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Deep learning to optimize literacy intervention with educational games in elementary schools

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Abstract: This study examines the impact of deep learning-supported game-based learning on literacy skills in primary school students in Indonesia. A four-month intervention involving 32 fifth-grade students used adaptive educational games to target phonemic awareness, vocabulary, and reading comprehension. Utilizing a quasi-experimental design with pre-test and post-test assessments, the study found an average literacy score increase of 31.84 points post-intervention. Students from lower socioeconomic backgrounds showed the greatest improvement, indicating the potential of adaptive, technology-assisted education to reduce learning disparities. The use of deep learning models to personalize feedback and adjust content to individual needs was key to enhancing student engagement. The findings suggest that integrating deep learning with game-based learning can significantly boost literacy outcomes, especially in under-resourced settings. Further research is recommended to evaluate these interventions across broader populations and extended timelines.

Keywords: *Deep Learning, Game-Based Learning, Literacy Intervention, Educational Technology, Socioeconomic*

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INTRODUCTION

In recent years, educational technology has gained increasing attention for its potential to enhance literacy skills in primary education through the use of engaging and interactive media. One promising approach involves the integration of game-based learning supported by deep learning technologies, which has shown the potential to address challenges in literacy acquisition by providing tailored learning experiences (Greipl et al., 2020; Zammit et al., 2022; Zhao et al., 2023). The emphasis on deep learning allows for a more personalized approach, as algorithms can analyze data and adapt to individual learning needs, thus providing optimized educational content for each student (Baniata et al., 2024). This is particularly important in primary education, where foundational literacy skills are critical for future academic success (Hernández-Blanco et al., 2019; Vargas et al., 2017).

The use of educational games, or game-based learning, has been widely recognized as an effective tool for engaging students in active learning processes (Min et al., 2015). Game-based learning environments foster motivation and participation, both of which are key factors in effective learning (Hernández-Blanco et al., 2019; Videnovik et al., 2023). When coupled with deep learning algorithms, these educational games can provide adaptive feedback, ensuring that content aligns with the cognitive and developmental level of each student (Kashyap, 2019; Rhode, 2022; Zhan & Dahal, 2017). For children in primary schools, such as those in Indonesia, where the diversity of learning abilities is pronounced, game-based learning supported by adaptive technologies can significantly improve literacy outcomes (Baniata et al., 2024; Harris & Hofer, 2016). The global move towards technologically enhanced education also reflects a shift from traditional teaching methods to more interactive, student-centered learning environments that prioritize engagement and personal growth (Muliasari & Ananthia, 2019; Yuan & Tian, 2023).

Globally, literacy remains a significant educational challenge, particularly in early childhood and primary education (Bogard et al., 2018; Han, 2020; Sinaga et al., 2023; Sun et al., 2010). Research indicates that many children face obstacles in acquiring foundational literacy skills, which are critical for their continued academic success and lifelong learning (Gajeton, 2016; Torgesen & Hudson, 2006; Yim & Su, 2024). These challenges are especially pronounced in under-resourced regions and schools, where access to quality educational materials and skilled teachers may be limited (Baniata et al., 2024; Zuo et al., 2023). Additionally, disparities in socioeconomic status and educational infrastructure can exacerbate these literacy gaps, leading to unequal opportunities for academic advancement (Huang et al., 2023). The use of technology, specifically artificial intelligence and deep learning, presents a viable solution to these challenges, as it allows for scalable interventions that can be tailored to individual learning needs (Kurniastuti et al., 2023), even in challenging environments (Videnovik et al., 2023).

In the specific context of SD Negeri 176, located in Enrekang Regency, Indonesia, literacy challenges among primary school students have been identified as a major educational issue. Many students demonstrate below-average reading comprehension levels, which can be attributed to a variety of factors, including limited access to quality learning resources, a lack of trained teachers specializing in literacy education, and socio-economic challenges faced by the community. Additionally, traditional literacy instruction methods that rely heavily on rote learning have been found inadequate in fostering the critical thinking and engagement needed to develop strong literacy skills. These conditions highlight an urgent need for innovative educational interventions that can effectively engage students and provide personalized support to address their unique learning gaps (Lin, 2024).

