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Development of MonoZooAR: A Multisensory Augmented Reality Game-Based Learning Technology for Enhancing Early Literacy Competencies in Children Aged 4–6 Years

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Abstract: This study aims to develop MonoZooAR, an augmented reality (AR)-based educational technology medium incorporating multisensory stimulation through a monopoly-style game framework, as an innovative approach to fostering early literacy competencies among children aged 4–6 years. The medium unifies three dimensional visual, auditory, tactile, and interactive narrative elements within a single integrated platform. A Research and Development (R&D) method was employed, guided by the ADDIE model (Analyse, Design, Development, Implementation, and Evaluation). The study was conducted in Dersan Hamlet, Semarang Regency, involving early childhood children and ECE teachers, alongside parents, as research participants. Data were gathered using expert validation sheets, observation protocols, response questionnaires, and product evaluation rubrics. The collected data were subsequently analyzed through combined qualitative and quantitative descriptive techniques, complemented by normalized gain (N-gain) calculations. Validation by the instructional media specialist (97%), ECE literacy specialist (95.5%), and ECE teachers (93.8%) consistently indicated Highly Feasible ratings. Field trials revealed substantial gains across all five early literacy dimensions, with the overall mean score rising from 2.06 to 3.66 and an N-Gain of 0.82 (High). Letter and Sound Knowledge recorded the highest gain (0.91), followed by Vocabulary (0.87), Phonological Awareness (0.82), Narrative Skills (0.81), and Print Awareness (0.69). This study demonstrates that the ADDIE-based MonoZooAR media is highly feasible and effective in enhancing early literacy skills among children aged 4–6. Expert validation exceeded 93%, while field trials yielded an overall N-gain of 0.82 (High category) across five literacy dimensions. These findings confirm that integrating 3D visuals, audio, tactile interaction, and narration within a phygital framework effectively shifts literacy learning from passive symbol memorization to active, experiential exploration.

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Introduction

Early literacy forms a foundational pillar for children's linguistic competencies, cognitive capacities, and scientific curiosity. Rooted in emergent literacy theory, this developmental continuum encompasses the precursor knowledge, attitudes, and skills acquired through continuous, environment-driven interactions with text and language from an early age (Rompas & Wijayanti, 2024). Core early literacy competencies comprise: (a) phonological awareness, essential for manipulating speech sounds in reading and spelling

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acquisition; (b) letter–sound correspondence, which underpins decoding mechanisms; (c) print awareness, encompassing book-handling conventions and text-object differentiation; (d) vocabulary expansion, which drives text comprehension; (e) narrative skills, enabling coherent storytelling; and (f) print motivation, fostering intrinsic engagement with reading materials (Majorano et al., 2021).

Research indicates that the use of media that engage multiple sensory modalities can have significant positive effects on children's early literacy skills. The combination of visual, auditory, and tactile stimuli reduces cognitive load, thereby facilitating learning through a distributed sensory processing approach (Fan et al., 2024). Children aged 5–7 years demonstrate a heightened reliance on stimuli particularly audio visual and tactile visual combinations while children aged 10–13 years begin to exhibit more balanced and efficient multisensory integration (Raduner et al., 2025). These findings indicate that age significantly influences multisensory integration and underscore the urgency of sensory stimulation in early literacy development (Melsiana & Wijayanti, 2023). Accordingly, the development of learning media for early childhood should leverage combinations of visual, auditory, and tactile input to optimize children's information absorption capacity, particularly during the preschool through early primary school years.

In the contemporary educational landscape, young children require innovative, engaging, and multisensory learning media. A multisensory approach incorporating visual, auditory, kinesthetics, and tactile elements has been demonstrated to be effective in enhancing early literacy through comprehensive sensory stimulation (Solichah & Fardana, 2024). While multisensory approaches are greatly needed to optimize literacy development and child engagement, their implementation in early childhood learning media remains notably limited (Kucirkov & Leon, 2023).

