author, without independent co-author review, a retained audit trail, double-coding, or inter-rater reliability statistics, a limitation acknowledged here and in the Limitation and Future Research Direction section, where a structured, multi-coder protocol is planned.

Methodological Screening Matrix

The methodological parameters are synthesised in the structural matrix in Table 1.

Conceptual Mapping: Neurodevelopmental Indicators to Learning Behaviours

Table 2 operationalises BrainGEM Neuro360 by translating functionally inferred neurodevelopmental constructs

Table 1
Methodological screening matrix for the integrative review

Component	Strategy Details	Target / Criteria
Database Search	Cross-Platform Indexing	Scopus, Web of Science, ERIC, PsycINFO, Google Scholar
Core Inclusion	Timeline & Target Group	Peer-reviewed studies (2019-2026); early and middle childhood (approx. ages 3-12)
Theoretical Anchors	Foundational Baselines	Hebb (1949), Piaget (1952), Vygotsky (1978), Diamond (2013)
Contextual Scaffolding	Policy Integration	IB PYP Framework, Malaysia Education Blueprint 2013-2025, UN SDG 4

Source: Authors' conceptual synthesis based on the reviewed literature

Table 2
Mapping inferred neurodevelopmental indicators to observable learning behaviours and pedagogical strategies

Neurodevelopmental Indicator (Functionally Inferred)	Observable Learning Behaviour	Pedagogical Strategy (NPLC Alignment)
Sustained Attention (Executive Control)	On-task focus during game-based inquiry cycles	Guided inquiry with cognitive scaffolds; attention anchoring through tiered game mechanics
Working Memory (Information Integration)	Recall and integration of prior knowledge in novel tasks	Sequential game challenges requiring reflection, planning, and knowledge transfer
Emotional Regulation (Self-Regulation)	Adaptive responses to challenge; high frustration tolerance	Teacher-mediated emotional coaching; safe-failure game design principles
Cognitive Flexibility (Strategy Shifting)	Ability to alter strategies and perspectives during problem-solving	Rotational and open-ended game tasks promoting divergent and lateral thinking
Reward Sensitivity (Motivation/Persistence)	Intrinsic motivation, task persistence, and sustained engagement	Immediate feedback loops, milestone rewards, and self-progress dashboards

Source: Authors' conceptual synthesis based on the reviewed literature
Note. Indicators are functionally inferred from observable learning behaviour, not derived from direct neural tracking. Post-pandemic disruptions (Chichinina & Gavrilova, 2022; Jones et al., 2026) are directly integrated into the strategy architecture

into observable classroom behaviours and aligned pedagogical strategies, grounded in established neuroeducation literature (Diamond, 2013; Howard-Jones, 2014; Immordino-Yang & Damasio, 2007) and targeting post-pandemic working memory and cognitive flexibility deficits (Chichinina & Gavrilova, 2022; Jones et al., 2026), a blueprint for observation protocols and metrics in subsequent empirical research.

Positioning BrainGEM Neuro360 as a Progressive Synthesis

BrainGEM Neuro360 is best understood not as a critique of existing approaches but as a progressive synthesis, extending established educational thinking into an integrated, post-pandemic model. Three bodies of work inform it: Universal Design for Learning (UDL; CAST, 2018); game-based cognitive-training research showing structured, adaptive practice can support executive function (e.g., Birtwistle et al., 2025); and distributed/transformational leadership theory (e.g., Ismail et al., 2018; Senge, 2006; Townsend, 2024), building forward from each rather than against them.

Where UDL offers flexible design principles, BrainGEM Neuro360 adds a specific, sequential neurodevelopmental mechanism (Axiom 2), a concrete phase-by-phase pathway rather than a general philosophy. Where cognitive-training

research shows structured practice builds executive-function skills in isolation, BrainGEM Neuro360 embeds the same adaptive challenge within classroom pedagogy and teacher-mediated relationships rather than as a standalone drill, proposed to support more durable engagement and transfer (H1–H2; Future Hypotheses section). Where leadership theory describes how schools sustain innovation generally, BrainGEM Neuro360 proposes, via Axiom 3, a specific mechanism: nesting classroom indicators and institutional governance in the same conceptual vocabulary.

BrainGEM Neuro360's contribution is thus progressive rather than oppositional: a more integrated, institutionally connected model than exists when these approaches are applied separately, itself a proposition the proposed validation programme is designed to test.

