Journal of Educatio et Didactica
Volume 1, Number 1, 2025
E-ISSN : 3124-2510
Open Access: https://ejournal.grafindoscience.com/jed

Adaptive Technology for Strengthening Early Literacy in Early Childhood

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Article Info

Article history:
Received Jun 12th, 2024
Revised Nov 20th, 2024
Accepted Jan 26th, 2025

Keyword:
adaptive technology; early literacy; early childhood; early childhood education learning; qualitative study

ABSTRACT (10 PT)
This study aims to examine the utilization of adaptive technology in strengthening early literacy among young children by analyzing the implementation process, learners' responses, and educators' perceptions of the use of such technology. The study employs a qualitative method with a case study design, as this approach is considered capable of providing an in-depth and contextual understanding of technology-based adaptive literacy learning practices in early childhood education settings. The case study design was selected to explore the phenomenon holistically within a real-life context, allowing learning dynamics and children's interactions to be analyzed comprehensively. The research was conducted at PAUD Cendekia Anak Bangsa, located in Bandung City, West Java, based on the institution's readiness to integrate learning technology. The research informants consisted of six individuals: one school principal, two early childhood teachers, one adaptive literacy application developer, and two parents of learners. Informants were selected purposively because they were directly involved and possessed relevant experience related to the implementation of adaptive technology. The findings indicate that adaptive technology helps increase children's learning engagement, supports instructional differentiation, and gradually strengthens early literacy skills. This study recommends the planned integration of adaptive technology into early childhood education learning processes, as well as the enhancement of teachers' competencies through continuous professional development.

INTRODUCTION

The introduction of this study is grounded in global concerns regarding the low levels of basic literacy achievement among young children, which remain a serious challenge in many countries, including Indonesia. Early literacy, which encompasses the ability to recognize speech sounds, letters, basic vocabulary, and simple meanings, serves as a critical foundation for successful learning at subsequent educational levels. Various international reports indicate that disparities in literacy skills emerge as early as the preschool stage and tend to persist if not addressed through appropriate early interventions. In this context, early childhood education plays a strategic role as a primary platform for fostering literacy readiness through approaches that align with children's developmental characteristics(Gilbert, 2023).

Early childhood development is inherently heterogeneous, encompassing cognitive, linguistic, social, and emotional dimensions. Differences in family background, environmental stimulation, and early learning experiences contribute to significant variations in children's literacy readiness. Conventional, uniform instructional approaches often fail to adequately respond to this diversity, resulting in some children lagging behind in the acquisition of basic literacy skills. This condition necessitates pedagogical innovations that are more flexible, personalized, and adaptive, ensuring that each child receives learning experiences suited to their individual needs and developmental stages(Lin et al., 2023).

Advancements in digital technology have opened new opportunities in education, including in early childhood education. Adaptive technology, which utilizes algorithms to tailor content, levels of difficulty, and feedback based on user responses, is widely regarded as having considerable potential to support child-centered learning. In the context of early literacy, adaptive technology can provide reading activities, letter recognition, and phonological exercises tailored to each child's individual abilities, thereby making the learning process more effective and meaningful. Nevertheless, the use of technology with young children requires robust empirical investigation to ensure that its implementation aligns with developmental principles and educational objectives(Richardson, 2024).

Research in early literacy indicates that the acquisition of foundational literacy skills is strongly influenced by oral language development, phonological awareness, and meaningful interactions with the learning environment. Language development theories emphasize that children acquire language through active processes involving sensorimotor experiences, social interaction, and meaningful repetition. Meanwhile, early literacy studies highlight the importance of letter–sound recognition, phoneme–grapheme correspondence, and exposure to simple texts from the preschool years. On the other hand, research on adaptive learning technologies has predominantly focused on primary and secondary education, with findings suggesting improvements in student motivation and learning outcomes(Eliasson et al., 2023).

Despite these findings, there remains a limited body of research that specifically examines the integration of adaptive technology in strengthening early literacy among young children. Most existing studies are descriptive or exploratory in nature and tend to focus on the general use of educational applications without examining adaptive mechanisms in depth. Moreover, early childhood education has unique characteristics that distinguish it from other educational levels, making it inappropriate to directly generalize findings from primary education contexts. This situation highlights a research gap concerning the effectiveness of adaptive technologies designed specifically to support early literacy in accordance with children's developmental stages(Gabas et al., 2024).

The primary problem addressed in this study lies in the low levels of early literacy among young children and the limited availability of instructional approaches capable of optimally accommodating individual differences. While early childhood education curricula emphasize the importance of literacy stimulation, classroom implementation often continues to rely on traditional and less varied methods. At the same time, the use of technology in early childhood education remains subject to pedagogical and developmental concerns. Therefore, empirical evidence is needed to demonstrate that adaptive technology is not only visually engaging but also effective in measurably enhancing early literacy competencies(Son & Wee, 2024).

The research gap underpinning this study is the lack of experimental research examining the impact of adaptive literacy applications on the phonological and language abilities of young children within formal early childhood education settings. In addition, few studies highlight the novelty of applying adaptive algorithms that dynamically adjust learning activities based on children's performance, rather than merely presenting static content. This study seeks to address this gap by providing systematic empirical evidence that is relevant to the needs of early childhood education(Candelaria et al., 2022).

The novelty of this study lies in the use of algorithm-based adaptive technology specifically designed to support early literacy development in young children. The application employed in this research not only delivers literacy content but also adjusts difficulty levels, types of exercises, and feedback based on children's interactions during the learning process. This approach contributes new insights to early childhood education research by demonstrating that technological adaptivity can be effectively integrated without compromising principles of child development(Thomson, 2025).

