

Phyigital Game-Based Learning in Early Childhood Education: An Exploratory Review

Tanmoyee Rajkhowa

Ludwigsburg University of Education, Germany

Helwan University, Cairo, Egypt

rajkhowa.tanmoyee@gmail.com

Abstract: This paper examines the role of phyigital game-based learning (PGBL) in early childhood education, with a specific focus on its potential to foster critical thinking and problem-solving skills in children aged 3 to 8 years. PGBL refers to hybrid educational tools that combine physical manipulatives with interactive digital interfaces, offering multisensory and responsive learning experiences that aim to enhance cognitive engagement and symbolic reasoning. Through a literature-based qualitative review, the study analyzes five representative tools—Osmo Tangram, KIBO Robot, LEGO DUPLO Stories, Marbotic Smart Letters, and PlayShifu Orboot Earth—selected for their pedagogical relevance, documented educational use, and theoretical grounding. Drawing from constructivist and socio-cultural learning theories, particularly those of Piaget, Papert, and Vygotsky, the paper explores how these tools embody principles such as hands-on learning, scaffolding, iterative exploration, and meaningful play. Each tool is evaluated in terms of its support for higher-order cognitive functions, including sequencing, spatial reasoning, emergent literacy, and collaborative learning. The findings reveal that while PGBL tools show promise in promoting engagement and foundational executive functions, their effectiveness depends on factors such as design flexibility, ease of integration into pedagogical practice, and inclusivity. Implementation challenges such as limited open-ended play, cognitive overload, unequal access to digital infrastructure, and the need for educator training are critically examined using Universal Design for Learning (UDL) and Technological Pedagogical Content Knowledge (TPACK) frameworks. Rather than presenting definitive causal claims, this review provides a structured synthesis of current academic literature, highlighting both the affordances and limitations of phyigital tools in early education. The analysis also underscores the importance of aligning PGBL tools with developmentally appropriate practices and culturally responsive pedagogy. By offering insights across tool design, implementation, and impact, the paper aims to inform educators, researchers, and policymakers seeking to enhance early learning environments through evidence-based, interactive technologies.

Keywords: Phyigital game-based learning, Early childhood education, Critical thinking, Learning theories, Constructivism, Problem-Solving

1. Introduction

Play is central to early childhood learning, supporting the development of cognitive, social, and emotional skills through exploration, experimentation, and symbolic reasoning (Hirsh-Pasek et al., 2009). As digital technologies increasingly permeate educational spaces, phyigital game-based learning (PGBL)—which merges physical manipulatives with digital feedback—has emerged as a promising modality in early childhood education (ECE). By leveraging the strengths of both physical play and digital interactivity, PGBL tools offer multisensory, adaptive experiences that align with how young children naturally learn.

This paper adopts a qualitative literature-based case study methodology to analyze five representative PGBL tools: Osmo, KIBO, LEGO DUPLO, Marbotic, and PlayShifu. These tools were selected for their relevance to ages 3–8, presence in formal ECE settings, and claims of supporting cognitive development. Each is examined in relation to learning theories, design features, and empirical findings to understand how such tools engage children in structured, playful problem-solving tasks.

Two guiding research questions frame this inquiry:

RQ1: How do selected phyigital game-based learning tools engage children in critical thinking and problem-solving processes?

RQ2: How can these tools be integrated into early childhood curricula to support holistic and inclusive learning?

The study is grounded in developmental learning theories that emphasize active, scaffolded engagement. Piaget's (1952) constructivist theory posits that children construct knowledge through direct interaction with their environment, with play acting as a key driver of cognitive development. Extending this, Papert's (1980) constructionism emphasizes learning through making—where children build tangible artifacts, often supported by technology, to reflect and deepen understanding. Complementing these perspectives, Vygotsky's (1978) socio-cultural theory highlights the role of social interaction and guided support in learning. His concept of the Zone of Proximal Development (ZPD) describes how children achieve more complex tasks with appropriate scaffolding—provided by adults, peers, or well-designed tools. PGBL platforms such as LEGO DUPLO Stories or

PlayShifu Orboot align with this model by offering structured prompts, feedback, and opportunities for collaboration that extend children's capabilities.