Field-based problem identification reveals that early childhood learning media remain constrained in terms of the diversity of sensory modalities employed. The majority of existing media engage only one or two senses, rendering them suboptimal for developing early literacy skills and cognitive capacities in young children. Early childhood education media generally rely predominantly on visual or auditory channels, thus failing to adequately address the multisensory needs of rapidly developing young children (Xiao et al., 2023). Although educators are aware of the importance of multisensory media, its practical implementation remains severely limited. The most commonly used media consist of simple audiovisual materials such as animations, videos, and two-dimensional illustrations, while kinesthetics and tactile elements are rarely incorporated. This results in suboptimal engagement in early literacy learning interactions and a subsequent decline in children's motivation (Handoko & Novitasari, 2019). Tactile stimulation has been shown to support children in learning tasks; the presence of touch-based elements such as finger movements or pressure assists young children in processing information more effectively than visual or auditory input alone.

On the other hand, Augmented Reality (AR) technology has gained increasing prominence in early learning contexts. AR-based media has demonstrated a measurable impact on the enhancement of children's reading abilities. The use of three-dimensional AR media in early literacy instruction has also been found to increase learning motivation among young children (Şimşek, 2024). Cross-national studies conducted in Europe and Greece indicate that AR media enhances alphabet recognition, vocabulary acquisition, and learning motivation among preschool-aged children (Korosidou, 2024). Furthermore, storybook media integrated with AR has been shown to strengthen narrative comprehension and storytelling skills in children compared to conventional print-based media. Nevertheless, a critical

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research gap persists: the vast majority of AR applications in early childhood education focus exclusively on dual modalities, namely, three-dimensional visualization and auditory input. Very few media developments simultaneously incorporate physical board game elements (tactile interaction) and interactive storytelling. Consequently, studies on multisensory AR specifically targeting early literacy remain remarkably limited, particularly those delivering fully integrated edutech solutions with comprehensive sensory stimulation.

In response to this gap, this study focuses on the development of MonoZooAR, an educational technology medium designed as a monopoly-style board game that integrates multisensory Augmented Reality (AR) technology through a combination of three-dimensional visuals, interactive audio, tactile feedback via sound buttons, and interactive narration. The media is designed to strengthen five essential early literacy components—phonology, letter knowledge, narrative comprehension, vocabulary, and print motivation—while supporting embodied cognition through gestural-bodily interactions. The development of MonoZooAR represents an innovative and critically needed solution for promoting early literacy more effectively and enjoyably. Specifically, this study aims to evaluate the validity, practicality, and effectiveness of MonoZooAR as a multisensory AR edutech tool in enhancing early literacy dimensions among young children.

Research Method

This study employs a Research and Development (R&D) method. This developmental research approach is designed to refine and improve upon pre-existing products. The study prioritizes product testing to ensure that the developed product is more effective, efficient, and appealing in its adoption compared to its predecessor. The objective of this research is to develop MonoZooAR, a multisensory, augmented reality-based educational technology medium for early literacy in early childhood. The study was conducted in Dersan Hamlet, Semarang Regency. The research subjects comprised: 1) early childhood children in Dersan Hamlet (n=36); 2) parents; and 3) Early Childhood Education (ECE) teachers (n = 4) in Dersan Hamlet.

MonoZooAR was developed using the ADDIE instructional design model following a systematic five-stage procedure (Filatro, 2023):(1) Analyze, identifying target developmental needs for the media; (2) Design, formulating the operational framework based on analysis outcomes; (3) Development, constructing the product and subjecting it to expert validation by early childhood literacy and ECE media specialists prior to revision; (4) Implementation, conducting limited-scale field testing within family settings and an ECE institution in Dersan Village, Semarang Regency; and (5) Evaluation, assessing trial outcomes through structured parent and teacher feedback.

The ADDIE development model was selected due to its procedural simplicity and accessibility, which facilitate ease of implementation. Despite its straightforward nature, the model is inherently systematic, as each stage must be executed in the prescribed sequential order without reordering. Furthermore, the model is well-suited to the developmental research needs of this study, as it applies to the development of instructional media, teaching materials, learning models, and instructional strategies (Min & Yunna, 2025).

The data collection instruments employed in this study included expert validation sheets, observation protocols, parent and teacher response questionnaires, and product evaluation rubrics. Data were initially obtained through expert validation conducted by a specialist in early childhood literacy and a specialist in ECE instructional media. Recommendations provided by these experts were analyzed and utilized to refine the media prior to field testing. The study adopted a field trial design to evaluate the practical

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implementation and effectiveness of MonoZooAR with young children. The intervention was carried out over 4 weeks, comprising 8 instructional sessions (2 sessions per week, lasting 30–45 minutes each). During these sessions, children engaged with MonoZooAR through physical board game navigation, 3D AR visualization, sound-activated tactile interaction, and interactive storytelling. To measure literacy gains, a pretest was administered prior to the intervention and a posttest was conducted upon completion of all sessions. Given the developmental characteristics of young learners, both pretest and posttest were administered individually through performance-based assessments and structured observational tasks using rubrics aligned with the five targeted early literacy dimensions.

