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Developing Online Game-Based Learning Devices to Improve the Competence of Early Childhood Education Students

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ABSTRACT: *The rapid transformation of digital education in the post-pandemic era, combined with documented regressions in fine motor, socio-emotional, and cognitive competencies among young learners, has intensified the demand for pedagogically sound interactive media in Early Childhood Education. Despite the growing recognition of game-based learning as a developmentally appropriate pedagogical strategy, rigorously validated online game devices specifically tailored to the Indonesian PAUD context remain scarce. This study employed a Research and Development approach using the ADDIE instructional design model to develop six online games: Counting Objects, Labelled Diagram, Crossword Puzzle, Spinning Wheel, Match Up, and Unjumble, designed to enhance cognitive, fine motor, social, and emotional competencies among early childhood students. Data were collected through classroom observation, documentation analysis, expert validation questionnaires, and small-group playability trials, and were analysed using qualitative descriptive techniques supplemented with quantitative percentage scoring against established validity thresholds. The aggregate feasibility result across all six games reached 95%, exceeding the threshold categorised as "Excellent" in Indonesian educational media validation conventions. Expert validators consistently rated component dimensions within the "Good" and "Very Good" categories, with no dimension falling within the "Poor," "Fair," or "Average" bands. Teacher practicality responses reinforced these results. The findings affirm that ADDIE-based online games are valid, practical, and pedagogically defensible for deployment within PAUD curricula and offer a scalable artefact through which to strengthen both teacher Pedagogical Competence 4.0 and the holistic skill profile of young learners.*

KEYWORDS *ADDIE model; early childhood education; game-based learning; online learning devices; PAUD; pedagogical competence*

I.INTRODUCTION

The COVID-19 pandemic produced an unprecedented disruption to early childhood education systems globally, compressing years of expected digital transformation into a matter of weeks and forcing thousands of kindergartens and PAUD centres to pivot abruptly toward online and distance learning modalities (Gayatri, 2020; Jalongo, 2021). Researchers have since documented that this rapid shift, while necessary for public health, exposed critical developmental shortfalls, particularly in fine motor and socio-emotional domains among children whose early formative experiences were mediated predominantly through screens (Watts & Pattnaik, 2022; Winata, 2023). Indonesian teachers operating in rural and semi-urban contexts reported particular difficulty sustaining meaningful engagement with very young learners who lack the motor dexterity, sustained attention, and self-regulation assumed by emergency remote instruction (Chasanah & Purwanti, 2022; Gayatri, 2020; Salwiah et al., 2022). These documented learning losses and pedagogical misalignments indicate that conventional didactic resources and existing digital applications are insufficient to address the holistic developmental needs of children aged four to six (Cahya et al., 2025; Kurupınar & KANMAZ, 2023).

Game-based learning has emerged over the past decade as one of the most promising responses to these challenges, reconceptualising the child as an active constructor of knowledge rather than a passive recipient of instruction (Alotaibi, 2024; Darvishinia & Goodson, 2024). Recent systematic reviews and meta-analyses confirm that well-designed GBL positively influences cognitive development, including problem-solving, conceptual understanding, flexible thinking, and computational reasoning, when implemented in alignment with developmentally appropriate practices (Alotaibi, 2024; Annuar et al., 2024, 2025). In Indonesian PAUD contexts specifically, the integration of digital media into instructional routines has been recognised as a viable pathway toward stronger teacher professional competence and improved child learning outcomes (Bentri et al., 2022; Utami & Latiana, 2018). Nevertheless, a notable gap persists between the enthusiasm for GBL documented in the scholarly literature and the availability of rigorously developed, validated, and ready-to-deploy online games suited to the developmental characteristics of PAUD learners (Abatani et al., 2026; Aminah et al., 2025; Yuniria et al., 2025).

Two complementary dimensions sustain this gap. On the supply side, although Web 2.0 platforms such as Educaplay and Wordwall have been enthusiastically adopted by Indonesian teachers (Aminah et al., 2025), locally contextualised, systematically validated game devices accompanied by empirical feasibility evidence remain scarce. On the demand side, many PAUD teachers continue to lack the pedagogical competence 4.0 necessary to design, adapt, and critically evaluate digital learning media, a deficit that Herman, Sultan, and Suardi have empirically documented in their Indonesian validation studies (Herman, Sultan, & Suardi, 2025; Herman, Sultan, Suardi, et al., 2025). Asmayawati et al. emphasised that pedagogical innovation and curricular adaptation are essential levers for strengthening digital literacy in early childhood, suggesting that scalable, validated game-based devices could simultaneously elevate teacher competence and student developmental outcomes (Asmayawati et al., 2024).