Despite growing market presence, many PGBL tools lack rigorous empirical validation, particularly concerning their impact on higher-order thinking skills such as critical thinking and problem-solving (Neumann & Neumann, 2017). Some designs are overly structured, limiting open-ended exploration (Resnick, 2006), while others raise concerns about cognitive overload, accessibility, and inconsistent pedagogical integration (Christakis et al., 2018; Mishra & Koehler, 2006). These gaps underscore the need for research that critically evaluates not only the engagement potential of PGBL but also its developmental relevance. By analyzing the pedagogical affordances and limitations of these tools, the study contributes to the discourse on the developmentally grounded integration of edtech, with implications for educators, designers, and policymakers working in early childhood education.

2. Literature Review

2.1 Theoretical Foundations

The integration of physical and digital play in early childhood education is grounded in classical developmental theories. Jean Piaget (1952) emphasized that children construct knowledge through active exploration and self-initiated interaction with their environment. His theory underscores that play is central to cognitive development, enabling children to experiment, assimilate new ideas, and solve problems through concrete manipulation. These activities are particularly evident in preoperational stages, where symbolic play and trial-and-error reasoning help refine mental schemas.

Seymour Papert's (1980) constructionism further elaborates this notion by advocating for "learning by making," where learners deepen understanding by creating tangible artifacts. Papert highlighted the value of tools like programmable robots that promote iterative problem-solving and creative thinking. Constructionist learning environments not only encourage autonomy but also provide scaffolds that allow learners to reflect on and refine their creations—concepts central to modern educational technologies.

Lev Vygotsky (1978) introduced the socio-cultural dimension through his Zone of Proximal Development (ZPD), wherein learners achieve higher-order thinking when supported by peers or adults. Guided play and collaborative problem-solving position learning within this zone. In phygital environments, interactive feedback and peer co-regulation serve as effective scaffolding mechanisms, externalizing cognitive processes and guiding learners toward mastery.

Contemporary neuroscience aligns with these perspectives. Diamond (2013) emphasizes that executive functions—planning, working memory, and cognitive flexibility—develop through goal-directed activities that demand self-regulation. Engaging with complex, playful challenges helps strengthen neural pathways critical for academic success. Moreover, social-emotional competencies are cultivated through cooperative play, where children negotiate roles, express empathy, and regulate emotions (Lillard, 2013). Collectively, these theoretical perspectives provide a foundation for designing learning environments that merge tactile exploration with digital interactivity to support holistic cognitive growth.

2.2 Phygital Game-Based Learning (PGBL) in Early Childhood

Phygital Game-Based Learning (PGBL) represents a pedagogical shift that blends physical manipulatives with digital interfaces, creating immersive, multisensory educational experiences tailored to early learners. Traditionally, physical and digital learning tools have existed in silos—blocks and puzzles fostering fine motor skills, while apps target numeracy or literacy through screen-based interactions. PGBL bridges this divide by offering hybrid platforms where physical inputs (e.g., letter tiles, robots) are recognized by digital systems and enhanced with interactive feedback.

This blended format leverages children's natural learning tendencies—particularly kinesthetic and visual learning styles—while maintaining the intrinsic motivation of play. Crucially, PGBL aligns with a "playful pedagogy" where educational goals are embedded within exploratory, game-like challenges that emphasize curiosity, experimentation, and collaboration (Torres et al., 2021). These platforms are particularly suited for young learners, whose cognitive engagement increases when activities are framed as games with evolving challenges and narratives.