Three data analysis techniques were employed in this study:1) Qualitative Descriptive Analysis; qualitative descriptive analysis was used to process narrative feedback and review comments obtained from the early childhood literacy experts, ECE media specialists, and ECE teachers. This analytical technique aimed to categorize qualitative responses and suggestions, which were subsequently used to guide product revisions during the development phase; 2) Quantitative Descriptive Analysis for Feasibility; quantitative descriptive analysis was applied to process the feasibility assessment scores provided by content and media experts, as well as teacher response questionnaires. Evaluation items were scored on a 1–4 qualitative rating scale (1 = Not Feasible, 2 = Less Feasible, 3 = Feasible, and 4 = Highly Feasible). The average scores were converted into feasibility percentage scores using the following equation:

$$P = \frac{\sum X}{\sum Xmax} X\ 100\%$$

Where P represents the feasibility percentage, $\sum X$ is the total score obtained from evaluators, and $\sum Xmax$ is the maximum possible score. Feasibility levels were categorized based on standard media criteria: Very Feasible (81–100%), Feasible (61–80%), Less Feasible (41–60%), and Not Feasible (≤40%); 3) Analysis of Early Literacy Effectiveness (Normalized Gain). To evaluate the effectiveness of MonoZooAR in improving children's early literacy competencies across the five targeted dimensions (phonological awareness, letter and sound knowledge, print awareness, vocabulary, and narrative skills), pretest and posttest observational scores were analyzed using the Normalized Gain (*N-gain*) formula proposed by Hake (Coletta & Steinert, 2020):

$$g = \frac{S_{spot} - S_{pre}}{S_{max} - S_{pre}}$$

Where g is the Normalized Gain score, S_{pre} is the mean pretest score, S_{post} is the mean posttest score, and S_{max} is the maximum attainable score (4.00). The calculated N-gain values were interpreted according to Hake's (1998) classification criteria to determine the magnitude of improvement: (1) High Gain: $g \geq 0.70$, (2) Medium Gain: $0.30 \leq g < 0.70$, and (3) $g < 0.30$

Results and Discussion

The MonoZooAR Multisensory Edutech Media was developed using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation), implemented at the Early Childhood Education (ECE) institution in Dersan Hamlet, Semarang Regency. The developmental stages proceeded as follows.

Analysis Stage

The Analysis Stage mapped the discrepancy between ideal early literacy objectives and classroom realities across three dimensions: (a) Needs Analysis, where observations in

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Dersan Hamlet revealed a heavy reliance on 2D printed books and unidirectional videos, leaving teachers struggling to incorporate kinesthetics and tactile stimulation into alphabet instruction; (b) Child Characteristics Analysis, which identified that local children aged 4–6 exhibited strong curiosity toward digital devices that remained unchanneled toward structured literacy learning; and (c) Curriculum Analysis, which aligned the media framework with the foundational literacy, STEAM, and technology learning outcomes specified under the Kurikulum Merdeka.

Design Stage

The Design Stage established the operational framework for MonoZooAR through three core components: (a) Storyboard Development, designing a "Monopoly Zoo" board layout where each space pairs an alphabet letter with a corresponding animal (e.g., A for Arwana, B for Beruang); (b) Multisensory Design, integrating realistic 3D visual animal models, auditory phonic sounds and short narratives, alongside physical sound-activated buttons on the board for tactile feedback; and (c) Instrument Development, compiling draft expert validation questionnaires and observational rubrics targeting phonological awareness, vocabulary, and narrative competencies.

Development Stage

The Development Stage transformed design specifications into a functional prototype through: (a) Media Production, building an interactive 3D AR visualization system using Unity 3D; (b) Hardware and Software Integration, synchronizing the physical board markers with tablet/smartphone software to ensure accurate 3D tracking; and (c) Expert Validation, conducting rigorous evaluations with an ECE content specialist (phonic accuracy and developmental fit), an instructional media specialist (technical quality and feasibility), and a local ECE teacher practitioner for practical implementation feedback.