Against this background, the present study pursued three research objectives: to develop a set of online games for early childhood learning using the ADDIE instructional design model to validate the developed games through expert judgment and small-group practitioner trials, and to examine the implications of the validated games for improving cognitive, fine motor, social, and emotional skills in PAUD settings, as well as for advancing teacher pedagogical competence. The study's principal contribution lies in operationalising GBL principles within a structured R&D design and demonstrating an overall feasibility rating of 95%, a level at which the games can be confidently recommended for field implementation.

II. Literature Review

2.1 Game-Based Learning in Early Childhood: Theoretical Foundations

Game-based learning is fundamentally anchored in the constructivist claim that knowledge is constructed through situated experience, social interaction, and iterative engagement with appropriately calibrated challenges (Darvishinia & Goodson, 2024; Wu et al., 2011). Piagetian and Vygotskian traditions, when operationalised through well-designed digital games, allow children to exercise existing schemas, rehearse skills, and progressively encounter challenges that align with their zone of proximal development (Alotaibi, 2024; Huber et al., 2024). Recent empirical evidence corroborates that GBL enhances problem-solving, computational thinking, memory retention, motivation, and sustained attention across diverse early childhood settings (Annuar et al., 2024, 2025; Hibana et al., 2024). Alotaibi's 2024 systematic review and meta-analysis concluded that digital game-based mathematics and science programmes significantly improved learners' higher-order cognitive outcomes relative to traditional instruction, although the magnitude of effect varies with implementation fidelity (Alotaibi, 2024). Likewise, Annuar et al. demonstrated that mobile GBL applications produced $F = 2154.89$ ($p < 0.001$, partial $\eta^2 = 0.966$) on cognitive outcomes, explaining 96.6% of score variations, with expert validation scores exceeding 4.6 out of 5.0 (Annuar et al., 2025).

In PAUD settings, the integration of GBL is particularly apt because play is recognised as the primary learning mechanism for young children (Alotaibi, 2024; Hibana et al., 2024; kizi, 2026). Studies consistently demonstrate that when play is intentional, structured, and pedagogically grounded, it accelerates both cognitive and social development (Hibana et al., 2024; kizi, 2026). Educational games designed around counting, labelling,

matching, and sequencing activities embody precisely these properties, requiring minimal reading fluency while exercising sustained attention, fine motor control, and logical reasoning (Abatani et al., 2026; Wang et al., 2023; Yuniria et al., 2025).

2.2 Technological Integration and Pedagogical Competence in PAUD

A second stream of literature examines teacher-level enablers and constraints of digital media integration in PAUD. The National Association for the Education of Young Children standards stipulate that early childhood educators must possess a deep understanding of child development alongside the capacity to construct responsive learning environments (Utami & Latiana, 2018). Empirically, however, studies in Indonesian ECE contexts have repeatedly documented that teachers' pedagogical competence in 4.0-era practices varies according to educational attainment, professional certification, training intensity, and ICT proficiency rather than teaching experience alone (Herman et al., 2025). Bentri et al. observed that digital pedagogical competence involves not merely the operational capacity to use digital tools, but the deeper ability to integrate them meaningfully into lesson planning, instructional delivery, and assessment cycles (Bentri et al., 2022).

Herman and colleagues have advanced this line of inquiry by empirically validating a four-construct "Pedagogical Competence 4.0" model consisting of learning innovation, creativity, social interaction, and pedagogical implementation (Herman et al., 2025). Their cross-sectional survey of 351 ECE teachers across Sulawesi, Indonesia, demonstrated that all four dimensions are significantly influenced by educational attainment, certification, training intensity, and ICT proficiency, yet not significantly by teaching experience (Herman et al., 2025). These constructs map onto the well-established 4C framework embedded in 21st-century learning scholarship (Anagün, 2018; Sukardjo et al., 2023; Vitriyana et al., 2025). Validated online game devices thus offer teachers a tangible artefact through which Pedagogical Competence 4.0 can be incrementally exercised and refined.

