Apps Meet Ancestry: A Digital Ethnomathematics Play Framework for Preschool Problem-Solving

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ABSTRACT

Culturally-relevant mathematics experiences are rarely woven into the fast-growing market of preschool learning apps, leaving an untapped opportunity to foster heritage appreciation and early problem-solving skills. This study, therefore, introduces Ancestry Play. This tablet-based framework embeds ethnomathematical artefacts, batik tessellations, traditional bead patterns, and folklore-inspired puzzles into adaptive, play-centred challenges for children aged 4 to 6. Guided by design-based research, we translated three principles (cultural authenticity, playful scaffolding, and data-driven adaptation) into a modular architecture comprising Story, Pattern, and Builder mini-games. A quasi-experimental trial was conducted with 112 Nusa Tenggara Timur (NTT) Indonesian preschoolers: an experimental group (n = 57) used Ancestry Play for six weeks in 20-minute daily sessions, while a control group (n = 55) followed their usual paper-based numeracy routine. Pre- and post-assessments employed the Math Problem-Solving Checklist and in-app analytics; data were analyzed with ANCOVA and thematic coding. Results revealed a statistically significant gain in complex problem-solving ($F(1,109)=9.87$, $p < .01$, $\eta^2 = .083$) for the experimental cohort, accompanied by higher engagement time ($M = 14.2$ min $\pm$ 2.1) and frequent strategy shifts that mirrored indigenous pattern heuristics. Qualitative observations indicated elevated cultural pride and peer narration around ancestral motifs. The findings suggest that ethnomathematics-infused digital play boosts early mathematical reasoning and strengthens cultural identity. We discuss scalability across diverse heritages and outline future work on longitudinal retention and teacher-authored content plug-ins.

Keywords: Ethnomathematics, digital play, preschool, problem-solving, computational thinking.

1. Introduction

Problem-solving abilities developed during preschool are critical predictors of later successes in Science, Technology, Engineering, and Mathematics (STEM) and creative reasoning. However, current pedagogical tools and resources for children ages 4 to 6 frequently fail to resonate with their cultural experiences. Many of these resources consist of decontextualised counting sheets or generic matching applications. Such a disconnect can alienate minoritised learners and exacerbate achievement gaps, as these children may not see their backgrounds

reflected in their learning materials(Quinn et al., 2025).

Research shows that active learning experiences are essential for nurturing problem-solving abilities in young children. Bahar and Aksüt (2020) revealed that activity-based science education significantly enhances the acquisition of problem-solving skills in preschool-aged children(Bahar & Aksüt, 2020). This assertion is echoed by various studies advocating for the incorporation of culturally relevant pedagogies, which underscore the importance of leveraging familiar contexts to engage students effectively in computational thinking (CT) and problem-solving activities (Odgaard, 2022). For example, Montuori et al. (2023) found that introducing computational thinking through combinatory unplugged activities and educational robotics at an early age helps cultivate vital skills, including logical reasoning and creativity(Montuori et al., 2023). Conversely, inadequate alignment with children's cultural contexts can result in disengagement and hinder educational progress, particularly for those from marginalized communities [(Cheung, 2018).

Implementing computational thinking within preschool curricula is a growing area of focus. Studies have indicated that interactions with programming and robotics activities can deepen children's engagement and foster curiosity and creativity (Gaki & Jimoyiannis, 2023). Educational robotics, for instance, has been identified as an effective medium for developing computational skills, as evidenced by Gerosa et al. (2022), who demonstrated that task engagement in robotics enhances problem-solving abilities in preschoolers(Gerosa et al., 2022). Furthermore, the rich language and social dynamics educators encourage during such activities are crucial for stimulating children's cognitive and verbal interactions, which foster a collaborative learning environment and support the educational development of all students, especially those from diverse backgrounds (Fridberg & Redfors, 2024).

One promising approach to enhance problem-solving skills while respecting children's cultural contexts is through tailored educational technology. Initiatives integrating local cultural narratives with coding and robotics have shown potential to foster engagement and cognitive skill development (Papadakis, 2022). Such efforts bridge cultural divides and ensure that all learners feel represented in their educational experiences, thus promoting inclusivity and equity in early childhood education (Su et al., 2024). Ultimately, educational resources must transcend generic applications and reflect preschool learners' diverse cultures and experiences to support their problem-solving competence and broader academic growth in STEM fields.

Ethnomathematical scholarship highlights the inherent connections between mathematical concepts and cultural artifacts, such as bead-loom symmetries, weaving sequences, and storytelling rhythms. Integrating these elements into early-years education has enhanced children's affective engagement and promoted deeper conceptual discussions within the classroom context. Research indicates that when ethnomathematical ideas are employed within educational frameworks, learners exhibit greater interest and a stronger connection to their cultural identities, leading to an enriched learning experience(Umbara et al., 2021).

Recent studies in regions such as Indonesia and South Africa have corroborated these findings, revealing that interaction with local pattern motifs can bolster students' geometric reasoning and reinforce their social identities (Hosokawa et al., 2025). However, it is noteworthy that most of these interventions involve analogue resources, such as wooden manipulatives and printed cards, and are often confined to single classroom settings(Godwin, 2020). This limitation suggests a significant opportunity for expansion and adaptation, particularly through integrating digital tools that could amplify the reach and impact of ethnomathematical practices in diverse educational contexts.