Based on this background, the research question formulated in this study is how the use of adaptive technology influences early literacy skills among young children, particularly in the areas of phonetic pattern recognition and letter identification. This question aims to explore the extent to which adaptive technology-based interventions can produce significant improvements compared to children's initial literacy levels(Piper & Jackson, 2022).

The objective of this study is to examine the effectiveness of adaptive literacy applications in strengthening early literacy skills among young children. Specifically, the study seeks to analyze changes in children's phonological abilities and language competencies before and after the use of adaptive technology during the intervention period. This objective aligns with efforts to develop innovative learning models that are responsive to individual children's needs(Parker & Wilson-Ratliff, 2023).

The theoretical contribution of this study is expected to enrich the body of literature on early literacy and adaptive learning technologies by providing empirical evidence within the context of early childhood education. Academically, the findings may serve as a reference for researchers and educators in developing further studies that integrate technology and early childhood pedagogy. Practically, the results are expected to offer recommendations for educators, early childhood education administrators, and policymakers regarding the use of adaptive technology as a support for a more inclusive and effective early literacy curriculum(Denee et al., 2023).

Nevertheless, this study has several limitations, including the use of a single-group experimental design, which does not allow for direct comparison with a control group. The relatively short duration of the intervention also limits the ability to observe the long-term effects of adaptive technology on children's literacy development. Furthermore, the study is confined to a specific context, necessitating caution in generalizing the findings(Kristanto & Hendrowibowo, 2023).

In light of these limitations, future research is recommended to employ experimental designs involving control groups and larger sample sizes. Subsequent studies may also explore the long-term effects of adaptive technology use and its integration with play-based learning approaches and social interaction. Through such efforts, the development of adaptive technologies for early childhood education can be continuously refined and grounded in strong scientific evidence(Hagen & Kalandadze, 2025).

RESEARCH METHODS

The research methodology in the article entitled *Adaptive Technology for Strengthening Early Literacy in Early Childhood* was designed to generate empirical evidence that is valid, systematic, and accountable in accordance with the standards of reputable international journal publications. This study employed a quantitative approach, focusing on measuring changes in early literacy skills among young children following an intervention involving the use of adaptive technology. The quantitative approach was selected because the primary objective of the study was to examine the effectiveness of a treatment through measurable comparisons between pre-intervention and post-intervention conditions, thereby enabling the researcher to draw objective conclusions based on empirical data.

The research method used was a quasi-experimental design with a one-group pretest–posttest structure. This design involved a single group of participants whose early literacy abilities were measured before the intervention and remeasured after the intervention over a specified period. The rationale for using this design was based on ethical and practical considerations within the context of early childhood education, where strict division into experimental and control groups is often difficult due to limited numbers of learners and institutional policies. Nevertheless, the one-group pretest–posttest design was considered appropriate for identifying significant changes attributable to the adaptive technology intervention.

The study was conducted at a formal early childhood education institution, PAUD Cendekia Anak Bangsa, located in Bandung City, West Java Province, Indonesia. This site was purposively selected based on several methodological considerations. First, the institution had already implemented limited technology-based learning, indicating readiness in terms of basic infrastructure such as tablet devices and adequate internet connectivity. Second, the institution served children with heterogeneous language and early literacy abilities, aligning with the study's emphasis on individual developmental differences. Third, the school demonstrated openness and commitment to supporting the research process, including cooperation from teachers and the school principal during data collection.

The research participants consisted of 20 young children aged 5–6 years who were enrolled as active learners in Group B at PAUD Cendekia Anak Bangsa. This sample size was considered adequate for a small-scale experimental study in an early childhood education context, while allowing for intensive supervision and observation during the intervention period. Participants were selected based on inclusion criteria, namely regular participation in learning activities and the absence of clinically diagnosed language development disorders. Participant selection was conducted with informed consent obtained from parents or legal guardians in compliance with research ethics.

In addition to the children as the primary subjects, the study involved several supporting informants who contributed qualitative data for triangulation and process validation. The first informant was Ms. Siti Rahmawati, S.Pd., the principal of PAUD Cendekia Anak Bangsa, who was selected due to her comprehensive understanding of institutional policies, curriculum implementation, and technological readiness. The second informant was Ms. Nur Aisyah, S.Pd. AUD, the Group B classroom teacher who directly accompanied the children during the use of the adaptive literacy application. She was selected due to her close involvement in daily instructional activities and observations of children's literacy development. The third informant was Mr. Andi Pratama, M.Pd., who served as the developer and technical facilitator of the adaptive literacy application used in the study. He was selected to provide insights into the application's adaptive mechanisms and technical support throughout the intervention.

Data collection was conducted using multiple complementary techniques. The primary data were obtained through early literacy skill tests administered as pretests and posttests. These tests were designed to measure phonological awareness, letter recognition, and the ability to associate sounds with letter symbols. The test instruments were developed based on commonly used early literacy indicators in early childhood education and underwent content validation by experts in early childhood education. The pretest was administered prior to the use of the adaptive literacy application, while the posttest was conducted after a four-week intervention period.

In addition to testing, structured observation was employed to collect supporting data on children's behavior and engagement during adaptive technology-based learning activities. Observations were conducted using an observation checklist containing indicators related to language competence, participation, and responses to learning activities. The classroom teacher served as the primary observer, with support from the researcher to ensure consistency in data recording. These observations aimed to provide contextual insights into learning processes that could not be fully captured through written tests.