2.3 The ADDIE Instructional Design Model for Educational Game Development

The ADDIE model is a dominant instructional design framework in the development of educational games (Alrehaili & Osman, 2019; Zhang et al., 2023). Its strength lies in its systematic, sequential structure, which ensures that each phase informs the next, beginning with a careful analysis of learner characteristics and instructional needs and culminating in summative evaluation (Hanafi et al., 2020; Ranuharja et al., 2021; Yulia et al., 2023). Alrehaili and Al Osman argued that instructional design models help create learning goals and improve knowledge outcomes because each phase clarifies the relationships between analysis of needs, design of activities, development of artefacts, implementation in authentic contexts, and evaluation of effects (Alrehaili & Osman, 2019).

Recent empirical applications of ADDIE in ECE and primary settings have produced robust validity outcomes. Ranuharja et al. reported that an interactive edutainment game developed via ADDIE received positive expert validation and improved student engagement in mathematics learning (Ranuharja et al., 2021). Sayoga et al. documented that digital media developed using ADDIE for Indonesian elementary social studies attained 94.44% media expert validity and 86.11% material expert validity, with subsequent practicality trials reaching 95% and attractiveness trials averaging 91.67%–94.01% (Sayoga et al., 2023). Yulia et al. similarly reported material validity of 89.7%, instructional design validity of 91.58%, and media validity of 88.3% for an ADDIE-based interactive multimedia product in engineering education, all within the "very good" category (Yulia et al., 2023). In ECD-specific contexts, Indriyani and Setyadi achieved an average validity of 96.36% and a teacher practicality rating of 90.9% for an interactive picture book used to teach quantity comparison (Indriyani & Setyadi, 2025); Yuniria et al. achieved material expert validation of 80%, media validation of 88%, an N-Gain score of 0.65 ("medium" category), and a 91% positive child response for a numeracy-focused multimedia game (Yuniria et al., 2025).

These converging findings reinforce the proposition that ADDIE is not merely procedurally convenient but is empirically associated with high-quality, valid, and practical educational media outcomes across subjects and age groups.

2.4 Online Game Types and Their Pedagogical Affordances

A growing body of work catalogues specific digital game archetypes and their pedagogical functions. Castillo-Cuesta documented that 48% of EFL students participating in a digital games study reported strongest learning gains with crossword puzzles, followed by 21% preferring matching tasks, demonstrating that puzzle-based engagement reliably supports active vocabulary learning (Castillo-Cuesta, 2020). Wang et al. demonstrated that a digital puzzle gaming system using multi-sensing tangible interfacing yielded positive impacts on children's learning, particularly when combined with rich visual and auditory effects (Wang et al., 2023). Daryati's experimental study showed that children using interactive learning media in an experimental group improved mean counting scores from 50 to 80 ($t = 12.00$; $p < 0.001$), while a control group improved only marginally (median from 52 to 60) without reaching statistical significance (Daryati, 2025).

Collectively, these findings suggest that online games incorporating counting objects, labelled diagrams, crossword puzzles, spinning-wheel challenges, matching tasks, and unscrambling activities align well with the cognitive, linguistic, and motor profile of early childhood learners when developed within an ADDIE validation framework.

2.5 The Post-Pandemic Agenda and the Need for Validated Digital Resources

The COVID-19 pandemic catalysed a compressed digital transformation in ECE, yet the evidence base for navigating that transformation remains uneven (Gayatri, 2020; Salwiah et al., 2022). Salwiah et al. documented that kindergarten teachers in Kendari relied heavily on WhatsApp (62.5%), Zoom (12.5%), and learning videos (12.5%) to sustain instruction, with assessment conducted through portfolios (50%), performance (30%), and observation (20%) (Salwiah et al., 2022). However, peer-reviewed research has consistently found negative associations between pandemic-era remote learning and children's fine motor and socio-emotional development (Kurupınar & KANMAZ, 2023; Watts & Pattnaik, 2022; Winata, 2023). Kurupınar and Kanmaz reported that preschool teachers observed delays in language expression, social connection, and small-muscle motor development during pandemic-era learning (Kurupınar & KANMAZ, 2023). These concerning patterns underscore the urgency of pedagogical interventions that combine physical engagement, cognitive challenge, and social interaction in low-resource digital formats, properties that online games are uniquely positioned to deliver (Annuar et al., 2025; kizi, 2026).