Implementation Stage

This stage involved the application of the media within authentic learning settings in Dersan Hamlet, simultaneously constituting a limited-scale field trial conducted with ECE play groups in Dersan Village. The trial aimed to observe early literacy skills among children aged 4–6 years. At this stage, learning scenario scripts were developed for the implementation of MonoZooAR, followed by observational assessment of the media's effectiveness in enhancing early literacy competencies across the following dimensions: 1) phonological awareness; 2) letter and sound knowledge; 3) print awareness; 4) vocabulary; and 5) narrative skills.

Evaluation Stage

This final stage involved a comprehensive assessment of the product's effectiveness and overall quality by measuring children's literacy scores before and after engagement with MonoZooAR. Effectiveness was evaluated through performance-based tasks and structured observations administered to children aged 4–6 years in Dersan Hamlet, using a pre-test prior to MonoZooAR implementation and a post-test following the intervention. The marked improvement in children's early literacy skills stems from the deliberate multisensory integration within MonoZooAR, which distributes cognitive load across simultaneous visual, auditory, and tactile channels. By pairing 3D AR visualizations with sound-activated physical buttons and interactive narration, the media bridges abstract grapheme-phoneme representations through concrete, physical-digital (phygital) engagement. These findings directly extend the work of Fan et al., 2024 by demonstrating that tactile-visual and auditory combinations not only increase child attraction but also drive measurable learning gains in early literacy. Furthermore, the empirical results support the developmental findings of(Raduner et al., 2025), confirming that young children (aged 5–7 years) rely heavily on

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audio-visual and tactile-visual associations for efficient cognitive processing and information retention during early learning tasks.

Table 1. Pre-Test and Post-Test Assessment Criteria for Early Literacy in MonoZooAR

Early Literacy Aspect	MonoZooAR-Based Assessment Criteria	Sample Activity
1) Phonological Awareness	1) The child is able to imitate the phoneme sounds of animals produced through the AR audio.	When scanning the Cow (*Sapi*) card, the audio emphasizes a prolonged sibilant sound: *"Sssss.... Sssss.... Sapi!"* The child is able to imitate the hissing sound, similar to a snake or escaping air: *"Sssss..."*
	2) The child is able to distinguish the initial sounds of animal names.	The teacher provides an instruction: *"Let's collect all the animals whose names begin with the sound 'm-m-m...'"* The child is able to point to the cards or direct the AR camera toward the spaces representing Monkey (*Monyet*), Civet (*Musang*), and Peacock (*Merak*).
	3) The child is able to identify rhyming words based on auditory stimulation.	The teacher provides an instruction: *"This is a Horse (Kuda). Its ending sound is* -da*. Let's find another word with the same ending sound!"* The child is able to search the board or produce words such as *"Garuda"* or *"Lada."*
2) Letter and Sound Knowledge	1) Accuracy in matching physical letter cards with the corresponding 3D object displayed on screen.	The child holds a card printed with the letter "M." On the tablet/smartphone screen, three 3D animal objects appear: Monkey (*Monyet*), Elephant (*Gajah*), and Snake (*Ular*). The child directs the camera toward the letter "M" card, whereupon a Monkey animation appears jumping onto the card.
	2) The ability to identify letter symbols that appear as AR markers.	The child scans a marker (a monopoly board space). A large rotating letter "B" appears on screen alongside a Bear (*Beruang*). The teacher asks, *"What letter is next to the Bear?"* The child responds confidently, *"That is the letter B!"*
	3) The ability to associate a specific letter sound with its written symbol.	The application produces a mysterious sound: *"/sssss/.../sssss/..."* (a hissing sound). The child is asked to identify the letter card representing that sound from a set of cards on the table. The child is able to select the card depicting a Cow (*Sapi*) or Lion (*Singa*).
3) Print Awareness	1) The ability to distinguish between a 3D animal illustration and its corresponding text label.	When the camera scans the Elephant (*Gajah*) space, a moving 3D elephant animation appears on screen with the text *"gajah"* displayed beneath it. The teacher asks: *"Point to the animal with the long trunk. Now point to the word that reads 'Gajah.'"* The child is able to touch the elephant illustration to trigger an interaction (elephant sound), and then touch the text label below it.
	2) Awareness of reading directionality as demonstrated through the narrative text displayed in the application.	The application presents an audio narration: *"The Mouse-deer is running through the forest."* Simultaneously, the narrative text appears on screen with a word-by-word highlight effect (colour change per word) or animated animal footprints that hop above each successive word. The teacher instructs: *"Let's follow the Mouse-deer's footprints with your finger as we read together!"* The child is able to move their index finger across the tablet screen, tracking the