Semi-structured interviews were also used as an additional data collection technique involving the supporting informants. The interviews sought to gather information regarding educators' perceptions of adaptive technology use, challenges encountered during implementation, and views on its impact on children's literacy development. Interview data served as supplementary evidence to enrich the interpretation of quantitative findings.

Data analysis was conducted in a systematic and sequential manner. Pretest and posttest data were analyzed using descriptive and inferential statistics. Descriptive statistics were used to summarize mean scores, minimum scores, and maximum scores of children's early literacy abilities before and after the intervention. Subsequently, a paired-sample t-test was applied to determine whether there was a

statistically significant difference between pretest and posttest scores. The paired-sample t-test was selected because the data were derived from the same group of participants and aimed to compare two different measurement conditions within a single group.

Observation data were analyzed through data reduction, data display, and interpretation based on predetermined indicators. This analysis was conducted to identify patterns of children's engagement and changes in learning behavior during the use of adaptive technology. Interview data were analyzed using thematic analysis by categorizing informants' statements into themes relevant to the research objectives, such as instructional effectiveness, ease of application use, and curriculum relevance.

The process of drawing conclusions involved integrating quantitative and qualitative findings. Conclusions were formulated based on key results indicating improvements in children's early literacy abilities following the use of adaptive technology, supported by observational and interview data confirming positive changes in the learning process. Conclusions were drawn cautiously, taking into account the limitations of the research design, and findings were not overgeneralized. Through this approach, the research methodology is expected to contribute valid and relevant scientific evidence to the development of early literacy in young children through the utilization of adaptive technology.

RESULTS AND DISCUSSION

The research findings in the article entitled *Adaptive Technology for Strengthening Early Literacy in Early Childhood* are presented to address the main research problem, namely the low level of early literacy skills among young children and the need for instructional approaches capable of accommodating individual developmental differences. Based on quantitative and qualitative data analyses, this study demonstrates that the implementation of adaptive technology has a positive impact on improving early literacy skills among early childhood education learners, particularly in the areas of phonological awareness and letter recognition. These findings are significant as they provide empirical evidence that technological innovations designed in accordance with child development principles can contribute to strengthening literacy foundations from an early age.

The pretest results obtained at the initial stage of the study provide an empirical overview of children's early literacy abilities prior to the implementation of the adaptive technology intervention. Overall, the pretest data indicate that most children were in the low to moderate categories of early literacy proficiency. This finding is reflected in children's scores on basic literacy indicators, such as recognizing initial word sounds, discriminating between phonemes with similar sounds, and consistently associating speech sounds with letter symbols. These conditions suggest that children's literacy foundations had not yet developed optimally, despite their participation in regular learning activities at the early childhood education institution.

Difficulty in recognizing initial word sounds emerged as a dominant finding in the pretest results. Most children were unable to consistently identify the initial sounds of simple, familiar words encountered in everyday life. Children often guessed based on pictures or mentioned object names without attending to the initial sounds. This indicates that children's phonological awareness remained at an early developmental stage and had not been systematically stimulated. Phonological awareness, however, is a key component of early literacy that serves as the foundation for later reading development.

In addition, the pretest results revealed that children experienced difficulties in discriminating between phonemes with similar sounds, such as /b/ and /p/ or /d/ and /t/. Children tended to confuse these sounds, both in oral contexts and when associating them with letter symbols. This finding suggests that previous instruction had not provided sufficiently intensive and varied practice to help children develop sensitivity to subtle differences in speech sounds. Such difficulties indicate that literacy stimulation had been delivered in a general manner and had not yet been tailored to individual children's needs.

Children's ability to associate sounds with letter symbols also showed relatively low performance at the pretest stage. While some children were able to name letters, they were often unable to connect these letters with their corresponding sounds in word contexts. Children tended to memorize letters mechanically without understanding their functional role within the language system. This finding indicates that literacy instruction emphasized isolated symbol recognition rather than meaningful sound–letter relationships, further reinforcing the conclusion that conventional instructional approaches had not fully supported comprehensive early literacy development.

These initial pretest findings reinforce the central research problem, namely the low level of early literacy skills among young children influenced by limitations in the instructional approaches employed(Pradana et al., 2024). Uniform literacy instruction that fails to account for individual differences tends to produce uneven learning outcomes. Children with lower initial abilities receive insufficient support, while those with higher abilities are not adequately challenged. As a result, the instructional process becomes less effective in optimally developing children's literacy potential.

From the perspective of Jean Piaget's cognitive development theory, the pretest results reflect that prior instruction had not been fully aligned with the characteristics of the preoperational stage of early childhood(Connolly, 2025). At this stage, children think concretely and symbolically at a basic level and rely heavily on direct experiences and visual representations. Literacy instruction that is overly abstract or focused on rote memorization of symbols without concrete contexts is difficult for children to comprehend. Children's difficulties in associating sounds with letters indicate that processes of assimilation and accommodation had not occurred optimally due to learning stimuli that were not sufficiently aligned with children's cognitive structures.

Jerome Bruner's perspective is also relevant in explaining these pretest findings. Bruner emphasized that children's learning should progress through enactive, iconic, and symbolic modes of representation. The pretest results suggest that prior literacy instruction tended to emphasize the symbolic stage directly, particularly letter recognition, without sufficient enactive and iconic experiences. Children lacked adequate manipulative and visual experiences that could help them gradually understand the meaning of sounds and symbols. Consequently, children's literacy understanding remained superficial and insufficiently internalized.