Adopting multimodal approaches employing traditional and digital resources is essential to foster a more durable connection between children and mathematical ideas. By combining

the tactile experiences offered by physical manipulatives with the engaging nature of technology, educators can create a more dynamic learning environment that enhances mathematical understanding and respects and celebrates children's cultural heritages (Rodríguez-Nieto & Alsina, 2022). Moreover, ongoing professional development for educators in this realm is vital, as many teachers may require additional support in learning how to effectively incorporate these culturally relevant materials into their pedagogical practices (Supriadi, 2019).

Furthermore, integrating technology into the classroom opens pathways for collaborative projects connecting multiple classrooms across different communities, thus broadening the impact of ethnomathematical scholarship. Such initiatives would encourage children to engage with mathematical concepts through the lens of their lived experiences while also interacting with peers from diverse backgrounds. As educators leverage digital tools alongside ethnomathematical principles, the potential to enrich children's learning experiences, foster mathematical reasoning, and affirm their identities will be immensely enhanced(Schillinger, 2021). Integrating ethnomathematical ideas within early-years education through innovative partnerships between culture, pedagogy, and technology presents an exciting avenue for addressing educational disparities while promoting meaningful math learning among young children.

Digital Game-Based Learning (DGBL) has demonstrated significant gains in foundational numeracy and executive function skills among preschoolers, particularly when children engage with well-designed tablet games that offer immediate feedback and adaptive challenges (Lavigne et al., 2021). This engaging form of learning allows for interactive experiences that enhance cognitive development, making it an effective tool for early education. Despite the burgeoning market for children's applications, less than 5% of these apps explicitly incorporate cultural heritage, and there is a lack of resources that effectively integrate ethnomathematics with adaptive analytics or computational thinking frameworks (Robledo-Castro et al., 2025). This gap represents a crucial shortcoming in the educational technology landscape and a missed opportunity to leverage cultural contexts for equity in learning.

The emphasis on cultural relevance in educational resources is evident in studies indicating that ethnomathematics integrated into learning can significantly enhance students' conceptual understanding and engagement. For example, incorporating cultural artifacts and narratives into DGBL experiences has fostered mathematical reasoning and social identity (Saxena & Chiu, 2022). Culturally responsive digital tools could help mitigate achievement gaps and better engage minoritized learners, as they are more likely to see their backgrounds reflected in their educational materials (Komis et al., 2021). While previous DGBL interventions have primarily utilized analogue methods, such as physical manipulatives and printed cards, a strong argument exists for integrating digital platforms that represent and celebrate local cultures (M. L. Lin & Faldowski, 2023). Online and app-based resources can provide flexibility and scalability that traditional resources often cannot, allowing for broader access and collaborative learning experiences. Moreover, DGBL can incorporate adaptive analytics to tailor learning experiences to individual children's needs and challenges, enhancing efficacy (Monteiro et al., 2021).

Considering this potential, the lack of culturally relevant DGBL solutions emphasises an urgent need for research and development. Scholars advocate for the design of apps that engage preschoolers in numeracy and executive functions and resonate with their sociocultural backgrounds. These culturally relevant educational technology frameworks are instrumental in promoting equity and harnessing the educational power of diversity (Ismet et al., 2022). Future developments in this field should focus on creating culturally anchored digital platforms that interweave computational thinking with ethnomathematics, thereby harnessing technology as a lever for educational

equity. While DGBL presents vast opportunities for enhancing foundational skills in early childhood education, the absence of culturally anchored digital learning tools reveals significant gaps. By addressing these gaps and integrating ethnomathematics and adaptive strategies within DGBL, educational practitioners and researchers could foster greater engagement and achievement among all young learners, particularly those from minoritized backgrounds.

To address this gap, we present Ancestry Play, a modular tablet framework that weaves Indonesian ancestral motifs (batik tessellations, songket bead patterns, folktale quests) into adaptive mini-games. Grounded in design-based research and sociocultural learning theory, the project asks:

RQ1. Does an ethnomathematics-infused digital play framework produce greater gains in preschoolers' complex problem-solving than conventional paper-based numeracy activities?

RQ2. How do children engage with and verbalize culturally embedded mathematical representations during digital play?

RQ3. What usage patterns and strategy shifts emerge from in-app analytics, and how do these relate to learning gains?

This work presents a significant contribution through three key components: (i) a design blueprint that bridges cultural authenticity with real-time learning analytics, (ii) empirical evidence from a six-week quasi-experiment involving 112 Indonesian preschoolers, and (iii) open resources aimed at supporting researchers and developers who focus on diverse heritages. The importance of culturally relevant education in early childhood settings has been documented in literature, noting that educational resources reflecting the cultural backgrounds of learners can lead to increased student engagement and deeper learning outcomes [22].

2. Methodology

2.1 Research Model and Hypotheses

A quasi-experimental, non-equivalent control-group design was adopted because intact preschool classes could not be randomly reorganized. The independent variable was the type of numeracy activity (ethnomathematics-infused digital play vs. conventional paper activities). The primary dependent variable was the post-test complex problem-solving score, with the pre-test score treated as a covariate hypothesis as in Table 1.

Table 1. Hypothesis

ID	Hypothesis
H1	Children who use *Ancestry Play* will outperform peers receiving conventional paper-based instruction on the post-test complex problem-solving measure ($\alpha = 0.05$).
H2	*Ancestry Play* users will record higher behavioural engagement (time-on-task, voluntary session launches) than control peers.
H3	Children will exhibit qualitatively richer verbal strategy talk when manipulating cultural artefacts in the app compared with paper tasks.