In an empirical study by Maldonado and Zekelman (2019), children using tangible app-linked games demonstrated high persistence, self-correction, and exploratory behavior. The physical components served to

anchor attention, while digital feedback sustained engagement and encouraged reflection. These environments foster active construction of knowledge, aligning with constructivist theories and advancing early executive function development.

Moreover, PGBL tools support inclusive learning by catering to multiple modalities—tactile, visual, auditory—thus accommodating neurodiverse learners. This multisensory input reduces cognitive load, enabling deeper processing of abstract concepts. The adaptive nature of digital elements allows for real-time scaffolding, with cues or corrections that help children remain within their ZPD. When combined with physical trial and error, these feedback loops become powerful mechanisms for building foundational skills.

2.3 Critical Thinking and Problem-Solving in Early Years

Fostering critical thinking and problem-solving skills in early childhood is crucial for developing adaptive learners who can navigate complex tasks effectively. These higher-order cognitive skills enable young children to evaluate options, generate solutions, and reflect on their reasoning processes. Bakken et al. (2017) identify these competencies as core pillars of early cognitive development and predictors of long-term academic success.

Play is a natural conduit for developing these skills. Activities such as constructing models, resolving peer conflicts, or completing puzzles inherently involve strategy formulation, hypothesis testing, and reflection. Educators can deepen these learning moments by using structured prompts, open-ended questions, or iterative tasks that challenge learners to revise and refine their approaches.

Digital components within PGBL environments enhance this process by providing immediate feedback, error correction, and varied pathways to success. For instance, coding toys like KIBO or puzzle-based apps like Osmo allow learners to debug errors, visualize alternatives, and build metacognitive awareness. These tasks mirror scientific inquiry: children form predictions, test their solutions, and adjust their strategies based on the outcomes.

Kazakoff et al. (2013) demonstrated the efficacy of such tools in a study involving 34 children (ages 4–6). After a one-week intervention using KIBO robotics kits, participants exhibited significantly improved sequencing skills—a foundational element of computational and logical reasoning. These gains occurred in a playful, learner-led context, underscoring the value of PGBL over traditional didactic instruction.

Importantly, many phygital tools encourage collaborative engagement, further enriching problem-solving. When learners negotiate building plans, divide coding tasks, or co-create narratives, they engage in distributed cognition—sharing mental models and refining ideas through peer interaction. These social learning experiences not only build cognitive flexibility but also foster empathy, communication, and resilience.

To illustrate how these principles are applied in practice, we examine five phygital learning tools that have gained traction in early childhood settings: Osmo, KIBO, LEGO DUPLO, PlayShifu Orboot, and Marbotic. Each tool combines physical manipulatives with digital content, targeting different age groups and learning domains, and aligning with slightly different theoretical emphases.

Table 1: It provides a comparative overview of these tools, including their intended age range, connections to learning theory, and key findings from studies on their use

Tool	Osmo	KIBO	LEGO DUPLO	PlayShifu Orboot	Marbotic
Intended Age Range	5–8 years	4–7 years	3–6 years	4–10 years	3–6 years
Learning Theory Alignment	Constructivist (Piaget), Social Constructivist (Vygotsky)	Constructionist (Papert), Cognitive Constructivist (Piaget)	Constructivist (Piaget), Socio-cultural (Vygotsky), Montessori	Constructivist, Multisensory Learning, Situated Cognition	Montessori, Embodied Cognition, Constructivist
Engagement in Critical Thinking & Problem-Solving	Promotes spatial reasoning and collaborative problem-solving via digital puzzles	Encourages sequencing, debugging, and planning through	Supports open-ended problem-solving, storytelling, and	Fosters exploratory learning and fact recall through	Enhances early literacy and logical reasoning via tactile letter