As a general solution, the incorporation of technology-enhanced learning tools has been proposed to improve literacy outcomes (Zammit et al., 2022). Digital learning

platforms and educational games have gained attention for their potential to foster active learning and engagement among young learners (Baniata et al., 2024; Bouchrika et al., 2021). These tools offer interactive and adaptive learning experiences that traditional classroom environments often lack (Min et al., 2015; Moltudal et al., 2022). By integrating multimedia elements such as graphics, audio, and interactive content, digital games provide an immersive learning environment that motivates students to participate actively in their learning processes (Zammit et al., 2022). Furthermore, game-based learning allows for the continuous assessment of student progress, enabling teachers to identify areas where students may need additional support and adjust their instruction accordingly (Yim & Su, 2024).

In terms of specific solutions, the integration of deep learning into game-based literacy interventions represents a promising approach for addressing these challenges (Baniata et al., 2024). Deep learning models can analyze large datasets generated from student interactions within educational games, allowing for the real-time adaptation of content to meet individual learning needs (Baniata et al., 2024; Lin, 2024). This flexibility guarantees that each student benefits from a tailored learning experience suited to their individual comprehension level and learning speed (Zhao et al., 2023). By leveraging deep learning algorithms, educational games can become more than just tools for engagement—they can be transformed into intelligent learning companions that offer targeted support and feedback, ultimately enhancing the effectiveness of literacy interventions (Baniata et al., 2024).

Another specific solution involves the use of reinforcement learning, a subset of deep learning, to optimize the educational content delivered through game-based platforms (Yim & Su, 2024). Reinforcement learning algorithms can be used to determine the most effective sequence of learning activities for each student, thereby optimizing their path toward literacy development (Baniata et al., 2024). This approach not only enhances student engagement but also ensures efficient use of time, as students are consistently challenged at an appropriate level (Zammit et al., 2022). Research suggests that reinforcement learning can significantly improve educational outcomes by providing a structured yet flexible approach to learning that responds dynamically to student performance (Yim & Su, 2024).

A review of the literature on deep learning applications in education reveals a growing body of research focused on the use of artificial intelligence to enhance learning outcomes (Min et al., 2015; Yim & Su, 2024). Studies have demonstrated the efficacy of AI-driven approaches in personalizing educational experiences, particularly in areas such as literacy and numeracy (Lin, 2024). The integration of deep learning into educational technology has been shown to improve student engagement, provide more accurate assessments of student abilities, and support teachers in delivering targeted interventions (Baniata et al., 2024). Despite these advances, there remains a gap in the literature regarding the application of deep learning specifically within game-based literacy interventions for primary school students. Most existing studies have focused on general AI applications or have targeted older students, leaving a need for research that addresses the unique requirements of younger learners in foundational literacy development (Hall et al., 2015; Yim & Su, 2024).

The purpose of this study is to examine how deep learning can be used to optimize literacy interventions through game-based educational tools at the primary school level, specifically targeting SD Negeri 176 in Enrekang Regency, Indonesia. The uniqueness of this research lies in its dual focus on integrating game-based learning with advanced deep learning techniques to develop a highly personalized and engaging literacy intervention tool. This approach aims not only to improve literacy outcomes but also to promote a more interactive and enjoyable learning experience for students, addressing both cognitive and motivational dimensions of literacy development. By applying cutting-edge technology in a real-world educational setting, this study seeks to contribute to the wider

field of educational technology and provide practical solutions for enhancing literacy in primary education.