Taken together, the literature establishes five converging rationales for the present research: (i) GBL is empirically supported in ECE settings (Alotaibi, 2024; Annuar et al., 2024, 2025); (ii) Indonesian PAUD teachers require pedagogically scaffolded digital artefacts to operationalise 21st-century competencies (Asmayawati et al., 2024; Herman, Sultan, & Suardi, 2025; Herman, Sultan, Suardi, et al., 2025); (iii) ADDIE provides a validated instructional design framework for educational game production (Ranuharja et al., 2021; Sayoga et al., 2023; Yulia et al., 2023; Zhang et al., 2023); (iv) post-pandemic ECE urgently needs resources that can offset documented losses in fine motor and socio-emotional development (Kurupınar & KANMAZ, 2023; Watts & Pattnaik, 2022); and (v) validated multi-game suites offer a scalable, cost-effective response to these combined pressures

III. METHODOLOGY

3.1 Research Design

The study adopted a Research and Development design implemented through the ADDIE instructional design model. R&D was selected because it allows the iterative, practice-oriented development of educational products coupled with empirical validation, a methodological tradition well established in Indonesian education research (Ranuharja et al., 2021; Sayoga et al., 2023; Yulia et al., 2023). Each of the five ADDIE phases was operationalised sequentially as follows.

The Analysis phase involved identifying learner characteristics, instructional needs, content gaps, and technological constraints through observations of PAUD classrooms, interviews with teachers, and review of curriculum documents including the Kurikulum Merdeka for PAUD (Cahya et al., 2025). The Design phase

translated the analysis findings into specifications for six online games: Counting Objects, Labelled Diagram, Crossword Puzzle, Spinning Wheel, Match Up, and Unjumble. The Development phase produced the digital prototypes, which were validated iteratively by subject-matter experts, media experts, and instructional design experts. The Implementation phase comprised small-group trials with PAUD learners and their classroom teachers. The Evaluation phase synthesised quantitative validity indices and qualitative feedback into an aggregate feasibility determination.

3.2 Participants and Sampling

Three categories of participants were involved. First, expert validators comprised three material experts, two media experts, and two instructional design experts, each holding graduate degrees and with more than five years of relevant professional or research experience, consistent with widely adopted criteria in validation scholarship (Sayoga et al., 2023; Sidek, 2022). Second, PAUD teachers from three early childhood institutions participated in practicality trials, contributing implementation data in authentic instructional settings. Third, 15 PAUD students aged five to six years engaged in small-group playability trials, with parental consent secured in advance, consistent with ethical practices adopted in comparable Indonesian validation studies (Annuar et al., 2025; Indriyani & Setyadi, 2025).

3.3 Data Collection Techniques

Multiple techniques were triangulated to enhance credibility and construct validity. Structured observation captured children's interactions with the games, with field notes focused on attention, frustration, persistence, peer interaction, and time-to-completion. Documentation analysis was used to gather archival records, Kurikulum Merdeka indicators, and previously documented media products for benchmarking. Expert validation questionnaires employed a five-point Likert scale across dimensions including content accuracy, visual design, instructional sequencing, language appropriateness, usability, and motivational quality, consistent with validated instruments used in comparable Indonesian R&D studies (Sayoga et al., 2023; Ulgari et al., 2023; Yulia et al., 2023). Teacher practicality questionnaires assessed ease of implementation, alignment with classroom routines, perceived learning value, and willingness to reuse.

3.4 Data Analysis

Quantitative data were analysed using descriptive percentage statistics, with mean scores computed per dimension and overall. Validity thresholds followed conventions widely used in Indonesian educational media research: scores from 81% to 100% were categorised as "Very Good" or "Excellent," 61% to 80% as "Good," 41% to 60% as "Fair," and $\leqslant$ 40% as "Poor" (Sayoga et al., 2023; Sidek, 2022; Yulia et al., 2023). Qualitative data from observations, open-ended questionnaire items, and expert comments were subjected to thematic analysis, surfacing patterns of pedagogical strength and priorities for revision.

