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PHYGITAL INTERFACE DESIGN FOR SOCIOEMOTIONAL: A QUALITATIVE CHILD-COMPUTER INTERACTION STUDY

Nurasilah Osman[1], Tengku Siti Meriam Tengku Wook[2], Maizatul Hayati Mohamad Yatim[3], Nor Masharah Husain[4], Norly Jamil[5], Nadia Akma Ahmad Zaki[6]

[1,3,4,5,6]Sultan Idris Education University 35900, Tanjong Malim, Perak, Malaysia
[2]Universiti Kebangsaan Malaysia 43600 UKM, Bangi, Selangor, Malaysia
E-Mail: m20221001765@siswa.upsi.edu.my, tsmeriam@ukm.edu.my, maizatul@meta.upsi.edu.my, masharah@meta.upsi.edu.my, norly@fpm.upsi.edu.my, nadiaakma@meta.upsi.edu.my

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Corresponding authors
*m20221001765@siswa.upsi.edu.my

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Abstract
Phygital learning environments, which merge tangible play with real-time digital feedback, are gaining attention in early childhood education, yet their socioemotional impact remains underexplored. Existing studies on phygital systems primarily emphasize cognitive or usability outcomes, leaving limited empirical evidence on how interface design shapes children's emotional and social behaviours. This study investigated how phygital interface design supports socioemotional competencies among Malaysian preschoolers. Fifteen children aged 5-6 from two preschools engaged with Osmo phygital games involving both individual and collaborative play. Video recordings, observation checklists, and field notes were analysed using reflexive thematic analysis, supported by triangulation and peer debriefing to ensure credible behavioural interpretation. Findings show socioemotional behaviours like self-awareness, self-control, self-concept, self-confidence, and social skills with empathy emerge from design features such as hybridization, tangibility, interactivity, multisensory feedback, contextual relevance, personalization, and collaboration. Embodied emotional feedback enhanced self-regulation, hybrid tangible-digital play promoted motivation and confidence, and collaborative interaction strengthened empathy and peer support. This study positions phygital interfaces as emotionally responsive systems that integrate affective, cognitive, and social learning, offering evidence-based design implications for child-centred educational technologies.

I. INTRODUCTION

Socioemotional learning (SEL) is critical in early childhood as it supports

self-awareness, emotional regulation, empathy, and prosocial behaviour that underpin collaboration and well-being (CASEL, 2017). Although Malaysia's curriculum emphasises interactive, play-based pedagogies to nurture these competencies (KPM, 2016), children's access to high-quality socioemotional experiences has become increasingly mediated by digital technologies. Digital learning tools provide cognitive benefits and convenience, yet they often lack embodied and affective engagement, resulting in limited opportunities for socioemotional development through unstructured play, physical cues, and peer interaction (Watts & Pattnaik, 2022). Studies show that children struggle with essential interpersonal skills when learning occurs predominantly in screen-based environments (Oliveira et al., 2024). This indicates an empirical gap in digital game design that often privileges cognitive outcomes over socioemotional growth.

Phygital interfaces offer a promising shift by linking tangible manipulation with real-time digital feedback, enabling children to co-construct meaning through sensorimotor and social engagement (Gelsomini et al., 2021; Zhong et al., 2023). Such hybrid learning environments have demonstrated potential to enhance motivation, creativity, and collaborative play (Del Vecchio et al., 2023). However, the current literature primarily reports user experience and usability, with limited evidence on how phygital interaction directly mediates socioemotional behaviours during authentic gameplay (Huang & Lajoie, 2023). Despite these promises, there are limited studies that have systematically observed how phygital interface design features shape socioemotional responses in early childhood education.

Addressing this gap, this study investigates phygital learning games as a medium for socioemotional growth. This research aims to identify: (1) how phygital games influence children's socioemotional development during play, and (2) which interface design features effectively support these skills. The findings contribute empirical insights to guide emotionally responsive and developmentally aligned phygital game design for holistic learning in modern educational contexts.

II. RELATED WORKS

2.1 Socioemotional Learning (SEL) in Early Childhood

Socioemotional learning (SEL) is central to early development and school readiness. It encompasses self-awareness, self-management, social awareness, relationship skills, and responsible decision-making (CASEL, 2017). These competencies grow through interactive play and emotionally responsive settings (Garaigordobil et al., 2022). Empirical evidence shows that structured SEL programs improve self-regulation and prosocial behaviours in kindergartens (Nilfyr & Ewe, 2025; Niu et al., 2025). Yet, such interventions remain classroom-based, relying heavily on adult facilitation and verbal instruction, with minimal integration of technology-mediated or hybrid play.