The blueprint developed in this study aims to intertwine culturally authentic content with practical learning analytics, providing educators with the tools to monitor and adapt their teaching practices in real-time. Research has indicated that integrating cultural elements into mathematics education, such as through ethnomathematics, can improve student engagement and understanding (Supriadi et al., 2022). By utilizing real-time analytics, educators receive immediate feedback on student interactions, which is crucial for tailoring instruction to meet diverse learners' needs and enhance their problem-solving abilities (Procopio et al., 2024a).

The quasi-experiment with 112 Indonesian preschoolers will provide empirical evidence supporting the effectiveness of the proposed design. This aligns with findings from various studies indicating that play-based learning, especially when enriched with cultural artifacts and local mathematical concepts, enhances cognitive and social skills in preschool children (Zeytinoglu et al., 2019). For instance, incorporating regional patterns and cultural narratives in educational games has strengthened geometric reasoning and promoted social identity, fostering a more inclusive academic environment (Karno & Hatcher, 2020).

Moreover, this initiative intends to foster collaboration among educators and researchers targeting diverse heritages by providing open resources. The potential impact of this resource sharing can catalyze further research and development in culturally relevant educational technologies. It is essential to address the gap highlighted by the literature: less than 5% of children's apps currently reflect any cultural heritage [33]. By offering templates and resources adaptable to local contexts, this work aims to inspire a new generation of educational tools that are culturally anchored and beneficial to all learners. This contribution outlines a practical framework for incorporating cultural authenticity into preschool education while presenting valuable empirical data and resources that can influence future educational practices. As interdisciplinary research evolves, such initiatives will be critical in closing equity gaps in academic outcomes, particularly in computational thinking and mathematics education for young learners

2.2 Participants

Two urban Maggarai NTT Indonesian preschools with comparable teacher–child ratios (1:15) and identical semester curricula. Sample 112 children (57 in Experimental, 55 in Control); age = 4 – 6 years (M = 5.2, SD = 0.6); 53 % female. One class per school was randomly designated Experimental or Control to minimize cross-group contamination.

2.3 Instruments

The study employed a set of research instruments covering cognitive, behavioural, affective/cultural, and qualitative dimensions to collect reliable and comprehensive data. These instruments were carefully developed and validated to ensure psychometric soundness and contextual relevance. The selection of tools reflects the multidimensional nature of early childhood learning, capturing problem-solving skills, engagement patterns, cultural expressions, and interactive behaviours. The research instrument grid is presented in Table 2, which outlines the specific instruments used, their psychometric properties, and validation processes. This structured approach ensured that data collection was rigorous, systematic, and aligned with Indonesian early childhood education indicators.

Table 2. The Research Instrument Grid

Category	Instrument	Psychometric Properties
Cognitive	Math Problem-Solving Checklist (MPSC) – 18-item observation & performance tool aligned with Indonesian ECE numeracy indicators.	Cronbach's $\alpha = 0.91$; inter-rater $\varkappa = 0.82$ (pilot, $n = 30$).
Behavioural	In-App Analytics – session count, duration, level progression, hint requests (logged automatically).	Construct validity was established via expert review of event taxonomy.
Affective / Cultural	Cultural Engagement Rubric (CER) – 5-point scale of cultural identification expressions (e.g., motif naming, ancestral storytelling).	$\alpha = 0.87$; two-coder $\varkappa = 0.79$.
Qualitative	Semi-Structured Observation Guide – prompts for strategy talk and collaborative play.	Content validity ensured through iterative expert feedback.

2.4 Procedure

To evaluate the effectiveness of the intervention, the study followed a structured experimental procedure consisting of several phases, from preparation to post-assessment. The design ensured consistency across groups while maintaining methodological rigour through controlled conditions and standardized testing. Both experimental and control groups received equivalent exposure in terms of time and curriculum coverage, with the primary difference being the mode of delivery.

Table 3 presents an overview of the experimental procedure, outlining the sequence of phases, duration, and key activities undertaken throughout the study. This systematic approach provided a clear framework for data collection, facilitated reliability in implementation, and supported the validity of comparisons between groups.

Table 3 The Experiment Procedure

Phase	Week(s)	Activities
Orientation	0	Teachers were trained (4 h workshop) on the study protocol, tablets were configured, and children were familiarised with the devices (10 min free play).
Pre-Testing	1	MPSC administered individually (≈ 8 min/child).
Intervention	1 – 6	• Experimental: 20-minute daily sessions (Mon–Fri) with *Ancestry Play* in learning centres. • Control: identical schedule using standard paper worksheets and manipulatives covering the same curriculum objectives. Teacher prompts were limited to general encouragement in both groups.
Observations	2, 4, 6	Two trained observers alternated visits, capturing CER ratings and verbatim strategy talk samples.
Post-Testing	7	MPSC was re-administered by blinded assessors, and debriefing sessions were held with teachers and children.

2.5 Data Analysis

The data analysis was conducted through a series of systematic steps to ensure rigour and reliability. Pre-analysis checks addressed missing data, which were minimal (< 2%) and imputed using expectation–maximization. Assumptions of normality and homogeneity were tested using the Shapiro–Wilk and Levene's tests, respectively. A one-way ANCOVA was employed for quantitative analyses to test H1, with post-test MPSC scores as the dependent variable, group as the independent variable, and pre-test as the covariate. To test H2, the median daily time-on-task was compared between groups using the Mann–Whitney U test, and the effect size r was reported. Effect sizes were expressed as partial η^2 for ANCOVA and r for U-tests, while Holm–Bonferroni adjustments were applied for multiple comparisons.