Conceptual Synthesis

Table 3 characterises how the retained sources align with the four thematic clusters and their evidentiary strength. Representation is described qualitatively rather than counted (Coding Process and Reflexivity section), to

Table 3
Mapping of retained sources to thematic clusters and evidentiary strength

Theme	Representation	Representative Sources	Evidentiary Strength
Neurodevelopmental activation	Well represented	Bavelier & Green (2019); Birtwistle et al. (2025); Chichinina & Gavrilova (2022); Diamond (2013); Gkintoni et al. (2026); Jones et al. (2026)	Moderate - meta-analytic support for small overall effects (g = 0.23); mechanism claims (dopamine, prefrontal consolidation) inferred from behaviour, not directly measured
Active inquiry pedagogy	Well represented	Csikszentmihalyi (1990); IBO (2018); Kolb (1984); Ryan & Deci (2020); Vygotsky (1978)	Strong for pedagogical alignment (established constructivist theory); theoretical rather than GBL-specific outcome data
Feedback and metacognition	Well represented	Howard-Jones et al. (2016); Junaštíková (2024); Nadeem et al. (2023); Zimmerman & Schunk (2011)	Moderate – consistent theoretical grounding; empirical GBL-specific transfer evidence is limited
Institutional leadership	Well represented	Bass & Riggio (2006); Fullan (2014); Ismail et al. (2018); Mydin et al. (2025); Spillane (2006); Townsend (2024)	Strong for general leadership theory; no source directly evaluates leadership of neuro-pedagogical GBL specifically – applied here as an extension

Note. "Well represented" indicates that each theme draws on a substantial cross-section of the retained corpus, discussed throughout the Neurocognitive Foundations and Conceptual Synthesis sections; this is a qualitative characterisation rather than a formal bibliometric tally, and several sources contribute to more than one theme. See Coding Process and Reflexivity for the conceptual synthesis approach

avoid implying a precision the process did not have. The following RQ1–RQ4 subsections accordingly state what is empirically established before distinguishing BrainGEM's own theoretical extension, noting rather than smoothing over mixed findings (e.g., the small effect size for cognitive-training transfer; Birtwistle et al., 2025).

RQ1: GBL and Neurodevelopmental Activation (NPLC Phase 1: Stimulus Activation)

Post-pandemic evidence documents a 0.5 *SD* shortfall in children's executive function growth relative to below historical norms (Jones et al., 2026; see also Chichinina & Gavrilova, 2022). Adaptive-difficulty game-based challenges are theorised to address these deficits by engaging processes associated with prefrontal neural consolidation (Diamond, 2013), a theoretical proposition, not a directly measured outcome.

Meta-analyses report associations between adaptive game-based learning and dopamine-linked emotional engagement indicators in early cognitive development (Alotaibi, 2024; Birtwistle et al., 2025), behaviourally inferred, not neurochemically measured, and treated as a theoretical mechanism informing NPLC design. Attentional control and visual memory are similarly linked to action-based gameplay on behavioural rather than neuroimaging evidence (Bavelier & Green, 2019), and gamified executive-task practice is associated with standardised academic achievement in one feasibility study (Eng et al., 2024), a single-study association warranting caution.

In sum, the integration of progressive gameplay, multisensory input, and real-time feedback is theorised to support neuroplasticity and post-pandemic recovery, a proposition, not a demonstrated outcome, intended to rebuild the cognitive capacity children need for active, inquiry-based learning (Nadeem et al., 2023), addressing RQ1.

Pedagogically Resonant Design Within Inquiry-Based Systems (NPLC Phases 2 and 4)

A child's curiosity, grounded in experience-dependent neuroplasticity, connects to inquiry-based systems like the IB PYP through three pathways: scaffolded-difficulty gameplay corresponding to Vygotsky's (1978) zone of proximal development; intrinsic flow, balancing challenge with skill to enter Csikszentmihalyi's (1990) “optimal flow,” nurturing agency and healthy risk-taking (Ryan & Deci, 2020); and reflective metacognition, converting in-game success into self-directed knowledge, consistent with self-regulated reflection models (Junaštíková, 2024; Zimmerman & Schunk, 2011).

These pathways indicate that the NPLC suits school systems valuing student agency, inquiry, and holistic development (IBO, 2018), addressing RQ2 and suggesting transferability across curricula.

RQ3: Contribution to Sustainable Quality Education (SDG 4 Across All Phases)

BrainGEM Neuro360 operationalises three UN SDG 4 targets in the classroom. SDG

4.1 (Equitable Quality Primary Education): neuro-informed GBL provides differentiated pathways for post-pandemic-affected, neurodiverse, and high-potential learners, with the NPLC's metacognition cycle targeting the foundational skills most disrupted, pending empirical confirmation. SDG 4.7 (Critical Thinking & Global Citizenship; UNESCO, 2020): adaptive gameplay embedding emotional intelligence and cooperative problem-solving is theorised to support neural consolidation processes in routine practice. SDG 4.c: operationalising the NPLC is intended to cultivate neuroeducation literacy, shifting teachers toward genuine professional capacity-building.