2.2 Digital and Hybrid Learning After the Pandemic

The pandemic accelerated digital learning but exposed its socioemotional limitations. Although online tools maintained academic continuity, they restricted peer collaboration and embodied communication (Motz et al., 2022). Children's interactions became screen-bound, weakening empathy and affective expression. Recent HCI research calls for hybrid or phygital pedagogies that balance digital efficiency with tangible and social engagement (Chaturvedi et al., 2021; Clifft & Assiouras, 2023). Early evidence suggests hybrid approaches

restore playfulness and collaboration lost during remote learning, yet their socioemotional impacts are rarely measured (Denik Arofah S & Thorik Aziz, 2024).

2.3 Tangible and Phygital Interfaces in Child-Computer Interaction (CCI)

Tangible user interfaces (TUIs) bridge physical actions to digital responses, supporting embodied cognition (Zhong et al., 2023). In "phygital" contexts, these systems combine real-world manipulation with digital feedback (Gelsomini et al., 2021). Studies show tangible feedback improves persistence, attention, and cooperative problem-solving (Della Longa et al., 2023; Nonnis & Bryan-Kinns, 2024). Yet, most focus on cognitive or motor outcomes, such as spatial reasoning rather than socioemotional aspects (Papadakis, 2021). When emotional or social effects are mentioned, they are often inferred rather than observed systematically, leaving a gap in connecting design affordances with affective outcomes.

Phygital environments intersect three theoretical domains: embodied cognition, socio-constructivism, and affective computing. Embodied cognition posits that learning and emotion arise from sensory and motor experience (Hauke et al., 2024). Socio-constructivism views emotion and cognition as co-constructed through social interaction (Cong-Lem, 2023). Affective computing explores digital systems that detect or respond to user emotions, though its application in young children remains limited due to ethical issues (Banzon et al., 2024). Integrating these perspectives, embodied affective interaction, where tangible, emotionally resonant feedback supports regulation that may scaffold socioemotional growth (Coninx & Stephan, 2021; Della Longa et al., 2023). Across prior studies, three insights emerge: (1) SEL is fundamental yet underrepresented in technology-mediated education; (2) digital learning cannot replicate embodied and relational play; and (3) phygital systems show promise but remain empirically under-examined in emotional domains. This study addresses these gaps by empirically observing preschoolers' socioemotional behaviours in phygital learning contexts, extending Child-Computer Interaction research toward emotional intelligence through design.

III. METHODOLOGY

3.1 Research Design

This study employed a qualitative naturalistic design within the Child-Computer Interaction (CCI) field (Tikkanen & Iivari, 2023) to capture the embodied socioemotional behaviours that emerge during authentic phygital play. Such an approach is necessary because young children often express emotions and social intentions through action, gesture, and interaction rather than verbal reports, which are difficult to quantify meaningfully (Lehnert et al., 2022). Non-participant observation and video-based analysis were conducted to minimise disruption and preserve the natural flow of play. Data were interpreted through reflexive thematic analysis (Braun & Clarke, 2019), enabling a contextualised and in-depth understanding of how interface design mediates socioemotional engagement.

3.2 Research Context and Materials

The study took place in two preschools in Tanjung Malim and Bangi, Malaysia, using the *Osmo Genius Starter Kit*, a phygital learning tool that links tangible puzzle pieces and letter tiles to a tablet through reflective AI sensing.

Two games were selected for their cognitive and affective affordances: Osmo Tangram, which promotes spatial reasoning with visual-auditory feedback, and Osmo Lettertopia, a collaborative word-building game encouraging communication and persistence (Toh & Kirschner, 2023). Learning spaces were arranged to encourage natural collaboration, with two unobtrusive cameras capturing interactions without disrupting play (Figure 1).

Figure 1. Phygital game using the Osmo Starter Kit

3.3 Participants and Selection Criteria

Fifteen typically developing children (eight girls and seven boys) aged 5-6 participated, selected through purposive sampling with the assistance of preschool administrators. This age range marks a critical phase for developing emotional regulation, empathy, and cooperative play (Richard et al., 2021). Criteria included: (a) no prior experience with Osmo, (b) basic familiarity with touchscreens, and (c) ability to communicate verbally or nonverbally. Parents provided written consent, and children gave verbal assent. Demographics are summarised in Table 1. Emphasising information power over sample size ensured the depth of behavioural analysis (Malterud et al., 2016).