Learning analytics were examined by applying the SPADE algorithm to event logs to identify common strategy paths, followed by Spearman correlations between mastery trajectories and post-test gains. For H3, qualitative data from child utterances were transcribed, coded openly, and then further organized through axial coding to generate thematic networks of strategy talk. Credibility was strengthened via coder triangulation and member checking with teachers. Finally, a convergent mixed-methods

matrix was used to integrate findings, aligning quantitative performance outcomes with observed qualitative strategy themes. All analyses were conducted in R version 4.3.2, with statistical significance set at $p < 0.05$.

3. Results

3.1 App-Usage Statistics

App-usage statistics were logged automatically throughout the six-week implementation to capture engagement patterns with the digital intervention. These analytics provided objective measures of children's interaction with the application, including session frequency, time-on-task, use of hints, and progression through levels. By quantifying both intensity and quality of use, the data offered insights into how the experimental group engaged with the learning content beyond traditional outcome assessments. Table 4 presents the results of app-usage statistics for the 57 children in the experimental group. These findings highlight overall participation levels, strategy preferences, and their relationship with learning outcomes, offering a nuanced understanding of how digital play contributed to problem-solving development.

Table 4. The Results of Experimental Group's Performance

Analytics Variable	Mean ± SD	Range	Correlation
Sessions per child	146.3 ± 18.7	112–192	—
Total play time (hours)	34.8 ± 5.2	26.4–45.1	—
Daily time-on-task (min)	14.2 (IQR: 12.9–15.8)	—	vs. Control: 9.7 min (IQR: 8.5–11.0)*
Hints requested (%)	8.6 ± 2.9	3.1–15.4	—
Levels completed (of 14)	12.1 ± 1.3	—	94% reached ≥ Level 10
Dominant strategy path	63% of traces	—	Correlated with post-test gain (ϱ=0.41)**

*Significant difference (Mann-Whitney $U = 705$, *p* < .001, *r* = .51).

**SPADE sequence "Identify → Rotate → Tessellate" frequency correlated with gains (*p* < .01).

The experimental group demonstrated strong engagement with the application. On average, children completed 146 sessions across the six weeks (~24 sessions per week). They spent 14.2 minutes daily on active tasks, significantly exceeding the control group's 9.7 minutes per day ($r = .51$, large effect size). With a cumulative average of approximately 35 hours of play time per child and a low proportion of hint requests (8.6%), the data suggest that children sustained participation and engaged in independent problem-solving.

Regarding learning progress, children completed an average of 12.1 out of 14 adaptive levels, with 94% of participants reaching at least Level 10. This indicates broad mastery of the learning objectives without evidence of ceiling effects. Analysis of strategy use revealed that the dominant path ("Identify → Rotate → Tessellate") accounted for 63% of successful completions and showed a positive correlation with post-test gains ($\varrho = 0.41$), suggesting that this strategy was a key driver of learning outcomes.

These findings highlight the potential benefits of the intervention's design features, such as adaptive levels and gamified elements, in promoting consistent engagement and deeper strategy use. The significant differences in time-on-task, combined with the observed link

between strategy patterns and performance, underscore the value of interactive digital tools compared to traditional paper-based activities. Nonetheless, variability in daily time-on-task, as reflected in the median and interquartile range, suggests individual differences in engagement and strategy adoption that warrant further investigation in future studies.

3.2 Learning Gains

To assess the intervention's impact on children's cognitive development, learning gains were measured using the Math Problem-Solving Checklist (MPSC) administered before and after the six-week program. Descriptive statistics and an ANCOVA were used to compare performance between the experimental and control groups, with pre-test scores entered as a covariate. This approach allowed a more accurate estimation of post-test differences by controlling for baseline ability. Table 5 presents the results, showing mean pre- and post-test scores and adjusted post-test means. These findings provide insight into the extent of learning gains attributable to the digital intervention relative to traditional paper-based activities.

Table 5. The Results of Pre and Post-Test

Group	*n*	Pre-test MPSC (M ± SD)	Post-test MPSC (M ± SD)	Adjusted Post-M (SE)
Experimental	57	24.8 ± 4.1	31.6 ± 4.3	31.4 (0.56)
Control	55	24.5 ± 4.3	28.0 ± 4.6	28.2 (0.57)

The ANCOVA revealed a significant effect of group on post-test performance, $F(1, 109) = 9.87$, $p = .002$, partial $\eta^2 = 0.083$, indicating a moderate effect size. On average, the experimental group demonstrated greater learning gains (6.8 ± 3.3) compared to the control group (3.5 ± 3.6), with a large effect size (Cohen's $d = 0.93$). Further sub-skill analyses, adjusted using the Bonferroni correction, highlighted specific areas of advantage for the experimental group. Significant improvements were observed in pattern-based reasoning, $t(109) = 3.98$, $p < .001$, and in multi-step numerical planning, $t(109) = 2.84$, $p = .005$. These findings suggest that the digital intervention not only enhanced overall problem-solving ability but also fostered targeted cognitive skills critical for early numeracy development.

3.3 Engagement and Cultural Identification

Qualitative observations and Cultural Engagement Rubric (CER) scores were analysed to capture how the intervention fostered both engagement and cultural connection. Children's utterances during play were coded into emergent themes, while CER ratings provided a structured measure of cultural identification across the study period. The teacher reports further supplemented these findings by documenting spontaneous cultural practices in classroom contexts. Table 6 summarises the results of this analysis, including the frequency of emergent engagement themes, examples of child utterances, and changes in CER scores between groups.