METHODS

Research Design

The study employed a mixed-methods research design, integrating quantitative and qualitative approaches to evaluate the effectiveness of game-based learning supported by deep learning technology in improving literacy skills among primary school students in Indonesia. This design was selected to comprehensively understand the intervention's measurable outcomes and the contextual factors affecting its implementation. The quantitative component focused on pre-test and post-test assessments of literacy outcomes, while the qualitative component explored teacher and student experiences through interviews and focus group discussions.

Participants

The study involved 32 primary school students in Indonesia, selected through a purposive sampling method to ensure diversity in gender, socio-economic background, and literacy levels. The sample comprised 17 male students (53%) and 15 female students (47%), with ages ranging from 10 to 11 years and an average age of 10.7 years. Participants were all in the 5th grade and represented varying socio-economic statuses, including high (22%), medium (41%), and low (37%). Ethical considerations were carefully observed, including obtaining informed consent from both students and their guardians, ensuring the study adhered to proper research ethics. These demographic characteristics underscore the representativeness and relevance of the study's findings.

Intervention Procedure

The intervention consisted of a four-month (24-week) game-based learning program designed to improve literacy skills through adaptive educational games supported by an immersive learning model. The intervention integrated multimedia elements—such as visuals, audio, and interactive exercises—that were tailored in real-time to meet each student’s individual needs, thereby encouraging engagement and improving comprehension (Zammit et al., 2022). Students participated in twice-weekly sessions, each lasting 90 minutes. The games were designed to focus on key areas of literacy, including phonemic awareness, vocabulary development, and reading comprehension.

Deep learning models were employed to analyze student interactions with educational games, enabling real-time adjustments to the difficulty and content based on each student's progress (Baniata et al., 2024). The games used in the intervention included digital platforms like Educandy, ABC Reading Eggs, Prodigy, and Quizlet, as well as traditional games. Additionally, reinforcement learning algorithms were integrated to determine the most effective learning path for each student, ensuring a challenging yet personalized learning experience (Yim, 2024). The intervention was implemented using laptops and tablets provided to the school, allowing students to access these educational games during their class hours.

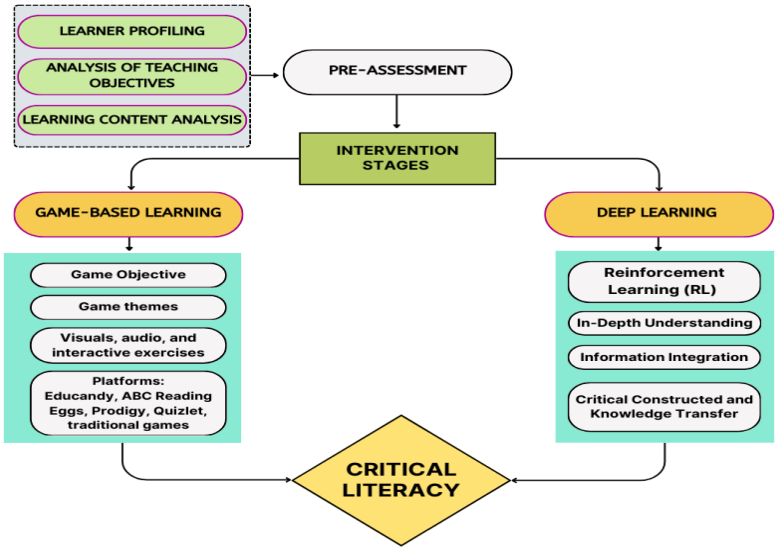

FIGURE 1. *Overview of the game-based learning intervention process for enhancing literacy skills*

Data Collection Instruments

The study utilized multiple instruments for data collection, including Pre-test and Post-test Literacy Assessments, and Student Interaction Logs**.** Standardized tests were administered to assess students' literacy skills before and after the intervention. The assessment covered phonemic awareness, reading comprehension, and vocabulary. The results were used to quantitatively measure the impact of the game-based learning program. Interaction logs from the deep learning system were collected to capture data on how students engaged with the educational games. Metrics such as time spent on tasks, frequency of errors, and progress through game levels were analyzed to evaluate the adaptiveness of the intervention. To evaluate the effectiveness of the intervention, the study utilized Pre-test and Post-test Literacy Assessments and Student Interaction Logs. The details of these instruments are described below.