Table 1: Demographics of the participants

Gender	Age	Participants (P)
Male	5	P3, P4
	6	P1, P6, P12, P13, P14
Female	5	P2, P5, P8, P9, P10, P15
	6	P7, P11

3.4 Data Collection Procedure

Each observation session lasted 20-25 minutes and was supported by three facilitators, one operating the recording system, two using observation checklists. Children played individually and in pairs, engaging with Osmo Tangram and Lettertopia. Data included video recordings, field notes, and brief think-aloud interviews *("What do you feel when playing?"* and *"What do you like about this game?"*) to elicit authentic emotional reflection without over-prompting. All sessions were conducted in Malay and later translated with cultural accuracy (Fig. 2).

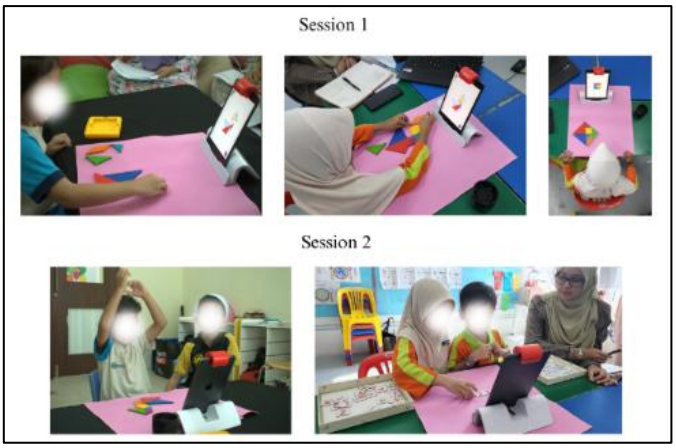

Figure 2. Participants during the fieldwork

3.5 Observation Checklist

A researcher-designed checklist combined phygital design specifications and socioemotional indicators. The phygital criteria were derived from a systematic review identifying key features such as tangibility, interactivity, and hybridization. Socioemotional indicators were adapted from expert interviews and established models like Goleman's (1995) Emotional Intelligence Theory, CASEL (2017) competencies, and Malaysia's Preschool Standard Curriculum (KSPK). This integration enabled analysis of how interface design elicited socioemotional responses through observable behaviours.

3.6 Data Analysis and Trustworthiness

A deductive-inductive coding approach was used to map observed behaviours to socioemotional components and phygital interface specifications. Thematic patterns were refined through iterative review of video recordings, observation notes, and brief think-aloud transcripts. Trustworthiness was enhanced through triangulation across multiple data sources, collaborative coding discussions among research members, and expert review to ensure interpretive rigor. Ethical approval was obtained from Universiti Pendidikan Sultan Idris's Research Ethics Committee (RMIC), with all procedures aligned to UNICEF's ethical standards for research involving children.

IV. RESULTS AND ANALYSIS

Analysis revealed five interrelated socioemotional domains emerging from children's phygital interactions: self-awareness, self-concept, self-control, self-confidence, and social skills with empathy. Each was closely associated with specific design specifications: multisensory feedback, hybridization, tangibility, personalization, interactivity, contextual relevance, and collaboration, demonstrating that Osmo's design actively mediated emotional expression and regulation.

4.1 Theme 1: Self-Awareness (Know and manage emotions)

Children exhibited self-awareness when multisensory feedback externalised emotional states. Visual and auditory cues transformed errors into learning signals, prompting reflection *("Hot or Cold?")*. This alignment between sensory cues and affective response supported emotion recognition and regulation, consistent with embodied cognition theory that ties emotional awareness to sensorimotor engagement (Speer et al., 2025; Winkielman et al., 2023). The

phygital system thus functioned as an affective mirror enabling real-time self-monitoring.

4.2 Theme 2: Develop Self-concept

The hybrid, playful design of Osmo encouraged children to perceive themselves as capable and autonomous learners. Integration of physical control and digital affirmation fostered agency and intrinsic motivation, echoing self-determination principles (Guo Nyuhuan, 2024). Verbal affirmations such as *"We can do this!"* reflected growing self-belief. The tangible-digital loop reinforced ownership of learning, illustrating how playfulness and hybridization can strengthen identity and engagement (Del Vecchio et al., 2023).

4.3 Theme 3: Develop self-control

Self-control surfaced through patient problem-solving during task validation. The interface's delayed feedback required children to wait, coordinate, and self-regulate. Contextual relevance, solving familiar puzzles and words, helps sustained focus and reduced impulsivity (Schmidt et al., 2020). Smooth feedback loops between physical manipulation and digital response minimised frustration, supporting persistence and attentional control (Lee & Lee, 2025). These mechanisms show how seamless design continuity nurtures emotional balance and behavioural regulation.