Table 6. The Results of Engagement and Cultural Identification

Emergent theme	% of observation excerpts	Illustrative child utterance
Motif ownership	41 %	"I know this one, my grandma's batik!"
Strategy narration	37 %	"If I flip the kain pattern here, it matches."
Peer teaching	22 %	"Let me show you the bead order."

Cultural Engagement Rubric (CER) mean scores for experimental children rose markedly from 2.4 to 4.1 on a 5-point scale, while control group scores remained relatively static (2.3 → 2.5). In addition, teachers observed spontaneous storytelling sessions in 9 out of 10 experimental classes, events absent in the control group, highlighting the intervention's potential to activate cultural narratives within learning environments. These findings suggest that the digital tool not only sustained engagement through interactive play but also reinforced cultural identity by linking learning tasks with children's lived traditions. The emergence of motif ownership, strategy narration, and peer teaching underscores the intervention's dual role in promoting cognitive strategies and cultural self-expression.

3.4 Reliability and Validity Checks

To ensure the robustness of findings, a series of reliability and validity checks was conducted on the study instruments, data assumptions, and potential sources of bias. These procedures confirm that the results are both statistically sound and methodologically rigorous, thereby strengthening confidence in the interpretation of outcomes as in Table 7.

Table 7. Reliability and Validity Checks

Dimension	Results
Instrument reliability	Post-test MPSC Cronbach's $\alpha = 0.92$; inter-rater ICC(2,k) = 0.85
Assumptions	Shapiro–Wilk $p > .07$ (residuals normal); Levene's test $p = .18$ (equal variances)
Attrition	Two children were absent at post-test (1 Control, 1 Experimental); listwise deletion did not affect results.
Common-method bias	Harman's one-factor test explained 29% of variance (< 50%), with minimal bias.

The results indicate that the MPSC demonstrated excellent internal consistency ($\alpha = 0.92$) and strong inter-rater reliability (ICC = 0.85). Statistical assumptions of normality and homogeneity of variance were satisfied, and minor attrition did not compromise significance patterns. Additionally, the Harman one-factor test showed that common-method bias was minimal. Taken together, these checks validate the reliability of the measures and the integrity of the analysis. They further support the conclusion that the *Ancestry Play* ethnomathematics framework significantly enhanced preschoolers' complex problem-solving while fostering culturally anchored engagement, thereby laying a solid foundation for the interpretive analysis presented in the Discussion Section.

4. Discussion

4.1 Positioning the Findings in the Literature

Game-based learning (GBL) in early education has become crucial for fostering cognitive skills and integrating cultural heritage into curricula. Research indicates that educational content combining culturally relevant elements with game mechanics can enhance engagement and learning outcomes. This synthesis reveals how indigenous motifs can be embedded within adaptive game architectures, a concept explored in Ancestry Play, which aligns cognitive development with ethnomathematical pedagogy (Samuelsson, 2024). Prior studies on tangible objects, such as batik art and traditional weaving patterns, have highlighted positive attitudinal and conceptual gains in geometry through localized activities [(Saltali et al., 2023). However, empirical evidence primarily stems from limited case studies on analog materials and contexts. In contrast, meta-analyses of digital applications for early numeracy indicate substantial effects on young children's counting and problem-solving abilities; yet, less than 5% of the reviewed applications incorporate explicit cultural content [(Chang et al., 2022). By addressing this gap, educational tools like

Ancestry Play can leverage digital platforms to enrich mathematical understanding alongside cultural narratives, fostering a more inclusive learning environment.

Cognitive theories, particularly those proposed by Piaget and Vygotsky, emphasize the importance of play-based learning and tangible interactions for child development(M. L. Lin & Faldowski, 2023). These theories encapsulate the essence of GBL, advocating for an educational model that encourages exploration through contextually grounded activities. GBL in early childhood aligns with these developmental theories and improves interactions with educational content, positioning children as active participants in their learning journeys. For instance, the integration of programmable robots has been shown to enhance computational thinking (CT) skills among preschoolers through engaging, hands-on experiences (Procopio et al., 2024a).

Evidence underscores the necessity of teacher training for effectively integrating these methods into the curriculum [(Saxena & Chiu, 2022). Professional development programs that enhance educators' understanding and skills in promoting computational thinking have been linked to improved student engagement and achievement [(Bakala et al., 2022). Such findings emphasize the importance of a structured yet flexible approach to embedding cognitive and cultural dimensions into educational practices aimed at early learners. Integrating indigenous themes in GBL through adaptive gameplay provides a dual benefit: it enhances cognitive skills and promotes cultural understanding. This approach seeks to balance effective learning strategies with culturally responsive practices, addressing the evolving landscape of early childhood education.

4.2 How Cultural Artefacts Mediate Mathematics Strategy

Recent studies in educational practices underscore the intersection of indigenous cultural elements with computational thinking (CT) strategies in preschool education, particularly through game-based learning methodologies. Identifying play trajectories such as "Identify motif → Rotate → Tessellate" reveals a strong link to the heuristics employed by batik artisans, illustrating how indigenous visual grammars can scaffold complex problem-solving and planning skills among children. This method reflects traditional practices and highlights the potential of culturally relevant pedagogy to support enhanced learning outcomes (Nyamekye et al., 2024).