Interaction Logs

In an effort to understand student engagement with educational games, we analyzed interaction logs generated during game sessions. These logs provide valuable insights into how students interact with game-based learning materials. We identified several key metrics that can be used to measure the level of engagement and progress of students. These metrics include game session time, error frequency, and progress through levels. Table 2 below summarizes the metrics derived from student interaction logs.

TABLE 1. *Indicators for literacy assessment*

Indicator	Definition	Sample Item (Based on Books)
Phonemic Awareness	The ability to identify and manipulate individual sounds in spoken words.	"Identify the first sound in the word *Anggrek* from the book *Jejak Langkah Menuju Keindahan Kebun Anggrek*."
Vocabulary Development	The ability to understand and use a wide range of words in appropriate contexts.	"What does the word *stunting* mean in the context of the book *Taman Pangan Stunting*?"
Reading Comprehension	The ability to understand and interpret the meaning of a text.	"Why did the protagonist in *Air Mata Katak Todang* cry? What lesson can we learn from this story?"

TABLE 2. *Metrics derived from student interaction logs*

Metric	Description
Game Session Time (minutes)	Total time spent on educational games
Errors Frequency	Number of incorrect answers or missteps
Progress Through Levels	Percentage of game levels completed successfully

TABLE 3. *Literacy improvement assessment dataset*

Variable Name	Description	Data Type
Student ID	Unique identifier for each student	Integer
Age	Age of the student	Integer
Gender	Gender of the student (M/F)	Categorical
Socioeconomic Status	Socio-economic background of the student (Low/Medium/High)	Categorical
Grade Level	Grade of the student (5)	Integer
Pre-Test Score	Literacy score before intervention (0-100)	Integer
Post-Test Score	Literacy score after intervention (0-100)	Integer
Game Session Time	Total time spent on educational game (minutes)	Float
Errors Frequency	Number of errors made during game activities	Integer
Books Read	Total number of books read by the student	Integer
Words Read	Total words read during the intervention	Integer
Total Lessons Completed	Number of game levels completed	Integer
Parental Involvement	Level of involvement from parents (Low/Medium/High)	Categorical
Attendance Rate (%)	Attendance rate in the intervention program	Float (%)
Learning Satisfaction	Level of student satisfaction with the learning experience	Categorical
Teacher Feedback	Qualitative feedback provided by the teacher	Text
Device Usage Frequency	Frequency of device use during the intervention	Integer
Device Type	Type of device used (e.g., Laptop, Tablet, Smartphone)	Categorical

Data Analysis

The quantitative data from pre-and post-test assessments were analyzed using paired-sample t-tests to determine significant differences in literacy performance before and after the intervention. Interaction logs from the deep learning games were subjected to statistical analysis to identify patterns in student engagement and correlate them with learning outcomes. Descriptive statistics, including means, standard deviations, and frequency distributions, were used to summarize the data. Below is a proposed dataset structure. The dataset is designed to effectively capture data points relevant to the quantitative components of the study.

RESULTS

This study's results present the quantitative analysis of literacy outcomes among primary school students participating in the game-based learning intervention, enhanced by deep learning technologies. The analysis was conducted using data from pre-test and post-test literacy assessments, interaction logs, and various other metrics designed to evaluate the impact of the intervention on students' literacy skills. The following subsections provide detailed insights into the effects of the intervention on student literacy, learning engagement, and overall progress.