Tool	Osmo	KIBO	LEGO DUPLO	PlayShifu Orboot	Marbotic
	and real-time feedback	hands-on robotics and code blocks	planning through block play	interactive AR globe	manipulation and app feedback
Design Features Facilitating Higher-Order Thinking	Immediate feedback, tangible-digital integration, visual cues within ZPD	Screen-free coding, iterative design, tangible programming blocks	Open-ended, symbolic play, collaborative construction	AR-based self-guided exploration, sensory-rich prompts	Tactile engagement, self-correcting inputs, phonics integration
Challenges / Limitations	Requires iPad; may restrict open-ended exploration if over-structured	Limited screen-based feedback; needs adult facilitation for deeper learning	Limited digital enhancement; relies on teacher scaffolding	Structured content may limit creativity; tech setup needed	Limited large-scale studies; tech dependency may hinder tactile-only play
Curricular Integration Potential	High potential for spatial reasoning, logic, and group tasks in STEM curriculum	Strong fit for coding, robotics, and computational thinking modules in early tech programs	Effective in integrated storytelling, motor skills, and SEL curriculum	Valuable for geography, vocabulary, and world knowledge learning centers	Well-suited for phonics, early reading, and inclusive multisensory literacy programs
Tool	Osmo	KIBO	LEGO DUPLO	PlayShifu Orboot	Marbotic
Key Empirical Findings	Improved spatial reasoning and peer collaboration in tangram tasks (Schroth et al., 2019)	Enhanced sequencing and executive function in preschoolers (Kazakoff et al., 2013)	Boosted planning and creativity through play (O'Byrne et al., 2018)	Increased engagement and vocabulary via AR (Kelpšienė, 2020)	Early evidence of literacy gains and task persistence (Maldonado & Zekelman, 2019)

These tools all integrate physical and digital elements but in diverse ways: Osmo and Marbotic use tangible manipulatives to teach concepts (spatial puzzles, literacy/numeracy) with real-time feedback; KIBO uses a programmable robot to teach sequencing and engineering design through hands-on construction; LEGO DUPLO leverages open-ended building and storytelling to develop cognitive and social skills; and Orboot employs augmented reality to inspire exploration of world knowledge. Their theoretical alignments reflect the design choices: for instance, KIBO explicitly draws on Papert's constructionism, encouraging children to learn programming by physically assembling code; Osmo and Orboot invoke Vygotskian ideas by scaffolding tasks with hints and allowing shared participation; Marbotic echoes Montessori by emphasizing self-paced, tactile learning. The evidence so far (though still emerging in some cases) suggests that phygital tools can indeed realize the promise of PGBL: increasing engagement, supporting diverse learners (through multiple modalities), and improving specific skills from executive functions to early literacy. However, the literature also notes the importance of balance – structured digital tasks should be balanced with open-ended play to avoid over-scaffolding, and educators must thoughtfully integrate these tools into curricula to harness their benefits truly. The following section will outline how the present study approached its analysis of PGBL tools and literature.

3. Methodology

This study adopts a literature-based qualitative synthesis methodology, drawing on principles of comparative case analysis as outlined by Creswell (2014) and Merriam (2009). Rather than conducting field-based empirical case studies, the paper constructs analytical case exemplars based on documented evidence from secondary sources. The goal is to synthesize educational affordances, theoretical alignments, and cognitive outcomes associated with selected phygital game-based learning (PGBL) tools in early childhood education (ECE).

The research is guided by a deductive conceptual framework grounded in constructivist, constructionist, and socio-cultural learning theories (Piaget, 1952; Papert, 1980; Vygotsky, 1978). A purposive sampling strategy was used to select five representative tools—Osmo Tangram, KIBO Robot, LEGO DUPLO Stories, Marbotic Smart Letters, and PlayShifu Orboot Earth—based on the following inclusion criteria: (1) designed for learners aged 3–

8 years; (2) blending physical manipulatives with digital interactivity; (3) documented use in formal or non-formal ECE settings; and (4) presence of at least one empirical or conceptual peer-reviewed source evaluating educational impact.