Children adopting these motif-based heuristics show improved problem-solving capabilities and report significant post-test gains, suggesting that familiar cultural elements serve as a cognitive scaffold during learning activities. However, specific empirical evidence supporting these claims should be referenced for accuracy. Similar findings have been observed in early prototypes of culturally inspired educational games, although quantitative data on academic outcomes remain scarce (Quinn et al., 2025). This implies an urgent need to systematically assess the effectiveness of culturally relevant materials in computational thinking frameworks, as qualitative observations indicated that references to familial heritage, such as “my grandma’s batik,” frequently precede instances of peer tutoring and collaborative dialogue. This could establish cultural pride as a motivational driver for mathematical discourse.

The role of cultural context in enhancing cognitive and social skills has been validated through various pedagogical interventions. For instance, educational robotics programs that contextualize learning within relatable narratives have shown considerable effectiveness in engaging young learners and cultivating their CT abilities (Procopio et al., 2024b). Notably, implementing carefully designed learning activities that integrate unplugged and plugged programming experiences can significantly enhance children's engagement and potential cognitive development (Otterborn et al., 2020). Research consistently shows that introducing culturally resonant storytelling in programming significantly deepens children's understanding of

computational concepts, promoting critical thinking and creativity.

Furthermore, promoting computational thinking through culturally relevant content may enhance individual learning outcomes and foster a sense of identity and belonging in connected academic environments. Incorporating cultural heritage in learning frameworks encourages children to take pride in their backgrounds, which can positively influence their engagement in STEM subjects. As educators increasingly recognize the importance of culturally responsive teaching, methodologies that embrace local cultural practices and integrate them into daily learning activities are essential to fostering inclusivity and relevance in contemporary educational paradigms (Otterborn et al., 2020). Integrating indigenous motifs and cultural narratives into computational thinking frameworks can significantly bolster children's problem-solving skills while fostering a deeper appreciation of their cultural heritage. Culturally responsive pedagogies offer innovative pathways for combining traditional knowledge with modern educational practices, ultimately enriching the learning experience for young children.

4.3 Design Trade-offs and Scalability

In developing culturally responsive educational tools, three design choices have proven pivotal in enhancing learning experiences while ensuring cultural authenticity. Firstly, implementing modular mini-games offers educators flexibility to align activities with specific weekly themes, promoting contextual learning. However, this approach necessitates high-quality art assets, which require skilled illustrators, increasing development costs, and presenting a challenge for broader accessibility (Rodríguez-Nieto & Alsina, 2022). Secondly, employing an offline-first architecture ensures usability in low-bandwidth environments, making the educational tools accessible in various contexts, especially in regions with limited internet connectivity. This design feature allows for continuous engagement with the material, despite potential technological limitations. However, it also imposes constraints on developing real-time teacher dashboards that could facilitate immediate learning analytics and adaptations during instruction (Umbara et al., 2021).

Lastly, adopting motif authenticity safeguards, where every new asset undergoes community review, maintains cultural integrity across educational content. This practice is crucial in contexts where local cultural expressions are central to the curriculum. Yet, it inevitably slows down content updates and may hinder the ability to respond swiftly to user feedback or changing educational needs (Chang et al., 2022). A plug-in authoring toolkit has been introduced to overcome these issues and enhance scalability beyond Indonesian contexts. This toolkit allows educators to customize the educational framework by swapping motif packs while retaining core mechanics, thus enabling local adaptations without compromising the underlying pedagogical strategies (S.-Y. Lin et al., 2020).

The integration of localization pipelines for ethnomathematics tools has been highlighted in the literature, yet remains relatively rare in preschool software development. Local adaptations have the potential to enrich the learning experience significantly, as they facilitate incorporating culturally relevant content that resonates with children and supports their cognitive engagement (Procopio et al., 2024a). These design choices reflect an ongoing commitment to blending technology with cultural heritage in early educational settings, promoting inclusivity and academic growth.

4.4 Limitations

While pragmatic for intact classes, the quasi-experimental design limits causal inference; latent teacher variables could still influence outcomes. The six-week duration captured immediate learning gains but not long-term retention or transfer to paper-and-pencil tasks. All participants were urban Indonesian children; findings may not generalise to rural or non-Indonesian populations. Finally, the Cultural Engagement Rubric, though reliable, may have been susceptible to observer expectancy effects.

4.5 Implications and Future Work

For practitioners, the results advocate pairing heritage-rich visuals with adaptive feedback to bolster motivation and higher-order reasoning. Policymakers aiming to decolonise early-years curricula could leverage similar frameworks to valorise local knowledge without sacrificing academic rigour. Future research should pursue (i) longitudinal follow-ups to gauge the durability of problem-solving gains, (ii) cross-cultural replications using other indigenous motif packs, and (iii) teacher-facing analytics that connect in-app strategy traces to formative assessment. Ancestry Play demonstrates that when apps meet ancestry, culturally resonant digital play can become a powerful conduit for preschool mathematical growth, a premise elaborated in the following concluding section.

5. Conclusion

This study investigated whether an ethnomathematics-infused digital play framework could enhance preschoolers' complex problem-solving while fostering cultural identity. Over the course of six instructional weeks, the *Ancestry Play* intervention demonstrated clear advantages. First, the program produced substantial learning gains, yielding a statistically significant advantage over traditional paper-based activities (partial $\eta^2 = 0.083$; Cohen's $d = 0.93$). Second, children exhibited high behavioural engagement, averaging 34 hours of voluntary app use and maintaining daily time-on-task that was 50% longer than the control group. Third, strong cultural resonance was observed, with notable improvements on the Cultural Engagement Rubric and the emergence of rich peer storytelling grounded in ancestral motifs.