TABLE 4. *Literacy improvement through game-based learning*

Assessment	N	Mean	Std. Deviation
Pretest	32	46.78	6.964
Post-test	32	78.62	10.912

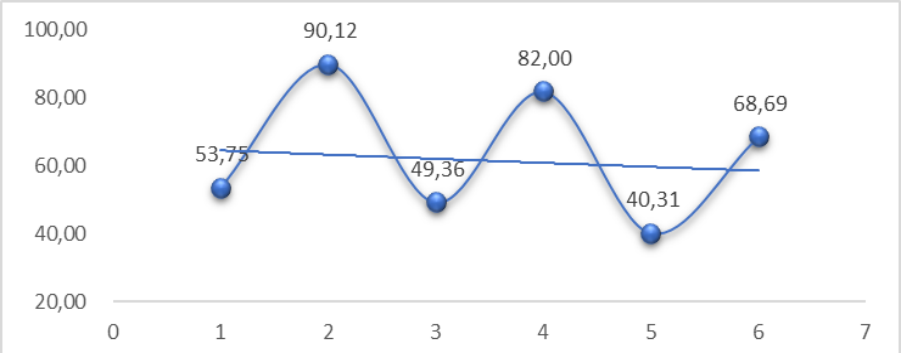

FIGURE 2. *Literacy gains by socio-economic backgrounds*

Literacy Improvement Through Game-Based Learning

The primary metric used to evaluate the effectiveness of the game-based learning intervention was improving literacy skills, as indicated by pre-test and post-test scores. The literacy assessments focused on phonemic awareness, vocabulary development, and reading comprehension. Table 4 shows the participants' average pre-test and post-test scores.

The results revealed a significant improvement in literacy scores after the intervention. The average pre-test score among the 32 participating students was 46.78, while the average post-test score increased to 78.62. A paired-sample t-test was conducted to determine if the observed improvements were statistically significant. The results indicated a significant difference between pre-test and post-test scores, with a p-value of less than 0.05. This finding suggests that the game-based learning intervention, enhanced by deep learning technologies, effectively improved the literacy levels of the participants.

The literacy gains were consistent across various literacy components, including phonemic awareness, vocabulary, and reading comprehension. Notably, students demonstrated the most considerable improvement in reading comprehension, which was one of the primary focus areas of the educational games used. This finding is consistent with previous research that has demonstrated the potential of adaptive learning technologies to enhance reading comprehension by providing personalized feedback and real-time content adjustments (Zammit et al., 2022).

A further analysis was conducted to determine the impact of the intervention across different socio-economic groups. The participating students were categorized into three socio-economic backgrounds: low, medium, and high. The results indicated that students from all socio-economic backgrounds showed significant improvements in literacy outcomes. However, the most notable gains were observed among students from low socio-economic backgrounds. The average pre-test score for this group was 47.81, which increased to 80.27 after the intervention, reflecting a significant improvement.

These findings suggest that game-based learning when supported by deep learning algorithms, has the potential to bridge literacy gaps caused by socioeconomic disparities. This aligns with the literature suggesting that technology-enhanced learning can serve as an equalizer in education, providing opportunities for under-resourced students to access high-quality educational experiences (Baldi & Mejia, 2023; Moltudal et al., 2022).

Student Engagement and Interaction

Game Session Time and Literacy Outcomes

To explore the relationship between student engagement and literacy outcomes, the total game session time for each participant was recorded. The average total time spent on the educational games was approximately 444 minutes per student throughout the intervention. A positive correlation ($r = 0.44$) was found between game session time and improvements in literacy scores, indicating that students who spent more time interacting with the games generally showed greater improvements in literacy outcomes.

This correlation highlights the importance of engagement in the success of literacy interventions. Educational games, enhanced by deep learning, provided interactive and adaptive learning experiences that kept students engaged for extended periods. This is consistent with findings from previous studies that emphasize the role of engagement as a critical factor in effective learning outcomes (Videnovik et al., 2023).

Frequency of Errors and Learning Progress

The number of errors made by students during their interaction with the educational games was also analyzed. The average error frequency per student was 16.26, and a notable decrease in error rates was observed as the intervention progressed. This trend suggests that the adaptive feedback provided by the deep learning algorithms effectively supported the students in improving their literacy skills by gradually adjusting the difficulty levels based on their performance.