		text from left to right.
	3) The ability to identify uppercase and lowercase letters within the media.	On the AR screen, the word "Singa" (Lion) features a prominent, gold capital letter "S" alongside standard lowercase letters "inga". Prompted by the teacher to identify and tap the capital letter followed by its smaller companions, the child first touches the capital "S" triggering a thunder sound effect or special animation and subsequently taps the lowercase letters.
4) Vocabulary	1) The ability to name animals rarely encountered in the immediate environment.	The teacher scans a space that reveals an exotic animal such as a Flamingo. The teacher instructs: *"Wow, look at this animal with the red crest! Do you know its name? Let's listen to what the application says!"* The child is able to correctly name the animal: *"Its name is Flamingo it has very long legs!"*
	2) The use of adjectives and action verbs to describe the movements of AR animals.	The child observes an animation of a Snake coiling around a tree branch on the AR screen. The teacher instructs: *"Look carefully — what is the Snake doing? How does it move?"* The child is able to provide a descriptive explanation: *"The snake is very long and scaly."*
	3) Willingness to use new vocabulary encountered in the interactive narration.	The MonoZooAR interactive narration presents a sentence such as: *"This Elephant has a very powerful trunk for gathering food."* The teacher instructs: *"Tell your friends what is most amazing about the Elephant."* The child confidently retells the new information: *"The Elephant has a trunk! It uses it to eat."*
5) Narrative Skills	1) The ability to retell the sequential actions of 3D animals in logical order.	When scanning the Bear (Beruang) space, the AR displays a three-step sequential animation: the bear waking up, walking to a river, and catching a fish. Guided by the teacher's prompt to recount the full event, the child successfully reconstructs the complete chronological sequence (beginning, middle, and end) based on the observation: "First the Bear woke up, then it walked to the water, and then finally snap! it caught a big fish."
	2) The ability to continue a story based on visual stimuli from the AR.	The application initiates a narrative prompt ("There was an Elephant that was very thirsty at the edge of the forest...") paired with a 3D AR animation of an elephant gazing toward a river. Upon the teacher's instruction to predict the next event, the child exercises imaginative and predictive reasoning to extend the story fragment based on the visual cue: "Then the elephant ran toward the river and drank lots of water.
	3) Accuracy in using cohesive language when recounting the play experience.	Upon completing a round of MonoZooAR, the child is prompted by the teacher to share their excitement about meeting the Elephant. The child successfully constructs a coherent narrative using connective words and referential pronouns (e.g., it, because): "I met the Elephant. It had a very long trunk. I liked it because the Elephant could spray water at me!"

Product quality was evaluated through expert assessments conducted by academic specialists comprising lecturers from the Primary Teacher Education and Early Childhood Teacher Education study programmes with specialisations in digital instructional media and

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early childhood literacy, as well as by ECE teachers from Dersan Hamlet, serving as practitioners who directly utilise the product within teaching and learning activities.

Table 2. Feasibility Assessment Results for MonoZooAR Media

Expert Category	Primary Evaluation Aspects	Mean Score	Percentage	Category
Instructional Media Specialist	AR visual quality, tracking stability, interactivity, and interface navigation for children.	3.88	97%	Highly Feasible
ECE Literacy Specialist	Accuracy of phonic methodology, vocabulary depth, narrative structure, and content alignment with the foundational learning phase.	3.82	95.5%	Highly Feasible

The expert evaluation results presented in Table 2 indicate that the principal strength of MonoZooAR lies in its sensory distribution. The instructional media specialist commended the tactile integration realised through physical buttons, a feature rarely found in general AR applications. The literacy specialist, meanwhile, emphasised that the phonetic sound feature effectively prevents letter mispronunciation errors that are frequently observed with conventional media. These expert assessment findings are further corroborated by user evaluation data obtained from ECE teachers in Dersan Hamlet, who serve as practitioners engaging directly with the product in classroom teaching and learning activities.