Data sources included peer-reviewed journal articles, white papers, implementation studies, and design reports. Each tool was examined through five deductive categories derived from the research questions: (a) critical thinking and problem-solving affordances; (b) alignment with developmental learning theories; (c) support for inclusive pedagogy (e.g., Universal Design for Learning); (d) curriculum integration feasibility (e.g., via TPACK framework); and (e) scalability and contextual viability.

This structured qualitative synthesis facilitates a cross-case understanding of how different PGBL tools support higher-order cognition in early learners. Although the study does not claim empirical generalizability, it contributes to theory-building and practical insight by consolidating and analyzing documented patterns across the existing literature.

4. Limitations

As a literature-based qualitative synthesis, the methodology is limited by its reliance on secondary data, which constrains the depth and granularity of analysis. The absence of primary fieldwork—such as direct observation, interviews, or classroom trials—restricts the ability to contextualize tool usage within diverse pedagogical environments. Additionally, the quality and scope of available empirical studies vary significantly across the selected tools, with some lacking robust or longitudinal evidence. As a result, the findings primarily reflect documented potential rather than confirmed outcomes. Despite these constraints, the methodology provides a structured, theory-informed lens for evaluating the educational affordances of PGBL tools.

5. Key Implementation Challenges in Phygital Game-Based Learning (PGBL)

The effective integration of Phygital Game-Based Learning (PGBL) tools in early childhood education (ECE) is shaped by several implementation challenges. These were identified through a conceptual synthesis of constructivist and constructionist learning theories (Piaget, 1952; Papert, 1980), the Universal Design for Learning (UDL) framework (Meyer et al., 2014), and principles of implementation science (Fixsen et al., 2005). This section outlines four recurrent and theoretically grounded challenges: (1) constraints on open-ended play and cognitive overload, (2) inequities in access and inclusion, (3) educator preparedness and pedagogical alignment, and (4) cost and scalability.

5.1 Constraints on Open-Ended Play and Cognitive Overload

PGBL tools often embed structured content and fixed gameplay, which can limit improvisation and agency—key tenets of constructionist learning. Papert (1980) emphasized learning through design and self-directed exploration, advocating for environments with “low floors” (easy entry), “high ceilings” (complexity), and “wide walls” (diversity of approaches) (Resnick, 2006). Tools that over-rely on prescriptive digital sequences may diminish children’s capacity for divergent thinking and reduce opportunities for iterative learning (Neumann & Neumann, 2017). Additionally, rapid feedback loops and multimodal stimuli, while engaging, can lead to cognitive overload in young learners. Christakis et al. (2018) caution that overstimulation from fast-paced media may hinder the development of attention span and executive function.

5.2 Inequities in Access and Inclusion

Disparities in infrastructure and inclusive design constrain the potential of PGBL to support diverse learners. Vygotsky’s (1978) sociocultural theory emphasizes the mediating role of tools within the Zone of Proximal Development (ZPD); however, this mediation is dependent on equitable access to these tools. Children in under-resourced environments may lack access to tablets, internet connectivity, or adaptive interfaces, thereby exacerbating educational inequalities (Pynnönen et al., 2022). The UDL framework stresses the importance of offering multiple means of engagement and expression; yet, many PGBL tools lack affordances for learners with sensory, motor, or linguistic diversity (Gargiulo & Metcalfe, 2022).

5.3 Educator Preparedness and Pedagogical Alignment

Effective PGBL use requires educators to shift from didactic instruction to constructivist facilitation (Bers, 2020). However, many early childhood educators lack the Technological Pedagogical Content Knowledge (TPACK) necessary to integrate PGBL into developmentally appropriate practices (Mishra & Koehler, 2006). Without sufficient training and curriculum alignment, tools risk being used superficially or as entertainment rather than

as vehicles for critical thinking and reflection (Donohue & Schomburg, 2017). This disconnect undermines the cognitive affordances of PGBL and may reinforce traditional hierarchies rather than promote learner autonomy.