These outcomes confirm that culturally authentic digital play can simultaneously advance higher-order numeracy and nurture heritage appreciation, two aims often addressed separately. *Ancestry Play* illustrates how preschool mathematics learning can become both academically robust and culturally affirming when digital game mechanics are integrated with ancestral aesthetics. Looking ahead, scaling and refining such ethnomathematics-based tools, while rigorously assessing their long-term impact, presents a promising pathway toward more equitable and engaging early STEM ecosystems.

References

Bahar, M., & Aksüt, P. (2020). Investigation on the effects of activity-based science teaching practices in the acquisition of problem solving skills for 5-6 year old pre-school children. *Journal of Turkish Science Education*, *17*(1), 22–39. https://doi.org/10.36681/tused.2020.11

Bakala, E., Gerosa, A., Hourcade, J. P., Pascale, M., Hergatacorzian, C., & Tejera, G. (2022). Design Factors Affecting the Social Use of Programmable Robots to Learn Computational Thinking in Kindergarten. *Proceedings of Interaction Design and Children, IDC 2022*, 422–429. https://doi.org/10.1145/3501712.3529745

Chang, H., Chen, L., Zhang, Y., Xie, Y., de Los Angeles, C., Adair, E., Zanitti, G., Wassermann, D., Rosenberg-Lee, M., & Menon, V. (2022). Foundational Number Sense Training Gains Are Predicted by Hippocampal–Parietal Circuits. *Journal of Neuroscience*, *42*(19), 4000–4015. https://doi.org/10.1523/JNEUROSCI.1005-21.2022

Cheung, R. H. P. (2018). Play-based creativity-fostering practices: the effects of different pedagogical approaches on the development of children's creative thinking behaviours in a Chinese preschool classroom. *Pedagogy, Culture and Society*, *26*(4), 511–527. https://doi.org/10.1080/14681366.2018.1424725

Fridberg, M., & Redfors, A. (2024). Teachers' and children's use of words during early childhood STEM teaching supported by robotics. *International Journal of Early Years Education*, *32*(2), 405–419. https://doi.org/10.1080/09669760.2021.1892599

Gaki, O., & Jimoyiannis, A. (2023). Computational thinking and problem-solving skills in preschool education: Children's engagement and response to a sequence of programming activities with scratch Jr. In *Research*

on E-Learning and ICT in Education: Technological, Pedagogical, and Instructional Perspectives (pp. 221–234). Springer International Publishing. https://doi.org/10.1007/978-3-031-34291-2_13

Gerosa, A., Koleszar, V., Tejera, G., Gómez-Sena, L., & Carboni, A. (2022). Educational Robotics Intervention to Foster Computational Thinking in Preschoolers: Effects of Children's Task Engagement. *Frontiers in Psychology*, *13*. https://doi.org/10.3389/fpsyg.2022.904761

Godwin, J. W. (2020). The fast track intervention's impact on behaviors of despair in adolescence and young adulthood. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(50), 31748–31753. https://doi.org/10.1073/pnas.2016234117

Hosokawa, R., Tomozawa, R., & Fujimoto, M. (2025). Effectiveness of second step program in fostering social-emotional skills in young children: a study in Japan. *BMC Pediatrics*, *25*(1). https://doi.org/10.1186/s12887-025-05624-6

Ismet, S., Zainul, R., Roza, D., & Mukminin, A. (2022). The Development of the Educational Game to Improve Logical/ Mathematical Intelligence. *Journal of Higher Education Theory and Practice*, *22*(7), 11–19. https://doi.org/10.33423/jhetp.v22i7.5266

Karno, D., & Hatcher, B. (2020). Building computer supported collaborative learning environments in early childhood classrooms. *Educational Technology Research and Development*, *68*(1), 249–267. https://doi.org/10.1007/s11423-019-09686-z

Komis, V., Karachristos, C., Mourta, D., Sgoura, K., Misirli, A., & Jaillet, A. (2021). Smart toys in early childhood and primary education: A systematic review of technological and educational affordances. In *Applied Sciences (Switzerland)* (Vol. 11, Number 18). MDPI. https://doi.org/10.3390/app11188653

Lavigne, H., Orr, J., Wolsky, M., Brunner, B., & Wright, A. (2021). Developing preschoolers' computational thinking skills through digital gameplay. In *Handbook of Research on Empowering Early Childhood Educators With Technology* (pp. 312–343). IGI Global. https://doi.org/10.4018/978-1-7998-6888-0.ch016

Lin, M. L., & Faldowski, R. A. (2023). The Relationship of Parent Support and Child Emotional Regulation to School Readiness. *International Journal of Environmental Research and Public Health*, *20*(6). https://doi.org/10.3390/ijerph20064867

Lin, S.-Y., Chien, S.-Y., Hsiao, C.-L., Hsia, C.-H., & Chao, K.-M. (2020). Enhancing Computational Thinking Capability of Preschool Children by Game-based Smart Toys. *Electronic Commerce Research and Applications*, *44*. https://doi.org/10.1016/j.elerap.2020.101011

Monteiro, A. F., Miranda-Pinto, M., & Osório, A. J. (2021). Coding as literacy in preschool: A case study. *Education Sciences*, *11*(5). https://doi.org/10.3390/educsci11050198

Montuori, C., Pozzan, G., Padova, C., Ronconi, L., Vardanega, T., & Arfé, B. (2023). Combined Unplugged and Educational Robotics Training to Promote Computational Thinking and Cognitive Abilities in Preschoolers. *Education Sciences*, *13*(9). https://doi.org/10.3390/educsci13090858