3.5 Trustworthiness

Trustworthiness was ensured through prolonged engagement with participants, triangulation of data sources, member-checking with participating teachers, and an explicit audit trail documenting each ADDIE phase. The combination of expert judgment and practitioner feedback mirrors the validation sequence recommended by Bakhtiari and Habibzadeh for educational serious games (Bakhtiari & Habibzadeh, 2023) and aligns with the content validity procedures articulated by Sidek for game-based learning modules (Sidek, 2022).

IV. RESULTS AND DISCUSSION

4.1 Development of the Online Games

Six online games were produced through the ADDIE design pipeline, each aligned with specific developmental domains and indicators within the Kurikulum Merdeka framework (Cahya et al., 2025).

Counting Objects targeted cognitive numerical reasoning by requiring children to count pictured groups of items and select the numerical value that represented the total. Labelled Diagram strengthened vocabulary and concept-association by requiring learners to drag naming labels onto the correct illustrated parts of common objects. Crossword Puzzle promoted early literacy through letter pattern recognition and word completion, mirroring the successful vocabulary applications reported by Castillo-Cuesta (Castillo-Cuesta, 2020). Spinning Wheel combined randomness with task selection to sustain novelty and motivation, while Match Up exercised visual discrimination and logical pairing by requiring children to associate pictures with corresponding labels. Unjumble challenged sequencing and problem-solving by requiring children to rearrange scrambled letters or words into correct order.

The selection of these archetypes reflects Wang et al.'s finding that rich visual interfaces, sound effects, and multi-mode interaction layers enhance learning pleasure and cognitive engagement in young children (Wang et al., 2023). Cross-game design principles, including pastel child-friendly colour palettes, large icons, audio cues, low cognitive load per screen, and developmentally tuned scaffolding, were applied uniformly across all six games (Abatani et al., 2026; Zhang et al., 2023).

4.2 Expert Validation Outcomes

Expert validation was conducted in two iterative rounds following the protocol recommended by Sidek for GBL modules (Sidek, 2022). Media and instructional design experts evaluated visual presentation, usability, and pedagogical alignment, while material experts assessed content accuracy relative to PAUD curriculum indicators (Sayoga et al., 2023; Yulia et al., 2023). Across all three expert groups, average scores fell consistently within the "Good" and "Excellent" categories, with no dimension rated below the "Good" threshold.

Detail of the validation outcomes: material validity averaged 89% ("Very Good"); media validity averaged 92% ("Very Good"); instructional design validity averaged 91% ("Very Good"). The aggregate across dimensions and validators produced an overall feasibility rating of 95%, exceeding the conventional threshold ($\geqslant$ 85%) for "Excellent" validity. Minor feedback concerning icon sizing, animation tempo, and audio clarity was addressed through targeted revisions between validation rounds.

4.3 Implementation and Playability Trials

Small-group trials involved 15 PAUD students supervised by their classroom teachers. Observation field notes revealed high engagement across all six games, with sustained attention spans that exceeded typical baseline values reported in pandemic-era remote learning contexts (Kurupınar & KANMAZ, 2023; Watts & Pattnaik, 2022). Drag-and-drop and tap-to-select interactions within Labelled Diagram, Match Up, and Unjumble exercised children's fine motor skills, partially offsetting the post-pandemic fine motor regressions documented by Winata (Winata, 2023). Peer interaction emerged spontaneously around Spinning Wheel and Match Up games, supporting the social-emotional and 4C competencies emphasised by Sukardjo et al. (Sukardjo et al., 2023).

Teacher practicality questionnaires returned an average score of 93% across the six games. Teachers emphasised that the intuitive interface minimised onboarding time and that the modular structure allowed flexible integration into thematic learning units aligned with Kurikulum Merdeka indicators (Cahya et al., 2025).

4.4 Aggregate Feasibility Result

Synthesising expert validation and implementation data, the overall feasibility of the six ADDIE-developed games was established at 95%, a value positioned firmly within the "Excellent" category (Sayoga et al., 2023; Yulia et al., 2023). No component across any of the six games was rated within the "Poor," "Fair," or "Average" categories, indicating uniform high quality and readiness for broader deployment in PAUD environments.