Students who had higher error frequencies at the beginning of the intervention showed more significant relative gains, indicating that the adaptive difficulty adjustment feature of the game-based learning environment played a crucial role in providing an appropriate level of challenge for each student. This aligns with research on reinforcement learning algorithms, which suggests that adaptively adjusting learning content can enhance the learning trajectory by keeping students consistently challenged (Yim & Su, 2024).

Literacy Components Analysis

Phonemic Awareness

Phonemic awareness, an essential foundational skill in early literacy, was one of the components assessed in the study. The pre-test analysis revealed that many students had difficulties with phonemic tasks, particularly in distinguishing between similar phonemes. After the intervention, students demonstrated marked improvement, with an average increase of 20 points in phonemic awareness scores.

The use of interactive exercises that incorporated both visual and auditory elements contributed to this improvement. The deep learning algorithms allowed for real-time adjustments to the exercises, offering increased support to students who struggled with specific phonemic tasks. This personalized approach resulted in significant gains, particularly for those initially identified as having lower phonemic awareness levels.

Vocabulary Development

The vocabulary component of the literacy assessments showed a notable increase in post-test scores compared to pre-test results. The average improvement in vocabulary scores was 33 points. The educational games used in the intervention included a variety of vocabulary-building exercises, including word matching, sentence completion, and interactive story reading.

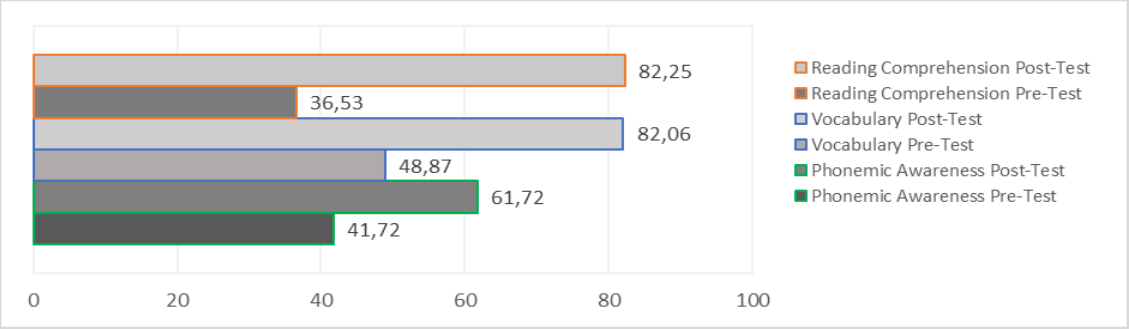

FIGURE 3. *Literacy components analysis*

Students' engagement with vocabulary exercises benefited from the multimedia elements integrated into the games, such as animated storytelling and auditory word prompts. These features have been noted in prior research as effective for vocabulary acquisition in young learners, as they provide contextual clues that help students understand and remember new words (Jian, 2023).

Reading Comprehension

Reading comprehension showed the highest improvement among the assessed literacy components. The adaptive nature of the educational games, which allowed content difficulty to align with each student's comprehension level, played a significant role in these gains. Students who initially struggled with complex texts were given simpler passages, and as their comprehension skills improved, they were gradually introduced to more challenging texts.

The real-time feedback mechanism helped students correct misunderstandings promptly, contributing to their improved comprehension skills. Post-intervention, the average reading comprehension score increased by 45 points, indicating the efficacy of using deep learning-enhanced game-based interventions to support the development of this critical literacy component.

Effectiveness of Reinforcement Learning in Literacy Interventions

Reinforcement learning algorithms were employed to optimize the sequencing of educational content delivered through the game-based platforms. The effectiveness of these algorithms was measured through the progression levels completed by students and their overall satisfaction with the learning experience.