Table 3. User Feasibility Evaluation of MonoZooAR Media

Respondent	Primary Evaluation Aspects	Mean Score	Percentage	Category
ECE Teachers	Ease of use (usability), child engagement, and time efficiency in content delivery.	3.75	93.8%	Highly Feasible

As presented in Table 3, MonoZooAR achieved a 93.8% teacher feasibility rating. Teachers highlighted its practical utility in streamlining lesson preparation by unifying visual, auditory, and textual elements into a single platform, while spontaneously enhancing children's attentional focus and orderly turn-taking during gameplay. Effectiveness analysis among children aged 4–6 years in Dersan Hamlet revealed significant early literacy gains across all five measured aspects. The overall mean score rose from 2.06 (beginning to develop) to 3.66 (developing very well), yielding a high-category N-gain of 0.82. Detailed results are summarized in Table 4.

Table 4. Pre-Test and Post-Test Results of MonoZooAR Implementation in Enhancing Early Literacy Skills in Early Childhood

No.	Early Literacy Assessment Aspect	Mean Pre-Test Score	Mean Post-Test Score	N-Gain (Improvement)
1	Phonological Awareness	2.10	3.65	0.82 (High)
2	Letter and Sound Knowledge	1.85	3.80	0.91 (High)
3	Print Awareness	2.40	3.50	0.69 (Moderate)
4	Vocabulary	2.05	3.75	0.87 (High)
5	Narrative Skills	1.90	3.60	0.81 (High)
	Overall Mean	**2.06 (BD)**	**3.66 (DVW)**	**0.82**

BD = Beginning to Develop; DVW = Developing Very Well

1) Enhancement of Phonological Awareness through Auditory–Visual Stimulation

Phonological awareness improved significantly (N-gain = 0.82), driven by MonoZooAR's interactive audio features that isolate phonemes and rhyming patterns. The synchronization of 3D visuals with high-quality audio enabled children to precisely imitate initial animal sounds. This aligns with Yépez-Moreno et al., (2025) who noted that interactive

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soundscapes with phonetic pronunciations enhance children's retention of rhymes and alliteration. Furthermore, Majorano et al., (2021) affirm that phonological awareness strongly predicts reading acquisition success, with instant auditory feedback technology facilitating more effective manipulation of speech sounds than conventional media.

2) Effectiveness of Letter and Sound Knowledge Acquisition

The highest achievement was recorded in this aspect, with an N-Gain of 0.91. Children's ability to match physical letter cards with AR objects demonstrates that the bridge between abstract symbols (graphemes) and sounds (phonemes) was established with considerable strength (Siron et al., 2021). Korosidou (2024) affirms that AR media dramatically enhances alphabet competency in preschool children by providing concrete representations of abstract letter symbols. The multisensory integration within MonoZooAR facilitated faster decoding processes through immersive and experiential learning.

3) Print Awareness and Digital Textual Interaction

Although recording a moderate N-Gain of 0.69, the print awareness aspect nonetheless demonstrated positive progress. Children began to develop awareness of reading directionality through narrative text that moves in synchrony with audio narration. According to Xiao et al., (2023), children's interaction with digital text within AR environments reinforces emergent literacy development. Rohim et al., (2026) found that children exhibit greater interest in written symbols when text appears "alive" or is directly associated with three-dimensional animations, thereby enhancing the functional awareness of writing as a communicative tool rather than mere marks on a surface. MonoZooAR assists children in distinguishing between visual objects (animal illustrations) and functional symbols (text labels), which constitutes a critical foundation for understanding the purpose of writing prior to achieving independent reading ability.

4) Vocabulary Expansion through Multisensory Experience

Children's vocabulary developed substantially, with an N-Gain of 0.87. Children's willingness to employ newly acquired terminology such as *"trunk" (belalai)* or *"habitat"* increased markedly, as they were able to directly observe these concepts represented as realistic three-dimensional objects. Research by Fan et al., (2024) demonstrates that the combination of visual–auditory–tactile stimuli reduces cognitive load, thereby strengthening long-term memory retention of new vocabulary. The distributed sensory approach inherent in MonoZooAR ensures that newly acquired words are retained even after the play session has concluded. Tyson, (2021) found that the use of AR in vocabulary learning enhanced children's memory retention by up to 45% compared to conventional instructional methods. MonoZooAR presents vocabulary in a tangible manner, whereby children not only hear a word but simultaneously observe its three-dimensional representation directly.