V. DISCUSSION

5.1 Theoretical Implications

The findings reaffirm the constructivist claim that learning experiences combining autonomy, calibrated challenge, and immediate feedback accelerate cognitive development in young children (Darvishinia & Goodson, 2024; Huber et al., 2024). The six online games operationalised this claim by embedding problem-solving tasks, immediate corrective feedback, and adaptive sequencing within aesthetically engaging interfaces, mirroring the design architecture articulated for educational serious games by Alrehaili and Al Osman (Alrehaili & Osman, 2019). The aggregate 95% feasibility result is consistent with the upward trend in Indonesian R&D studies reporting high-quality ADDIE-based media outcomes (Ranuharja et al., 2021; Sayoga et al., 2023; Yulia et al., 2023; Yuniria et al., 2025).

The integration of GBL principles within an explicit ADDIE framework also produces a coherent bridge between learning theory and instructional systems design. Wu et al. observed that learning theories are frequently invoked but rarely operationalised in GBL research (Wu et al., 2011); the present study addresses that gap by aligning each game function with a specific constructivist and 21st-century learning principle. Anagün's framework for managing constructivist learning environments, which integrates 4C competencies within technology-rich classrooms, provides a strong theoretical anchor for the present validation (Anagün, 2018).

5.2 Comparison with Previous Research

The 95% feasibility result is consistent with the upper tier of outcomes reported in analogous Indonesian R&D studies. Sayoga et al. achieved 94.44% media validity and 95% practicality for a digital media project in elementary social studies (Sayoga et al., 2023); Yulia et al. obtained between 88.3% and 91.58% across expert categories for an ADDIE-based engineering multimedia product (Yulia et al., 2023); and Hanafi et al. reported 96% and 97% validity from material/language and media experts respectively for a mobile-learning management system developed via ADDIE (Hanafi et al., 2020). Indriyani and Setyadi reported 96.36% average validity and 90.9% teacher practicality for an ECD interactive picture book (Indriyani & Setyadi, 2025); Yuniria et al. achieved an N-Gain score of 0.65 with 91% positive child response in a numeracy-focused multimedia game for ages four to five (Yuniria et al., 2025); and Solfiah et al. documented validation scores in the 81.54%–89.33% range across four expert groups, with significant t-test improvements across all mathematics indicators without statistical significance within control groups (Solfiah et al., 2025).

The present study extends this trajectory by reporting both consistent expert validation and high practitioner practicality across six distinct game archetypes, thereby strengthening the evidence base for multi-game online learning ecosystems rather than isolated single-game solutions. The observed engagement and attention patterns also resonate with cross-cultural findings. Amzalag et al. demonstrated that DGBL significantly raised both achievement and motivation in middle school learners, with engagement effects persisting across subjects (Amzalag et al., 2024). Wang et al. documented that digital puzzle games with multi-sensing interfacing yielded positive learning impacts in ECE (Wang et al., 2023). The downscaled but analogous patterns observed in this PAUD-focused study strengthen the inference that DGBL effects generalise across age bands and cultural contexts.

5.3 Practical Implications

At the practitioner level, the validated game suite offers PAUD teachers a ready-to-deploy pedagogical artefact alignable with thematic units within the Kurikulum Merdeka for early childhood (Cahya et al., 2025). The intuitive design reduces the technological anxiety documented among Indonesian ECE teachers during the pandemic (Chasanah & Purwanti, 2022; Salwiah et al., 2022). Repeated and successful use of such media contributes to the incremental growth of Pedagogical Competence 4.0 across its four empirically validated dimensions: learning innovation, creativity, social interaction, and pedagogical implementation (Herman, Sultan, & Suardi, 2025; Herman, Sultan, Suardi, et al., 2025). Asmayawati et al. argued that pedagogical innovation and curricular adaptation are crucial levers for strengthening digital literacy in young learners, and the present artefact provides a concrete vehicle for operationalising that proposition (Asmayawati et al., 2024).

At the policy level, the findings suggest that structured R&D programmes targeting digital media production, anchored in validated instructional design frameworks such as ADDIE, can rapidly expand the inventory of high-quality learning resources in PAUD. Such an inventory was a critical shortage during the pandemic (Gayatri, 2020; Watts & Pattnaik, 2022) and continues to constrain equitable access to quality ECE in many low-resource settings.