4.4 Theme 4: Develop Self-confidence

Tangible control and personalised digital feedback enhanced confidence and mastery. Children celebrated success with phrases such as *"Yeay. I did it!"*, a direct manifestation of Bandura's self-efficacy built through repeated accomplishment (S. Kim & Bong, 2023; Kleppang et al., 2023). Personalization, such as displaying names or characters, strengthened the emotional salience of achievement (Pardini et al., 2022). The phygital loop of challenge, feedback, and success created a positive reinforcement cycle that bolstered self-worth and resilience.

4.5 Theme 5: Develop Social Skills and Empathy

Collaborative gameplay fostered cooperation, empathy, and social awareness. Children naturally negotiated roles, coordinated actions, and supported one another's efforts *("Let me help you")*. These interactions exemplified co-regulation and shared agency central to socio-constructivist learning (Silva et al., 2023). The physical proximity and shared goals inherent in tangible interfaces mediated empathy and reduced competitiveness, aligning with theories emphasising peer scaffolding as a foundation for prosocial growth (Rudolph et al., 2023).

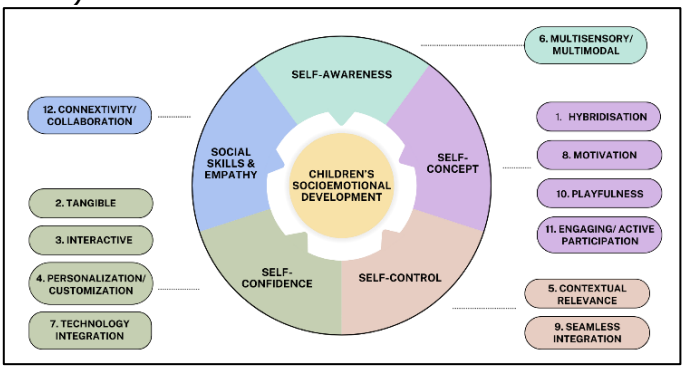

Figure 3. Phygital interface on socioemotional development

Based on the analysis, Figure 3 indicates that the phygital interface supports children's socioemotional development, as most participants displayed excitement and positive behaviours after gameplay. It offers an engaging entry point into interactive learning by merging hands-on activities with digital play. These observations lead to several design recommendations to enhance the phygital interface's effectiveness:

- Use child-friendly fonts with clearly distinguishable uppercase and lowercase letters on both sides of the tiles.
- Select colours that are easily identifiable and nameable by children.
- Incorporate joyful background music to boost motivation.
- Embed interactive narratives to deepen socioemotional engagement.
- Include non-player characters (NPCs) that model positive behaviours.
- Design games within culturally relevant contexts for the target users.
- Integrate content that focuses on socioemotional themes to directly support children's socioemotional growth.
- Offer parental controls to help manage playtime and usage.

V. DISCUSSION

This study demonstrates that phygital learning environments, where tangible interaction is seamlessly integrated with digital feedback, can actively nurture socioemotional development in young children. Beyond supporting cognitive engagement, these systems provide emotionally responsive spaces that encourage the competencies of socioemotional learning.

5.1 Embodied Interaction as Emotional Scaffolding

The results reaffirm the Embodied Cognition principle, where emotion and cognition are interlinked with bodily experience (Hauke et al., 2024). By translating affect into visual, auditory, and tactile cues, the phygital interface externalised children's emotional states, enabling awareness and regulation. Such embodied feedback acted as an emotional scaffold, guiding children to reflect and persist through frustration, similar to prior studies showing that tangible systems enhance emotional literacy through physical interaction (Coninx & Stephan, 2021; Della Longa et al., 2023). Thus, bodily engagement becomes a pathway for cultivating self-regulation and emotional resilience.

5.2 Autonomy and Motivation Through Hybrid Design

Consistent with Self-Determination Theory (SDT) by Ryan & Deci (2020), hybrid tangible-digital environments supported autonomy, competence, and relatedness. The synchronization of physical control and digital affirmation enhanced intrinsic motivation and persistence (Hatira & Sarac, 2024). Repeated mastery experiences strengthened self-efficacy and emotional balance (Linge et al., 2021), reflecting Bandura's concept that self-confidence develops through successful challenge resolution (S. Kim & Bong, 2023). Hence, hybrid feedback systems transform play into authentic mastery learning.