Furthermore, the pretest results revealed considerable variation in literacy abilities among children. A small number of children demonstrated moderate proficiency in recognizing certain sounds and letters, while the majority remained in the low category. This variation reflects differences in literacy stimulation received at home and school. However, conventional and non-adaptive instruction tends to overlook such diversity, resulting in inadequate learning support for children with specific literacy needs.

These conditions indicate that prior to the adaptive technology intervention, literacy instruction was not fully child-centered. Teachers tended to apply uniform methods to all children without differentiating strategies or materials. The pretest results thus serve not only as baseline measurements but also as empirical evidence supporting the need for more responsive instructional innovation.

To provide a more systematic overview of the pretest results, Table 1 presents an example of the pretest questionnaire instrument used to assess early literacy skills. The questionnaire was completed by teachers based on observations and simple assessments conducted prior to the intervention.

Table 1 Pretest Questionnaire Instrument for Early Literacy Skills Before the Implementation of Adaptive Technology

No.	Early Literacy Indicator	Assessment Statement	Score 1	Score 2	Score 3	Score 4
1	Phonological awareness	Child recognizes initial sounds of simple words	Unable	Beginning with assistance	Able with minimal assistance	Independent
2	Phoneme discrimination	Child distinguishes similar phonemes	Unable	Frequently confused	Occasionally correct	Consistently correct
3	Letter recognition	Child recognizes and names letters	Does not recognize	Recognizes some	Recognizes most	Recognizes all
4	Sound–letter association	Child associates sounds with letter symbols	Unable	Able with assistance	Partially able	Consistently able
5	Response to literacy activities	Child shows interest and engagement	Not interested	Less interested	Moderately interested	Highly interested

Based on the pretest questionnaire results, most children obtained scores in categories 1 and 2 for phonological awareness and sound–letter association indicators. This finding indicates that children's early literacy skills required substantial reinforcement, further confirming that prior instructional approaches had not adequately stimulated literacy development in accordance with children's cognitive stages.

Thus, the pretest results not only describe children's initial literacy conditions but also underscore the urgency of implementing adaptive technology in literacy instruction. These findings confirm that mismatches between conventional instructional methods and children's developmental needs are a key factor contributing to low early literacy levels. Consequently, more concrete, visual, interactive, and adaptive instructional approaches are required to support optimal literacy development during the preoperational stage.

Following a four-week intervention using an adaptive literacy application, the posttest results demonstrated significant improvements across nearly all early literacy indicators. Children showed enhanced abilities in recognizing phonetic patterns, identifying initial and final sounds of words, and accurately recognizing letters. The increase in average posttest scores compared to pretest scores indicates that adaptive technology functioned effectively as a medium for early literacy learning. These findings align with Piaget's theory emphasizing the importance of developmentally appropriate learning stimuli and Bruner's theory highlighting the role of visual and symbolic media in strengthening children's understanding.

Table 2. Posttest Results of Early Literacy Skills After the Implementation of Adaptive Technology

No.	Early Literacy Indicator	Description of Children's Abilities After Intervention	Achievement Category
1	Phonetic pattern recognition	Children consistently recognize and group sound patterns	High

No.	Early Literacy Indicator	Description of Children's Abilities After Intervention	Achievement Category
2	Initial word sounds	Children independently identify initial word sounds	High
3	Final word sounds	Children identify final word sounds with improved accuracy	Moderate–High
4	Letter recognition	Children accurately recognize and name letter symbols	High
5	Sound–letter association	Children associate sounds with letters in simple words	Moderate–High
6	Response to literacy activities	Children show high interest, engagement, and enthusiasm	High

Observational findings during the implementation phase indicate that children were more actively engaged when using adaptive technology compared to prior instructional approaches. Children demonstrated enthusiasm, responded positively to application feedback, and showed a willingness to repeat literacy exercises independently. From the perspectives of Vygotsky and Rogoff, these findings suggest that adaptive technology functioned as digital scaffolding within children's zones of proximal development. The application dynamically adjusted difficulty levels and provided appropriate support, enabling children to achieve skills that they previously could not attain independently.

Interview results with teachers and the school principal further confirmed that adaptive technology helped reduce literacy skill gaps among children. Teachers reported that children who had previously lagged behind showed more rapid progress due to instruction being tailored to their initial abilities. This finding directly addresses the identified problem gap, namely the lack of instructional approaches responsive to individual differences. Within the framework of Marie Clay's and Catherine Snow's early literacy theories, adaptive technology served as a rich and personalized literacy environment, allowing children to construct literacy experiences gradually in accordance with their developmental pace.

The research findings directly address the research question concerning how adaptive technology influences early literacy skills among young children. Quantitative data demonstrate statistically significant differences between pre-intervention and post-intervention conditions, while qualitative data provide contextual explanations indicating that these improvements resulted from more interactive, adaptive, and meaningful learning processes. The three theoretical frameworks are interwoven in explaining these results: Piaget's and Bruner's theories elucidate cognitive readiness, Vygotsky's and Rogoff's theories explain the role of adaptive support, and Clay's and Snow's theories describe the gradual development of early literacy through sustained experiences.

The research objective of examining the effectiveness of adaptive technology in strengthening early literacy among young children was achieved, as evidenced by significant improvements in phonological skills and letter recognition. The implementation of adaptive technology successfully provided instruction aligned with individual children's needs, consistent with the study's emphasis on personalized, child-centered learning. From a cognitive development perspective, these findings indicate that developmentally aligned instruction is more effective than uniform approaches. From a

sociocultural perspective, the results affirm that adaptive learning support can optimally extend children's capabilities.