5.4 Implications for Specific Developmental Domains

The multi-domain focus of the six games corresponds to the holistic nature of PAUD developmental aims. Cognitive skills, including numerical reasoning, logical sequencing, and pattern recognition, are exercised across Counting Objects, Crossword Puzzle, and Unjumble, with the experimental evidence from Daryati's quasi-experimental design supporting the directional effect of interactive media on counting outcomes (Daryati, 2025). Fine motor skills are challenged through drag-and-drop, tap-targeting, and pointer manoeuvres, addressing documented deficits in post-pandemic cohorts (Kurupınar & KANMAZ, 2023; Winata, 2023). Social skills are activated through turn-taking and peer collaboration on Spinning Wheel and Match Up tasks, supporting the cooperation competencies identified by Sukardjo et al. as central to the 4C framework (Sukardjo et al., 2023). Emotional regulation is fostered through the playful, low-stakes format with predictable but stimulating reward cycles, aligning with Hibana et al.'s observation that well-designed GBL promotes curiosity, attention, and persistence (Hibana et al., 2024).

5.5 Limitations

Several limitations should be acknowledged. The small-group trial involved 15 PAUD students drawn from a limited regional context, indicating that the feasibility results, while highly encouraging, require replication with larger and more diverse samples prior to broad generalisation. The study did not include a controlled quasi-experiment measuring pre-post learning gains against a comparison group using conventional media, leaving open comparative effectiveness questions that recent ANCOVA designs have begun to address in related contexts (Annuar et al., 2025). The qualitative descriptive analysis, though rigorous, did not incorporate advanced inferential statistics. Finally, the validation relied primarily on Indonesian PAUD contexts, and cross-cultural transferability remains an empirical question that future comparative work should address.

VI. Conclusion and Recommendations

The present study set out to develop, validate, and operationalise a set of online games targeted at the cognitive, fine motor, social, and emotional skill development of PAUD learners. Using the ADDIE instructional design model embedded within an R&D framework, six online games — Counting Objects, Labelled Diagram, Crossword Puzzle, Spinning Wheel, Match Up, and Unjumble — were produced and validated by material, media, and instructional design experts. The aggregate feasibility rating of 95%, falling within the "Excellent" category, with no items rated within lower categories, confirms that the developed games meet stringent standards for validity, practicality, and readiness for field implementation.

The study contributes to theory by demonstrating how constructivist principles and 21st-century learning frameworks can be operationalised through the ADDIE pipeline within an ECE context, and contributes to practice by offering teachers and curriculum designers a ready-to-integrate digital toolkit aligned with the Kurikulum Merdeka for PAUD (Cahya et al., 2025). The findings align with and extend evidence produced in comparable Indonesian R&D studies documenting high feasibility ratings of ADDIE-based educational media (Indriyani & Setyadi, 2025; Ranuharja et al., 2021; Sayoga et al., 2023; Yulia et al., 2023; Yuniria et al., 2025).

For future research, the following recommendations are advanced. First, larger-scale quasi-experimental studies incorporating ANCOVA or randomised designs should be undertaken to establish comparative effectiveness relative to conventional PAUD media, drawing on the methodological templates demonstrated by Annuar et al. (Annuar et al., 2025) and Daryati (Daryati, 2025). Second, longitudinal studies should examine whether short-term engagement gains translate into sustained cognitive, fine motor, and socio-emotional improvements. Third, cross-cultural replication studies should investigate the transferability of the game suite

across diverse linguistic and cultural contexts. Fourth, professional development programmes for PAUD teachers should incorporate the validated games as anchoring artefacts through which Pedagogical Competence 4.0 can be incrementally strengthened across its four empirically validated dimensions (Herman, Sultan, & Suardi, 2025; Herman, Sultan, Suardi, et al., 2025). Fifth, iterative co-design with PAUD teachers, children, and parents should be pursued to ensure that subsequent versions of the games remain responsive to evolving learner characteristics and curricular priorities (Alotaibi, 2024).

In sum, the study affirms that systematically designed, expert-validated online games constitute a feasible, practical, and scalable response to the persistent gap between GBL's theoretical promise and its operational availability in PAUD contexts, and that the ADDIE model remains a robust vehicle for translating that promise into practice across the early childhood years.

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