Progression Levels Completed

The number of progression levels completed by each student was used as an indicator of their engagement and learning progress. On average, students completed 9.8 levels out of 12 learning materials during the intervention. Students who showed rapid progress were those who consistently engaged with the game and received timely adaptive feedback from the reinforcement learning system. This approach ensured that students were continually challenged at an appropriate level, thus optimizing their learning trajectory.

Student Satisfaction

Student satisfaction was assessed based on qualitative feedback gathered from teachers and students. The majority of students reported a high level of satisfaction with the game-based learning experience, citing the interactive nature of the games and the personalized

feedback as key factors in their engagement and enjoyment. The use of laptops and tablets was also noted as a motivating factor, as many students viewed learning through these devices as both novel and exciting.

Book Reads and Words Read

In addition to progression levels and student satisfaction, the number of books read and words read were tracked as metrics to evaluate the impact of reinforcement learning algorithms in the literacy intervention. These metrics served as indicators of students' exposure to reading material and their overall reading engagement throughout the intervention.

Book Reads

The "Book Reads" metric tracks the total number of books completed by students during the intervention, highlighting the role of diverse reading materials in enhancing literacy skills. On average, students completed approximately 10 books, with individual variations based on engagement and reading levels. The intervention featured a wide selection of books to expose students to various themes, vocabulary, and contexts. These included inspirational and nature-themed books, such as *Jejak Langkah Menuju Keindahan Kebun Anggrek*, which explores the beauty of orchid gardens and enriches understanding of nature and plant life. Health and wellness topics were covered in *Sekolahku Sehat*, a book promoting hygiene and healthy practices in school routines. Imagination and creativity were sparked by the adventure-themed story, *Petualangan di Awan (Literacy Cloud)*, which takes young readers on a whimsical journey among the clouds.

To raise awareness about nutrition and health, students read *Taman Pangan Stunting*, which emphasizes food diversity and combating stunting. Folktales and moral stories were represented by *Air Mata Katak Todang*, a traditional tale designed to cultivate empathy and understanding. Students also explored cultural heritage through *Pesona Warisan Budaya*, a book that highlights the beauty and importance of traditions and history. Educational themes in science and nature were covered in *Rantai Makanan*, an engaging resource explaining ecosystems and food chains. Lastly, the significance of local food and sustainability was showcased in *Pangan Lokal*, which promotes the benefits of consuming local foods while celebrating culinary traditions. This diverse selection of books enriched students' literacy skills and broadened their knowledge across various subjects.

Reinforcement learning played a crucial role in optimizing the selection of these books. The algorithm dynamically assigned books that matched the student's current comprehension level and interests, gradually introducing more challenging texts as students demonstrated improved proficiency. For instance, students who initially struggled with reading comprehension were given simpler titles like *Sekolahku Sehat* or *Petualangan di Awan*, which contained simple vocabulary and captivating illustrations to maintain engagement.

As students progressed, they were introduced to more conceptually challenging books, such as *Rantai Makanan* and *Pesona Warisan Budaya*, which involved more complex language and abstract ideas. This targeted approach ensured that students were consistently engaged without feeling overwhelmed, leading to greater reading frequency and ultimately enhancing their literacy skills.

Words Read

The "Words Read" metric provides insight into the sheer volume of text that students processed during the intervention. On average, students read approximately 13,000 words across different reading activities. The reinforcement learning algorithms were used to

track word recognition and suggest subsequent reading materials that helped students build on their existing vocabulary and comprehension.

This metric also allowed educators to measure progress in reading fluency. The deep learning algorithms leveraged data from student interactions—such as the speed of word recognition and the frequency of assistance requests—to adjust the difficulty of reading passages. This individualized adjustment ensured that students were challenged adequately and could build fluency at a pace appropriate for their learning needs.