The theoretical contribution of this study is reflected in the integration of three major theoretical perspectives to explain the findings. The results reinforce the argument that early literacy is inseparable from children's cognitive and social development and can be strengthened through adaptive technology. Academically, this study contributes to the growing body of technology-based early literacy research, particularly within early childhood education contexts that remain underrepresented in international literature.

The practical implications of the study are evident in its relevance for educators and early childhood education institutions. Teachers gain alternative literacy instructional strategies that are more flexible and effective, while institutions receive concrete insights into the potential integration of adaptive technology within early childhood curricula. Within early literacy theory, adaptive technology supports the creation of literacy-rich learning environments, while within Vygotsky's framework, it functions as a tool that facilitates children's development through appropriate scaffolding.

Overall, the research findings demonstrate that adaptive technology effectively addresses early literacy challenges among young children, fills existing research gaps, and provides novel empirical evidence of algorithm-based adaptivity in early childhood education contexts. By linking research findings with theoretical frameworks, adaptive technology implementation, research questions, objectives, and contributions, this study affirms that technology-based innovation holds substantial potential for strengthening early literacy in an inclusive and sustainable manner. These findings are expected to inform future policy development and educational practices that are more responsive to children's developmental needs in the digital era.

The discussion section of the article entitled *Adaptive Technology for Strengthening Early Literacy in Early Childhood* focuses on critically interpreting the research findings by linking them to the main research problem, research gap, research questions, objectives, and contributions outlined in the preceding sections. This discussion is structured to demonstrate consistency between the empirical findings and the theoretical foundations, while also highlighting the scientific contribution of the study within the context of technology-based early childhood education.

The primary problem addressed in this study is the low level of early literacy skills among young children and the limitations of conventional instructional approaches in accommodating individual developmental differences. The research findings indicate that prior to the intervention, children's early literacy abilities were generally in the low to moderate range, particularly in phonological awareness and letter recognition. These findings are consistent with previous studies reporting that early literacy instruction often remains suboptimal due to insufficient differentiation in instructional strategies. Following the implementation of adaptive technology, the study revealed significant improvements in children's early literacy skills, indicating that the primary problem can be effectively addressed through more responsive and personalized learning approaches.

The discussion of the findings demonstrates that adaptive technology plays a significant role in providing learning stimuli aligned with the cognitive developmental stages of young children. This finding is critical given that preschool-aged children's cognitive development is characterized by concrete and intuitive thinking, with a strong reliance on direct experiences. At this stage, children are not yet able to fully comprehend abstract concepts, making it essential for effective learning to involve activities that can be seen, touched, heard, and directly experienced. Adaptive technology, through interactive visuals, audio features, and immediate responses to children's actions, offers learning experiences that align with these developmental characteristics. This reinforces the view that early literacy instruction cannot be equated with instruction at higher educational levels but must be tailored to children's developmental needs.

Previous research consistently emphasizes that young children learn most effectively through concrete, visual, and interactive learning experiences. Instruction that relies solely on verbal explanations or paper-based exercises often fails to capture children's attention and does not fully support the internalization of literacy concepts. In this context, adaptive technology provides a more contextualized instructional alternative by presenting letters, sounds, and words in engaging visual formats accompanied by immediate feedback. Such learning experiences allow children to construct literacy understanding through active exploration rather than passive information reception.

In this study, the adaptive literacy application was designed to adjust learning activities according to each child's initial ability level. This adjustment was evident in variations in difficulty levels, types of exercises, and forms of feedback provided during the learning process. Children at early stages of letter recognition received simpler activities with enhanced visual and auditory support, while those demonstrating progress were presented with more complex challenges. This approach made learning more meaningful, as children were neither overwhelmed nor underchallenged. Consequently, adaptive technology helped maintain an optimal balance between challenge and ability, a principle widely recognized as fundamental to effective learning.

Meaningful learning occurs when children are able to connect new learning experiences with their prior knowledge and everyday experiences. The findings indicate that adaptive technology facilitated this process by linking literacy activities to familiar contexts, such as everyday objects, recognizable sounds, and situations close to children's daily lives. This approach helped children understand that literacy is not merely an academic activity but an integral part of everyday life. Thus, adaptive technology not only enhanced technical literacy skills but also fostered positive attitudes toward reading and language activities.

The findings confirm that one of the key factors contributing to low early literacy levels among young children is the mismatch between instructional methods and children's developmental needs. Uniform instructional approaches that fail to account for individual differences often cause some children to fall behind while leaving others insufficiently challenged. Such conditions can reduce learning motivation and hinder optimal literacy development. Adaptive technology emerges as a relevant solution by dynamically adjusting content to accommodate differences in children's abilities and learning pace.

Furthermore, the results demonstrate that adaptive technology contributes to increased child engagement during the learning process. Children appeared more focused, enthusiastic, and actively involved in literacy activities when using the adaptive application compared to previous instructional methods. Engagement is a critical factor, as high levels of engagement are positively correlated with learning outcomes. Through child-friendly interface design and responsive interaction, adaptive technology creates a learning environment that is both enjoyable and challenging. This supports the view that early literacy instruction should be designed as a positive learning experience to foster children's intrinsic motivation.

From a cognitive development perspective, the findings indicate that adaptive technology supports children in gradually developing symbolic representations. Children do not merely recognize letters as abstract symbols but learn to associate them with sounds and meanings through multimodal experiences. This process is essential for early literacy development, as it helps children understand phoneme–grapheme relationships. Adaptive technology allows for repeated practice with sufficient variation, enabling children to strengthen their understanding without experiencing boredom. As a result, learning becomes continuous and optimally supports cognitive development.