This multilingual, culturally responsive design operationalises SDG 4 at curriculum and classroom-management levels, intended to close cognitive equity gaps and addressing RQ3 (Ramachandaran et al., 2025).

RQ4: Strategic Leadership for Sustainable Implementation

Three leadership mechanisms sustain neuro-educational ecosystems and scale the framework institutionally: Distributed Leadership and Teacher Empowerment (SDG 4.c), distributing ownership through shared inquiry and structured continuing professional development (CPD) (Nadeem, 2024; Spillane, 2006; Townsend, 2024); Professional Learning Communities (PLCs) practising transformational leadership to interpret cognitive data and design differentiated instruction together (Bass & Riggio, 2006; Mydin et al., 2025); and data-informed decision-making using AI-enabled formative analytics to tell a story of student growth rather than serve compliance (Fullan, 2014; Immordino-Yang et al., 2018).

Together, these pillars suggest that implementing the framework represents a cultural shift relevant to RQ4 (Figure 4).

Integrative Synthesis: BrainGEM Neuro360 as an Interdependent Ecosystem

The NPLC phases function as an integrated engine for a child's cognitive and systemic recovery: Phase 1 establishes attentional readiness against post-pandemic sensory overload; Phase 2 converts that into active,

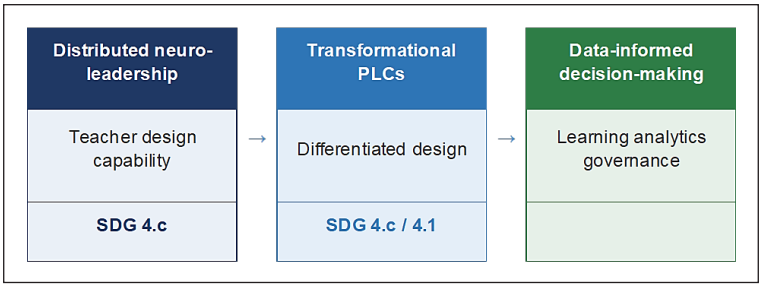

Figure 4. Strategic leadership architecture for sustaining and scaling BrainGEM Neuro360 across institutions, aligned with the targets of UN SDG 4.c and 4.1
Source: Authors' conceptual synthesis based on the reviewed literature

self-regulated problem-solving; Phase 3 uses immediate feedback theorised to engage dopamine-linked reward processes associated with durable retention (a proposition, not a measured effect); and Phase 4 cements metacognitive self-regulation for knowledge transfer, supported by an institutional leadership layer, professional learning communities, and data governance aligning with Malaysia's education blueprint, the ASEAN Education agenda, and the UN SDG vision of resilient, future-ready schools.

DISCUSSION AND CONCLUSION

Returning to the three gaps identified in the Problem Statement: the disconnect between neuroeducation research and classroom-ready game design (Gap 1) is addressed by the NPLC's translation of behaviourally inferred constructs into phase-specific moves (Axiom 1); the absent school-management roadmap (Gap 2) is addressed by nesting that cycle within the leadership architecture set out under RQ4 (Figure 4; Axiom 3) and the unconfirmed status of brain-informed models generally (Gap 3) is why this paper is positioned as a theoretical framework requiring empirical validation, not a confirmed solution.

This research introduces the theoretically grounded BrainGEM Neuro360 framework, integrating neuroscience, game-based pedagogy, and school management into a cohesive educational ecosystem. Its adaptive-difficulty gameplay mechanisms are proposed as a potential approach to address the post-pandemic neurodevelopmental recovery pathway, a set of theoretical propositions requiring empirical verification, not a demonstrated effect. Operationalised via the NPLC within inquiry-based models such as the IB PYP, the framework translates neuroscience theory into a proposed structure for daily classroom routines, intended to support SDG 4 equity mandates and offer administrators a roadmap for sustainable institutional change, pending the empirical field testing outlined in the Limitation and Future Research Direction section.

In conclusion, the NPLC is proposed as a conceptual model integrating daily classroom practice with school governance, equipping administrators with a data-informed feedback loop to evaluate, deploy, and scale brain-informed architecture, a candidate enabler of potential relevance to inclusive educational practice, pending empirical testing. As school networks navigate post-pandemic neurodevelopmental equity gaps, this model is offered as both a pedagogical framework and a governance instrument for sustainable transformation. Its capacity to help children recover, learn, and thrive remains a proposition that the proposed research programme is designed to test.

IMPLICATION OF THE STUDY

School-Level Implications

Sustaining this framework would plausibly require a shift from transactional, top-down management toward the distributed

instructional leadership already described in educational-management research (Ismail et al., 2018; Townsend, 2024). Consistent with Axiom 3, this paper applies, rather than proposes, new distributed and transformational leadership constructs (Senge, 2006), proposing that such leaders function as brain-informed instructional coordinators. Whether this shift is necessary or sufficient is an empirical question for furture research.