5.3 Social Co-Regulation and Empathic Interaction

Phygital play also fostered social co-regulation, where collaboration and empathy were integral to the interface design. Joint manipulation of tangible objects required communication, turn-taking, and shared attention, resulting in empathy enacted through play. This supports socio-constructivist perspectives that learning and emotion co-develop through social engagement (Cong-Lem, 2023). Cooperative dynamics observed here resonate with studies showing that

hybrid play contexts promote peer negotiation and embodied empathy (Aslan et al., 2022; Rudolph et al., 2023).

5.4 Design Principles for Emotionally Intelligent Phygital Interface

Synthesizing the empirical findings and theoretical perspectives, this study identifies five interrelated design principles that define emotionally intelligent phygital learning systems shown in figure 4. Other than the embodied feedback and the autonomy-driven hybridization principle, the Contextual and Cultural Relevance Principle underscores the need to ground learning activities in familiar, meaningful, and culturally resonant contexts, which reduce cognitive load, affirm children's identity, and sustain engagement (D. Kim et al., 2021; Quinn et al., 2025). Meanwhile, the Personalized Mastery Principle focuses on adaptive feedback mechanisms that validate effort and incremental progress rather than outcome alone, thus enhancing competence, persistence, and self-efficacy (Mejeh et al., 2024). Finally, the Collaborative Empathy Principle positions joint tangible activity as central to socioemotional learning, where coordinated physical play fosters turn-taking, cooperation, and empathy are skills essential for relational awareness and emotional growth (Cong-Lem, 2023; Rudolph et al., 2023).

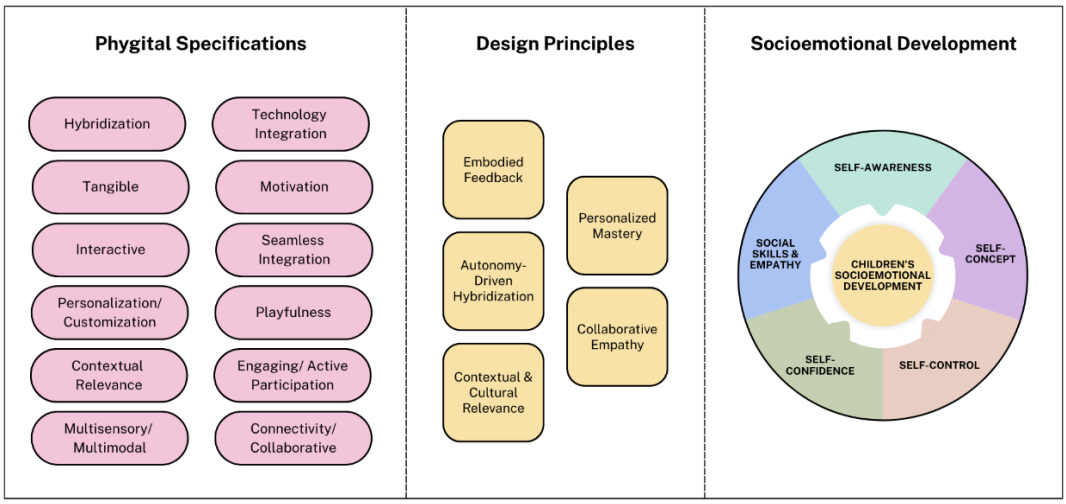

Figure 4. Phygital Specifications with Design Principles to Support Socioemotional Growth

Therefore, these principles articulate how design can intentionally align technical affordances with psychological and cultural needs, positioning the phygital interface not merely as an educational tool but as an emotional ecosystem that scaffolds the development of self-regulation, motivation, and empathy through embodied, playful, and collaborative interaction.

VI. CONCLUSION AND FUTURE WORK

This study establishes that phygital interface specifications, including multisensory feedback, hybridization, contextual relevance, tangibility, personalization, interactivity, and collaboration, play a pivotal role in fostering socioemotional development in technology-enhanced learning environments by bringing out emotional awareness, self-regulation, confidence, and empathy through intentional design. The findings advance Human-Computer Interaction and Child-Computer Interaction by demonstrating that phygital systems actively

mediate affective learning through design-based emotional scaffolding, addressing current educational needs for hybrid modalities that restore physical and relational engagement in digital contexts. The study's generalizability remains limited by its single-platform implementation and small sample size. Future work should investigate these design specifications across broader phygital systems, populations, and domains using mixed-method and longitudinal approaches to strengthen empirical evidence and develop universal design principles for emotionally responsive phygital games and learning environments.

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