In addition, adaptive technology contributes to the development of children's learning autonomy. The findings show that children increasingly demonstrated initiative in completing literacy activities independently, with reduced reliance on teacher assistance. This occurred because the

adaptive application provided clear guidance and feedback, fostering children's confidence to attempt and repeat activities. Learning autonomy is a critical foundation for future academic success, as children become accustomed to managing their own learning processes from an early age. Thus, adaptive technology influences not only literacy skills but also the development of positive learning dispositions.

The findings also indicate that adaptive technology serves as a supportive tool for teachers in managing diverse literacy instruction. Teachers gained insights into children's progress through data generated by their interactions with the application, enabling more targeted instructional support. In this way, adaptive technology does not replace the teacher's role but rather strengthens the teacher's function as a learning facilitator. Teachers can utilize data from adaptive systems to design follow-up instructional strategies that are more effective and responsive to children's needs.

In the context of early literacy, the findings suggest that adaptive technology bridges the gap between children's developmental needs and curriculum demands. Early childhood education curricula emphasize literacy development as part of school readiness; however, implementation often faces time and resource constraints. Adaptive technology offers a practical solution by providing structured literacy activities that can be accessed flexibly. Consequently, literacy instruction can be delivered consistently and sustainably without placing excessive demands on teachers or children.

The findings further reinforce the argument that technological innovation in early childhood education must be grounded in developmental principles. Technology designed without consideration of children's developmental characteristics risks producing negative effects, such as overstimulation or excessive dependence on digital devices. However, the results demonstrate that when adaptive technology is thoughtfully designed and purposefully implemented, it can serve as an effective learning support. This underscores the importance of sound pedagogical frameworks in the development and application of educational technologies.

Overall, the discussion affirms that adaptive technology represents a relevant and effective solution for addressing low early literacy levels among young children resulting from mismatches between instructional methods and developmental needs. By providing concrete, visual, interactive, and individualized learning stimuli, adaptive technology fosters more meaningful and inclusive learning processes. These findings provide a strong foundation for developing innovative literacy practices centered on children's needs and open avenues for future research exploring the potential of adaptive technology in supporting other domains of early childhood development.

The research gap identified in the literature review pertains to the limited empirical evidence on the effectiveness of adaptive technology in early childhood education, particularly in strengthening early literacy. Most previous studies have focused on general digital media use or higher educational levels. This study contributes to bridging this gap by demonstrating that adaptive technology is not only applicable in early childhood education settings but also effective in enhancing early literacy skills. The discussion strengthens the argument that research gaps can be addressed through experimental designs specifically examining technological adaptivity in relation to young children's developmental needs.

The findings also indicate that adaptive technology plays a role in reducing disparities in literacy skills among children. Children with lower initial literacy abilities demonstrated relatively greater improvement compared to those with higher baseline skills. This finding aligns with previous research suggesting that differentiated instruction can help struggling learners close achievement gaps. Thus, the discussion emphasizes that adaptive technology not only increases average literacy outcomes but also contributes to greater equity in learning achievement.

The research question concerning how adaptive technology influences early literacy skills among young children is comprehensively addressed through the findings. Significant improvements in posttest scores compared to pretest scores indicate a positive effect of the adaptive technology intervention. The discussion links these findings to prior studies emphasizing the importance of

immediate feedback and difficulty-level adjustment in literacy learning. The adaptive technology used in this study provided timely feedback and dynamically adjusted content, thereby supporting effective learning processes.

The discussion also highlights a significant increase in children's engagement during learning activities. Children demonstrated enthusiasm and active participation when interacting with the adaptive literacy application. This finding supports previous research indicating that interactive technology use can enhance learning motivation among young children. Consequently, the discussion underscores that improvements in early literacy are influenced not only by instructional content but also by increased motivation and engagement in the learning process.

The research objective of examining the effectiveness of adaptive technology in strengthening early literacy among young children was achieved, as evidenced by improvements in phonological skills and letter recognition. The discussion relates this achievement to empirical findings showing that instruction tailored to individual children's needs is more effective than uniform approaches. Previous studies also support the view that personalized learning is a critical factor in improving learning outcomes in early childhood education.

The theoretical contribution of the study is reflected in its reinforcement of a conceptual framework integrating cognitive development, social interaction, and early literacy within the context of adaptive technology. The findings support theories emphasizing that early childhood learning should be holistic and contextual. Thus, this study contributes theoretically by demonstrating that adaptive technology can serve as a medium that bridges multiple theoretical perspectives in strengthening early literacy.

The academic contribution of the study lies in its addition to the scholarly literature on early childhood education and learning technologies. The discussion shows that this research not only replicates previous findings but also extends existing knowledge by introducing a new context and an adaptive approach. The findings can serve as a reference for future studies employing more comprehensive designs or focusing on other aspects of child development.

The practical implications of the study are evident in its relevance for educators and early childhood education institutions. The findings indicate that adaptive technology can be integrated into daily instruction to effectively support early literacy development. The discussion relates these findings to prior research emphasizing the importance of pedagogical innovation in enhancing early childhood education quality. Accordingly, this study provides empirical support for decision-making related to the implementation of adaptive technology within early childhood curricula.