One future direction is equipping teachers with AI-driven, adaptive gameplay tools offering data-informed insight into student NPLC engagement, potentially freeing teacher time for relational support (cf. Mohd Amin et al., 2025; Niyazova et al., 2026), proposed for future piloting, not a system built or evaluated here.

National-Level Implications

For future consideration, the authors propose incorporating neuroeducation literacy into national teacher certification and CPD pathways (SDG 4.c), consistent with calls for structured neuroscience-literacy training (Schmied & Jamaludin, 2023) and evidence that untrained teachers hold correctable brain-based misconceptions (Grospietsch & Mayer, 2019). The NPLC's observable dimensions are similarly proposed, pending validation, as a possible national benchmarking basis, propositions for policymakers to test and debate (cf. UNESCO, 2022), not validated recommendations.

Regional-Level Implications

The NPLC is proposed, for future evaluation, as a potentially inclusive, multilingual-compatible curricular design fitting ASEAN's sociocultural diversity (Southeast Asian Ministers of Education Organization, 2021): (a) Phase 1 stimulus materials in the child's home language alongside instruction language; (b) bilingual/non-verbal Phase 3 feedback, consistent with evidence that teacher code-switching supports bilingual cognitive flexibility (Sun et al., 2020) and documented English/Malay mismatches in Malaysian preschools (Yussof & Sun, 2020); (c) teacher CPD (National-Level Implications section) on code-switching and culturally relevant content (Maaruf et al., 2025; Mohamad et al., 2018); and (d) leadership dashboards (School-Level Implications section) disaggregating engagement by language background. Whether these choices support equity, narrowing rather than widening the disparities motivating SDG 4 (Ramachandaran et al., 2025), is an empirical question for future research, not resolved here.

LIMITATION AND FUTURE RESEARCH DIRECTION

This paper identifies three natural boundaries. First, as a conceptual synthesis, the NPLC's propositions have been developed through existing literature and now await empirical verification in real-world settings. Second, while built with IB and progressive Malaysian/ASEAN systems in mind, deploying this model

within non-IB, heavily centralised, or low-resource schools may require local structural adjustments. Finally, to protect against "neuromyths" and keep classroom data actionable, all neurodevelopmental milestones are inferred from observable behaviours rather than measured directly through clinical neuroimaging.

Formal critical appraisal of source quality, not undertaken in the present synthesis (Coding Process and Reflexivity section), is planned to use the Mixed Methods Appraisal Tool (MMAT) developed by Hong et al. (2018), applied to empirical and meta-analytic sources, with theoretical and policy sources exempted given their conceptual rather than evidentiary role (Screening and Thematic Synthesis section).

The upcoming research programme involves four pathways: first, qualitative case studies tracking live implementations in diverse ASEAN classrooms; second, longitudinal mixed-methods inquiries tracking how NPLC-guided learning shapes executive functions and academic achievement over several school cycles; and third, a standardised quantitative assessment generating comparable analytics on behavioural progress and attentional control across Southeast Asian settings, refining the model while actively prioritising equitable and inclusive metrics aligned with SDG 4. Fourth, future research should examine the leadership competencies and institutional conditions enabling administrators to translate the NPLC into sustained, school-wide practice, grounding the strategic leadership architecture proposed here.

Future Hypotheses

Consistent with the axioms set out in the Introduction, the validation phase above can be organised around specific, falsifiable hypotheses rather than general pathways alone:

- **H1 (Axiom 1 test):** Teacher- and parent-rated behavioural EF indicators (Table 2) will show measurable pre–post change after a full term of NPLC exposure, relative to a non-NPLC comparison classroom.
- **H2 (Axiom 2 test):** Classrooms implementing all four NPLC phases in sequence will show stronger engagement and behavioural indicators than classrooms implementing the same activities out of sequence.
- **H3 (Axiom 3 test):** School-level aggregated NPLC indicator data will be usable by leaders to identify classrooms needing additional support, evidenced by dashboard-informed decisions corresponding to independently observed needs.
- **H4 (Equity test):** Multilingual NPLC adaptations (home-language stimulus materials, bilingual feedback) will be associated with more equitable engagement indicators across language-background subgroups than single-language delivery.

These hypotheses are proposed as a starting point for the empirical programme in this section; they are not tested in the present study and should not be read as findings.

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CONFLICT OF INTEREST

The first author is the founder of BrainGEM, the organisation that developed the BrainGEM Neuro360 framework, and therefore holds a professional and financial interest in it. The other authors declare no competing interests.

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