5.4 Cost and Scalability

PGBL tools often combine physical kits with digital subscriptions, presenting financial barriers to widespread adoption. Fixsen et al. (2005) emphasize the need for scalable and sustainable implementation strategies in educational innovation. Public institutions with limited budgets face challenges related to device procurement, maintenance, and teacher training. Without open-source alternatives or modular pricing, the scalability of PGBL remains restricted.

In sum, these implementation challenges are not merely logistical but reflect deeper tensions between pedagogical ideals and practical realities. Anchoring these categories in theory ensures a rigorous evaluative framework and highlights pathways for addressing systemic constraints.

6. Tools Overview

This section presents an analytical overview of the five representative phygital game-based learning (PGBL) tools that integrate physical manipulatives with digital feedback mechanisms in early childhood education (ECE). Drawing on key implementation challenges outlined earlier, each tool is evaluated in terms of its design features, educational affordances, and empirical evidence of impact.

6.1 Osmo Tangram

Osmo Tangram utilizes physical puzzle pieces and a tablet-mounted reflector to enable spatial problem-solving through real-time digital feedback. Research demonstrates that Osmo enhances children's engagement and collaborative reasoning by aligning physical manipulation with visual cues that scaffold learning within the Zone of Proximal Development (ZPD) (Schroth et al., 2019). However, limitations include potential overstimulation and restricted exploratory space, which may hinder open-ended play.

6.2 KIBO Robot

Developed by the DevTech Research Group, KIBO is a screen-free robotics platform that fosters computational thinking through tangible programming blocks. Grounded in Papert's constructionist theory, KIBO enables iterative, hands-on learning by encouraging children to build, test, and revise sequences (Bers, 2018). Empirical studies indicate significant improvements in sequencing and planning skills (Kazakoff et al., 2013). However, high costs and the need for intensive teacher training present barriers to scalability.

6.3 LEGO DUPLO Stories

LEGO DUPLO Stories combines physical block construction with digital storytelling via smart assistants, such as Alexa (Poulter, 2020). It supports open-ended creativity, spatial reasoning, and collaborative play—key attributes for early STEM readiness (Diezmann & Watters, 2000). The platform aligns with constructivist pedagogy by encouraging symbolic representation and hypothesis testing. Nevertheless, usability challenges and the dependency on external devices can affect autonomous exploration.

6.4 Marbotic Smart Letters

Marbotic Smart Letters integrate wooden alphabet pieces with phonics-based apps, delivering multisensory feedback that supports emergent literacy. The tool reflects Montessori principles and promotes cognitive flexibility through tactile experimentation (Maldonado & Zekelman, 2019). Although promising, the limited scope of peer-reviewed evidence and high dependency on tablets may reduce its inclusivity and limit its alignment with universal design.

6.5 PlayShifu Orboot Earth

PlayShifu's Orboot Earth utilizes augmented reality (AR) to provide interactive geography learning through a physical globe and companion app. It promotes curiosity, vocabulary enrichment, and contextual learning by situating information in real-world settings (Kelpšienė, 2020). However, its structured content design may constrain imaginative play, and access to AR-compatible devices can pose equity challenges.

Table 2: It presents a comparative synthesis of the five analyzed PGBL tools, evaluated across five key dimensions derived from the implementation challenges: open-ended play and cognitive flexibility, accessibility and equity, educator integration, cost and sustainability, and empirical evidence. This synthesis links theoretical constructs to practical considerations in early childhood education