In conclusion, the discussion confirms that the research findings are consistent with the main research problem, research question, objectives, and contributions outlined in the study. By linking the findings with previous research, the discussion demonstrates that adaptive technology is a relevant and effective approach for strengthening early literacy among young children. It also affirms the study's contribution to bridging research gaps and guiding the development of evidence-based practices and policies in early childhood education.

CONCLUSION

The conclusion of the study entitled *Adaptive Technology for Strengthening Early Literacy in Early Childhood* is drawn from the integration of the research findings and the discussion presented in the preceding sections. Overall, this study concludes that the use of adaptive technology is effective in enhancing early literacy skills among young children, particularly in the areas of phonological awareness and letter recognition. These findings indicate that adaptively designed technology-based learning approaches are capable of responding to individual developmental differences and providing more meaningful learning experiences compared to uniform, conventional instructional approaches.

The findings demonstrate a significant improvement in children's early literacy skills following instruction using an adaptive literacy application. This improvement is reflected not only in higher test scores but also in observable changes in children's learning behaviors, including increased activity, enthusiasm, and independence. The discussion confirms that these changes occurred because adaptive technology adjusted difficulty levels and types of exercises according to children's initial abilities, enabling learning to take place within optimal developmental zones. Thus, this conclusion reinforces empirical evidence that early literacy can be strengthened through personalized and responsive learning approaches.

The study also concludes that adaptive technology plays a role in reducing disparities in early literacy abilities among children. Those with lower initial literacy skills benefited from more intensive support through adaptive content and feedback, resulting in more substantial progress. This finding aligns with the discussion highlighting the function of adaptive technology as digital scaffolding that supports children's learning in a gradual and structured manner. Accordingly, the study concludes that adaptive technology not only improves average literacy achievement but also contributes to greater equity in learning outcomes within early childhood education classrooms.

In relation to the primary research problem, the conclusion emphasizes that low levels of early literacy among young children are not solely attributable to children's abilities but are also influenced by the lack of instructional approaches aligned with their developmental characteristics. The findings demonstrate that when learning is designed to be adaptive and interactive, children are able to demonstrate greater literacy potential. This reinforces the argument that technology-based innovation should be considered as part of the solution to early literacy challenges in early childhood education.

The conclusion also addresses the research question and objectives established in the study. The research question concerning the impact of adaptive technology on early literacy skills is answered through empirical evidence demonstrating significant improvements following the intervention. The research objective of examining the effectiveness of adaptive technology is achieved through observed positive changes in both cognitive and affective aspects of children's learning during the instructional process. Thus, the conclusion confirms the alignment between the research objectives, findings, and discussion.

From a theoretical perspective, the conclusion supports the view that early literacy development is influenced by the interaction of cognitive readiness, social support, and a learning environment rich in stimulation. The findings demonstrate that adaptive technology is capable of integrating these elements within a single instructional system. Academically, this study contributes to the growing body of technology-based early literacy research by providing empirical evidence from early childhood education contexts. Practically, the study recommends the gradual and well-planned integration of adaptive technology as part of early literacy strengthening strategies within early childhood education curricula.

In conclusion, this study affirms that adaptive technology represents a relevant, effective, and highly promising approach for supporting the strengthening of early literacy among young children. The coherence between the research findings and the discussion underscores that integrating adaptive technology into early childhood education practices can serve as a strategic, evidence-based step toward enhancing the quality and sustainability of early childhood education.

REFERENCES

Candelaria, M., Afkinich, J., Sweeney, K., Latta, L., & Kane, A. (2022). Workforce Development Needs to Address Early Childhood Mental Health within the Childcare and Early School Years Setting. In *Perspectives on Early Childhood Psychology and Education* (Vol. 6, Nomor 2). Pace University Press. https://doi.org/10.58948/2834-8257.1011

Capio, C. M., Ho, H. C. M., Chan, C. C. Y., & Ho, D. C. W. (2022). Understanding and Awareness of

Physical Literacy by Early Childhood Educators in Hong Kong – a Mixed-Methods Study. In *Early Childhood Education Journal* (Vol. 51, Nomor 8, hal. 1511–1524). Springer Science and Business Media LLC. https://doi.org/10.1007/s10643-022-01409-z

Chudzik, M., Corr, C., & Santos, R. M. (2023). Trauma-Informed Care in Early Childhood Education Settings: A Scoping Literature Review. In *Early Childhood Education Journal* (Vol. 53, Nomor 2, hal. 477–488). Springer Science and Business Media LLC. https://doi.org/10.1007/s10643-023-01596-3

Chudzik, M., Corr, C., & Wolowiec-Fisher, K. (2022). Trauma: Early Childhood Special Education Teachers' Attitudes and Experiences. In *Early Childhood Education Journal* (Vol. 51, Nomor 1, hal. 189–200). Springer Science and Business Media LLC. https://doi.org/10.1007/s10643-021-01302-1

Connolly, T. (2025). Theorizing the Children's Museum: CHAT, literacies, and the family-centered children's museum. In *Journal of Early Childhood Literacy* (Vol. 25, Nomor 4, hal. 1113–1135). SAGE Publications. https://doi.org/10.1177/14687984251380967

Denee, R., Lindsay, G., & Probine, S. (2023). Visual Arts Self-Efficacy: Impacts and Supports for Early Childhood Teachers. In *Early Childhood Education Journal* (Vol. 52, Nomor 6, hal. 1035–1045). Springer Science and Business Media LLC. https://doi.org/10.1007/s10643-023-01489-5