5) Stimulation of Narrative Skills and Embodied Cognition

Narrative skills improved substantially (N-gain = 0.82), as children progressed from single-word utterances to constructing cohesive sentences describing AR animal behaviors. This supports Solichah & Fardana (2024), who noted that multisensory approaches combining kinesthetic engagement and dynamic visualization enhance narrative competencies. MonoZooAR leverages embodied cognition, where bodily movements such as device rotation encode experiences into rich episodic memory, enabling children to articulate action relationships using pronouns and connectives (Suo et al., 2026). Overall, the cumulative (N-gain = 0.82) confirms that MonoZooAR is an effective edutech tool for accelerating early literacy. This efficacy stems from physical-digital (*phygital*) sensory integration; balanced sensory input optimizes information absorption (Liu et al., 2024) while

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phygital interactions establish a robust cognitive foundation for young learners (Pasqualotto & Filosofi, 2023).

The development and field trial of MonoZooAR in Dersan Hamlet demonstrate that Augmented Reality technology, when built upon a multisensory framework, is capable of transforming early literacy instruction from passive, rote symbol memorization into meaningful, experiential exploration. In alignment with Kairu, 2021 this media offers an innovative, inclusive edutech solution that equips children in rural communities with literacy readiness comparable to their peers in urban centers. Practically, these findings carry significant implications for key stakeholders in both educational environments. For ECE teachers in rural settings, MonoZooAR serves as a cost-effective, all-in-one instructional tool that alleviates preparation burdens by consolidating multiple physical teaching aids into a single gamified platform. In urban classrooms, it provides a structured mechanism to channel children's existing screen time toward pedagogical literacy goals while optimizing attention and classroom conduct. For parents across both contexts, the intuitive, sound-activated design enables home-based literacy reinforcement without requiring specialized technical expertise or extensive pedagogical background. Consequently, the broader adoption of MonoZooAR sets a promising standard for the development of adaptive, interactive, and developmentally aligned early literacy media.

Conclusion

This study concludes that MonoZooAR, a multisensory augmented reality-based educational technology medium developed through the ADDIE instructional design model, is both highly feasible and effective in strengthening early literacy skills among children aged 4–6 years. Expert feasibility ratings consistently exceeded 93% across all evaluator categories, while field trial results yielded an overall normalised gain of 0.82, classified within the High category, across five measured dimensions of early literacy. These findings confirm that the systematic integration of three-dimensional visual, auditory, tactile, and interactive narrative stimulation within a phygital game-based framework produces significant and measurable literacy gains in early childhood learners. Collectively, the results highlight the critical role of multisensory stimulation in early literacy development, demonstrating that MonoZooAR effectively bridges the gap between abstract symbolic learning and meaningful experiential engagement, thereby repositioning literacy acquisition from passive symbol memorisation toward active, embodied exploration.

Recommendation

Based on the findings, ECE educators and institutional policymakers are advised to prioritize the integration of multisensory augmented reality media into early literacy programs across both urban and rural educational contexts. MonoZooAR demonstrates a clear capacity to reduce teacher preparation workload, maintain children's attentional focus, and accelerate foundational literacy competencies in alignment with the Kurikulum Merdeka framework. To ensure equitable and cost-effective implementation in resource-constrained rural areas, MonoZooAR is engineered for low-resource deployment. Rather than relying on high-specification tablet devices, the platform can be effectively executed using entry-level Android smartphones that teachers or schools already possess. Furthermore, the physical components such as the monopoly board game, markers, and tactile sound activated elements can be produced locally using low-cost, durable printed cardboard materials. Schools can also adopt a shared device rotation model, where a single mobile device serves small collaborative learning groups during guided center time, thereby minimizing hardware acquisition costs.

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Curriculum developers and edutech designers are further encouraged to adopt this low-cost, phygital design approach as a blueprint for next-generation ECE instructional tools. Future research should examine the effectiveness of MonoZooAR through larger-scale experimental designs employing randomized control groups, extended intervention periods, and broader geographical and socioeconomic contexts to strengthen external validity and inform evidence-based policy for inclusive early childhood education.

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