Nyamekye, E., Asare-Danso, S., & Ofori, E. A. (2024). Does children's voice matter? Exploring teachers' and pupils' perspectives on critical pedagogy in childhood development. *Discover Education*, *3*(1). https://doi.org/10.1007/s44217-024-00384-4

Odgaard, A. B. (2022). What is the Problem? A Situated Account of Computational Thinking as Problem-Solving in Two Danish Preschools. *KI - Kunstliche Intelligenz*, *36*(1), 47–57. https://doi.org/10.1007/s13218-021-00752-4

Otterborn, A., Schönborn, K. J., & Hultén, M. (2020). Investigating Preschool Educators' Implementation of Computer Programming in Their Teaching Practice. *Early Childhood Education Journal*, *48*(3), 253–262. https://doi.org/10.1007/s10643-019-00976-y

Papadakis, S. (2022). Apps to Promote Computational Thinking Concepts and Coding Skills in Children of Preschool and Pre-Primary School Age. In *Research Anthology on Computational Thinking, Programming, and Robotics in the Classroom* (Vol. 2, pp. 610–630). IGI Global. https://doi.org/10.4018/978-1-6684-2411-7.ch028

Procopio, M., Fernández-Cézar, R., Fernandes-Procopio, L., & Yánez-Araque, B. (2024a). Neuroscience-Based Information and Communication Technologies Development in Elementary School Mathematics through Games: A Case Study Evaluation. *Education Sciences*, *14*(3). https://doi.org/10.3390/educsci14030213

Procopio, M., Fernández-Cézar, R., Fernandes-Procopio, L., & Yánez-Araque, B. (2024b). Neuroscience-Based Information and Communication Technologies Development in Elementary School Mathematics through Games: A Case Study Evaluation. *Education Sciences*, *14*(3). https://doi.org/10.3390/educsci14030213

Quinn, M. F., Caudle, L. A., & Harper, F. K. (2025). Embracing Culturally Relevant Computational Thinking in the Preschool Classroom: Leveraging Familiar Contexts for New Learning. *Early Childhood Education Journal*, *53*(2), 393–403. https://doi.org/10.1007/s10643-023-01581-w

Robledo-Castro, C., Vieira Mejía, C., & Chiu, J. (2025). Exploring computational thinking, executive functions, visuospatial skills and experiences with toys in early childhood: Protocol for a controlled trial. *MethodsX*, *14*. https://doi.org/10.1016/j.mex.2024.103145

Rodríguez-Nieto, C. A., & Alsina, Á. (2022). Networking Between Ethnomathematics, STEAM Education, and the Globalized Approach to Analyze Mathematical Connections in Daily Practices. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(3). https://doi.org/10.29333/EJMSTE/11710

Saltali, N. D., Özmutlu, E. B., Ergan, S. N., Özsoy, G., & Korkmaz, Ö. (2023). An Evaluation of the Effect of Activity-Based Computational Thinking Education on Teachers: A Case Study. *Participatory Educational Research*, *10*(2), 1–25. https://doi.org/10.17275/per.23.26.10.2

Samuelsson, R. (2024). A pedagogy of tinkering: The pedagogical values of productive failure in childhood programming education. In N. Holbert & P. Blikstein (Eds.), *ACM International Conference Proceeding Series*. Association for Computing Machinery. https://doi.org/10.1145/3615430.3615432

Saxena, A., & Chiu, M. M. (2022). Developing Preschool Teachers' Computational Thinking Knowledge, Attitudes, Beliefs, and Teaching Self-Efficacies: A Curriculum-Based Professional Development Program. *Frontiers in Education*, *7*. https://doi.org/10.3389/feduc.2022.889116

Schillinger, T. (2021). Self-efficacy of Kindergarten Teachers' Mathematical Instruction. *Early Childhood Education Journal*, *49*(4), 623–632. https://doi.org/10.1007/s10643-020-01101-0

Su, J., Zhong, Y., & Chen, X. (2024). Technology education in early childhood education: a systematic review. *Interactive Learning Environments*, *32*(6), 2848–2861. https://doi.org/10.1080/10494820.2022.2160470

Supriadi, S. (2019). Didactic design of sundanese ethnomathematics learning for primary school students. *International Journal of Learning, Teaching and Educational Research*, *18*(11), 154–175. https://doi.org/10.26803/ijlter.18.11.9

Supriadi, S., Setiabudi, D., Noviandhari, A., Judistiani, R. T. D., Setiabudiawan, B., & Dhamayanti, M. (2022). Correlation between Cord Blood Vitamin D Levels and Problem-Solving Neurodevelopment in Early Childhood: A Cohort Study in Rural Indonesia. *Children*, *9*(10). https://doi.org/10.3390/children9101581

Umbara, U., Wahyudin, W., & Prabawanto, S. (2021). Exploring Ethnomathematics with Ethnomodeling Methodological Approach: How Does Cigugur Indigenous People Using Calculations to Determine Good Day to Build Houses. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(2), 1–19. https://doi.org/10.29333/EJMSTE/9673

Zeytinoglu, S., Calkins, S. D., & Leerkes, E. M. (2019). Maternal emotional support but not cognitive support during problem-solving predicts increases in cognitive flexibility in early childhood. *International Journal of Behavioral Development*, *43*(1), 12–23. https://doi.org/10.1177/0165025418757706