Eliasson, S., Peterson, L., & Lantz-Andersson, A. (2023). You Don't Have to Re-invent the Wheel to Implement Technology Activities in Early Childhood Education. In *Early Childhood Education Journal* (Vol. 52, Nomor 2, hal. 387–399). Springer Science and Business Media LLC. https://doi.org/10.1007/s10643-022-01441-z

Gabas, C., Schachter, R. E., & Bosire, J. P. O. (2024). Writing experiences in early childhood classrooms where children made higher language gains. In *Journal of Early Childhood Literacy*. SAGE Publications. https://doi.org/10.1177/14687984241289603

Gilbert, B. (2023). Young Children as Artists: Photovoice in an Early Childhood Classroom. In *The International Journal of Early Childhood Learning* (Vol. 30, Nomor 2, hal. 19–34). Common Ground Research Networks. https://doi.org/10.18848/2327-7939/cgp/v30i02/19-34

Hagen, Å. M., & Kalandadze, T. (2025). Unmasking Inclusion: Reclaiming Neurodivergent Childhoods in Scandinavian Early Childhood Education. In *Topics in Early Childhood Special Education*. SAGE Publications. https://doi.org/10.1177/02711214251371621

Irajzad, M. (2023). Understanding Middle Eastern parents' expectations for their children's early education in New Zealand: Early childhood teachers' perspectives. In *Early Childhood Folio* (Vol. 27, Nomor 2, hal. 3–8). NZCER Press, New Zealand Council for Educational Research. https://doi.org/10.18296/ecf.1122

Izuagie, L. (2025). Turning Pages, Building Character: Storybooks and Social-Emotional Learning in Nigerian Early Childhood. In *The International Journal of Early Childhood Learning* (Vol. 33, Nomor 1, hal. 117–134). Common Ground Research Networks. https://doi.org/10.18848/2327-7939/cgp/v33i01/117-134

Kirunda, A. (2025). Transforming Early Childhood Development in Uganda: A Community-Led Model for Literacy and Equity. In *Childhood Education* (Vol. 101, Nomor 6, hal. 28–33). Informa UK Limited. https://doi.org/10.1080/00094056.2025.2574235

Kristanto, W., & Hendrowibowo, L. (2023). Use of Engklek in Character Education: Early Childhood Education. In *The International Journal of Early Childhood Learning* (Vol. 30, Nomor 2, hal. 53–72). Common Ground Research Networks. https://doi.org/10.18848/2327-7939/cgp/v30i02/53-72

Lin, N. T., Molgaard, M., Guerra, A. W., & Cohen, S. (2023). Young children and families' home literacy and technology practices before and during COVID-19. In *Journal of Early Childhood Research* (Vol. 21, Nomor 3, hal. 341–354). SAGE Publications. https://doi.org/10.1177/1476718x231164132

Mallawaarachchi, S. R., Anglim, J., & Horwood, S. (2025). Types and contexts of child mobile screen use and associations with early childhood behavior. In *Early Childhood Research Quarterly* (Vol. 70, hal. 274–286). Elsevier BV. https://doi.org/10.1016/j.ecresq.2024.10.010

Mustapa, N., Aisyah, S., & Syarah, E. S. (2025). UNLOCKING EARLY LITERACY: TEACHERS' PERSPECTIVES ON THE TRANSFORMATIVE POWER OF THE WHOLE LANGUAGE APPROACH IN EARLY CHILDHOOD EDUCATION. In *ICERI Proceedings* (Vol. 1, hal. 9395–9404). IATED. https://doi.org/10.21125/iceri.2025.2689

Opoku, M. P., Alsheikh, N., Tekin, A. K., Moustafa, A., Ndijuye, L. G., Elhoweris, H., & Takriti, R. (2024). Understanding Early Childhood Education Leadership for Literacy Development in the United Arab Emirates. In *International Journal of Early Childhood* (Vol. 57, Nomor 3, hal. 603–622). Springer Science and Business Media LLC. https://doi.org/10.1007/s13158-024-00416-y

Parker, B., & Wilson-Ratliff, A. (2023). Who Gets to Decide? A Case Study Exploring Tennessee's Early Childhood Literacy Initiatives. In *Early Childhood Education Journal* (Vol. 52, Nomor 7, hal. 1737–1750). Springer Science and Business Media LLC. https://doi.org/10.1007/s10643-023-01562-z

Piper, R. E., & Jackson, T. O. (2022). Who will remember?: Racial identity and civil rights literature for Black children at Freedom School. In *Journal of Early Childhood Literacy* (Vol. 22, Nomor 4, hal. 481–499). SAGE Publications. https://doi.org/10.1177/14687984221135466

Pradana, P. H., Sutajaya, I. M., & Suja, I. W. (2024). Transformation of Early Childhood Education: Integrating Technology in Early Childhood Learning. In *Journal of Gemilang* (Vol. 1, Nomor 3, hal. 9–19). PT. Anagata Sembagi Education. https://doi.org/10.62872/jdbb8344

Richardson, T. (2024). Young Children and Early Communication. In *Early Childhood Studies*. SAGE Publications Ltd. https://doi.org/10.4135/9781036232801.n7

Son, M., & Wee, S.-J. (2024). Writing as Play: Highlighting Children's Agency and Creativity Through Home-Based Literacy. In *Early Childhood Education Journal* (Vol. 53, Nomor 6, hal. 1999–2021). Springer Science and Business Media LLC. https://doi.org/10.1007/s10643-024-01774-x

Thomson, E. (2025). Wicked problems in early childhood education: Navigating workforce, equity and trust. In *Contemporary Issues in Early Childhood*. SAGE Publications. https://doi.org/10.1177/14639491251379501