Tool	Osmo Tangram	KIBO Robot	LEGO DUPLO Stories	Marbotic Letters	Orboot Earth (AR)
Open-Ended Play & Cognitive Flexibility	Moderate: Scaffolded problem-solving with limited free play	High: Constructionist iterative play	High: Promotes symbolic, creative construction	Moderate-High: Tactile literacy engagement	Moderate: Curiosity-driven, but pre-set narratives
Accessibility & Equity	Requires tablet & base (moderate access)	High cost; low accessibility in low-income settings	Relies on smart assistant devices	Tablet-dependent; limited UDL adaptation	High tech requirement; AR device needed
Educator Integration	Minimal setup; moderate pedagogical alignment	Requires intensive training (TPACK)	Moderate teacher facilitation	Low training threshold	Moderate integration
Cost & Sustainability	Moderate cost; app-based	Expensive hardware; non-scalable	Moderate cost; branded ecosystem	Mid-cost; limited classroom trials	Moderate-High cost
Empirical Evidence	Engagement, spatial reasoning (Schroth et al., 2019)	Sequencing, planning (Kazakoff et al., 2013)	Spatial & social skills (Diezmann & Watters, 2000)	Engagement, phonics (Maldonado & Zekelman, 2019)	Vocabulary, geography interest (Kelpšienė, 2020)

7. Discussion

Phyigital learning tools hold transformative potential when aligned with core principles of cognitive development. However, their educational value is contingent on how well they uphold the tenets of play, learner agency, and scaffolding.

Osmo’s visual-spatial games promote symbolic thinking and collaboration, aligning with Piaget’s constructivist learning theory. KIBO’s screen-free robotics supports early coding skills while reinforcing executive functions—especially when children engage in debugging and iterative design (Diamond, 2013; Bers, 2018). LEGO DUPLO Stories, through guided storytelling and brick-building, facilitate SEL and spatial reasoning, though reliance on Alexa narrows the scope for child-led inquiry. PlayShifu’s Orboot globe and Marbotic’s tactile phonics apps exemplify multisensory learning (Torres et al., 2021).

Yet, while these tools claim to foster critical thinking, the empirical validation varies widely—some, like KIBO, offer rigorous classroom-based results (Kazakoff et al., 2013), while others rely on qualitative or design-based observations (Maldonado & Zekelman, 2019). When assessed against implementation challenges, gaps become evident. For instance, while KIBO aligns with constructionist “low floor, high ceiling” principles, it demands high educator involvement. Similarly, Orboot encourages cultural learning but is limited in unstructured play. These gaps necessitate design enhancements grounded in universal design for learning (Meyer et al., 2014) and iterative evaluation models.

Thus, a critical takeaway is that the success of PGBL hinges not merely on tool design, but on the contextual integration of educator training, equitable access, developmental alignment, and curriculum synergy. Bridging these gaps can not only catalyze stronger learning outcomes but also foster innovation in inclusive digital pedagogy.

8. Conclusion

Phyigital game-based learning tools offer promising avenues for fostering higher-order thinking in early childhood. However, their long-term educational value requires further investigation. Future research should

adopt longitudinal, cross-cultural, and multi-method approaches to assess sustained cognitive and socio-emotional outcomes. Emphasis must also be placed on inclusive design aligned with Universal Design for Learning (UDL) to support diverse learners. By integrating cognitive assessments, classroom observations, and teacher insights, future studies can deepen understanding of how PGBL tools contribute meaningfully to differentiated instruction and holistic development across varied educational contexts.

Ethics Declaration: This research study draws exclusively on publicly accessible academic literature, institutional reports, and secondary data sources. No primary data involving human participants was collected, and no confidential or proprietary information was accessed through non-disclosure agreements. Consequently, ethical approval was not required for this study. All case analyses—Osmo, KIBO, Marbotic, PlayShifu, and LEGO DUPLO Stories—are based on open-source materials and existing research. Appropriate scholarly conventions and citation practices have been followed throughout to ensure academic integrity.

AI Declaration: Artificial intelligence tools, specifically ChatGPT and Perplexity AI, were utilized to aid in identifying recent academic references and publicly available literature relevant to the study. As the author, I conducted the conceptual framing, thematic development, structure, and writing of this paper independently without generative language support from AI tools. All AI-assisted outputs were critically evaluated and verified against original academic sources before inclusion.

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