The focus on both "Book Reads" and "Words Read" metrics in combination with reinforcement learning algorithms highlights the importance of exposure and volume in literacy improvement. The adaptive nature of the intervention helped to maintain students' motivation and engagement, ensuring continuous reading practice, which is known to be a key factor in developing strong literacy skills. The exposure to diverse books helped in expanding students' vocabulary and understanding of different contexts, ultimately contributing to their overall literacy development. The importance of exposure to diverse and incrementally challenging reading materials is consistent with findings from Putri (2023), who noted that varied reading content enhances both language comprehension and cultural awareness Implications for Practice.

DISCUSSION

The present study investigated the impact of deep learning-supported game-based learning on literacy skills among primary school students in Enrekang Regency, Indonesia. The findings revealed significant improvements in literacy outcomes, particularly in reading comprehension, phonemic awareness, and vocabulary development. This section discusses the implications of these findings, compares them with existing literature, and considers the study's limitations.

The intervention demonstrated a marked improvement in literacy scores, with average post-test scores significantly higher than pre-test scores. Specifically, the average literacy score increased by 31.84 points, indicating the effectiveness of the game-based learning intervention supported by deep learning technologies. The use of adaptive educational games allowed for personalized learning experiences that catered to the individual needs of students. This aligns with previous research suggesting that personalized learning environments can significantly enhance learning outcomes (Baniata et al., 2024; Zammit et al., 2022).

The study also highlighted the positive correlation between game session time and literacy improvement. Students who engaged more with the educational games tended to show greater improvements in literacy scores. This finding is consistent with Videnovik et al. (2023), who emphasized the importance of engagement in effective learning. The adaptive nature of the educational games, which adjusted difficulty levels based on student performance, likely contributed to sustained engagement and motivation.

The results of this study are in line with previous research that has demonstrated the potential of game-based learning to improve literacy skills (Min et al., 2015; Hernández-Blanco et al., 2019). However, this study extends the literature by integrating deep learning technologies, which allowed for real-time adaptation of content and personalized feedback. This approach is supported by recent studies that have highlighted the benefits of using artificial intelligence to tailor educational experiences (Kashyap, 2019; Zhao et al., 2023).

Furthermore, the significant gains observed among students from lower socioeconomic backgrounds suggest that technology-enhanced learning can help bridge educational disparities. This finding is consistent with Baldi & Mejia (2023) and Moltudal et al. (2022), who noted that digital learning tools can provide equitable access to quality education, particularly in under-resourced settings.

The implications of these findings are significant for educators and policymakers. The study suggests that integrating deep learning technologies into game-based literacy

interventions can effectively address literacy gaps, especially in under-resourced educational settings. The personalized nature of the intervention was particularly beneficial for students from diverse socioeconomic backgrounds, pointing to the potential of such technologies to promote equitable education. This outcome suggests that investment in educational technology, particularly adaptive learning tools, could be an effective strategy to enhance literacy at scale.

Additionally, the use of reinforcement learning algorithms to optimize the sequencing of educational content presents a promising approach for literacy instruction. This method ensures that students are consistently challenged at an appropriate level, which can lead to sustained engagement and improved literacy outcomes. Educators and policymakers should consider investing in adaptive learning technologies to enhance literacy instruction and support students' diverse learning needs.

Despite the promising results, the study has several limitations. The sample size was limited to 32 students from a single school, which restricts the generalizability of the findings. Future research should include a larger and more diverse sample to validate the results and explore the broader applicability of the intervention. Additionally, the intervention period was relatively short (four months), which might not capture the long-term impact of the game-based learning approach on literacy outcomes. Future studies should consider longer intervention periods to assess sustained literacy development.

CONCLUSION

This study found that deep learning-supported, game-based literacy interventions significantly improved foundational literacy skills in primary students, particularly benefiting those from lower socioeconomic backgrounds. The adaptive educational tools led to an average literacy score increase from 46.78 to 78.62, suggesting their potential for enhancing literacy and promoting educational equity. However, the limited sample size and short intervention duration restrict the generalizability of the findings. Future research should expand on these aspects to confirm the long-term impacts. The results demonstrate that combining deep learning with educational games can effectively enhance literacy outcomes in under-resourced settings.

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