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Development of AI-Based interactive picture story E-Books to improve early childhood math skills

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ABSTRACT

This study developed an artificial intelligence-based interactive picture story e-book to support mathematics learning among children aged 5–6 years. The study employed a research and development approach using the Borg and Gall development model. The development process included needs analysis, product development, expert validation, revision, limited field testing, and large-scale field testing. Product feasibility and practicality were assessed through expert evaluation and user responses, while effectiveness was examined by comparing children's mathematics performance before and after implementation using the Wilcoxon Signed-Rank Test. The developed e-book achieved a feasibility score of 90.74% and a practicality score of 92.84%. Significant differences were found between pretest and posttest performance in the limited field trial involving 11 children ($Z = -2.705$; $p = .007$) and the large-scale field trial involving 45 children ($Z = -5.865$; $p < .001$). The findings indicated that the developed e-book was feasible and practical and showed promising potential for supporting early childhood mathematics learning through contextual, visual, and interactive learning experiences.

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Introduction

Mathematics constitutes a fundamental domain of learning because mathematical concepts are continuously applied in everyday activities, including counting, measuring, comparing, identifying patterns, and solving problems (Agbata et al., 2024; Onoshakpokaiye E, 2023). Developing mathematical competence from early childhood is therefore essential for establishing foundations for subsequent learning and academic development (Libertus, 2025; Louw & Claassens, 2024). In early childhood education, mathematical learning extends beyond the acquisition of numerical knowledge and is closely associated with broader cognitive development, including logical thinking, systematic reasoning, memory, conceptual understanding, and problem-solving abilities (Kanevski et al., 2022; Menon & Chang, 2021; Meylani, 2024). Appropriate exposure to mathematical concepts during the early years can consequently strengthen not only children's emerging numeracy but also their critical reasoning and problem-solving capacities, which are important for later academic achievement (Yasmin & Amiruddin, 2026). These considerations position early mathematical competence as an important developmental foundation that requires learning experiences appropriate to the cognitive and developmental characteristics of young children.

Despite its importance, the development of mathematical competence in early childhood remains challenging. Many young children experience difficulties in understanding fundamental mathematical concepts,

particularly when learning activities provide insufficient opportunities to explore concepts through meaningful and concrete experiences (Aunio et al., 2025; Mahmudah et al., 2026). Such difficulties may be reinforced by teacher-centered instructional practices that emphasize information delivery rather than active exploration, interaction, and contextual learning (Bhardwaj et al., 2025; Cheng & Chen, 2022). Consequently, mathematics may be perceived as difficult even during the early stages of education (Outhwaite et al., 2024; Petropoulou et al., 2024). The broader concern regarding mathematical competence is also reflected in the Programme for International Student Assessment, which indicates that Indonesian students continue to demonstrate comparatively low mathematics achievement relative to many neighboring countries in Southeast Asia (OECD, 2023). Although PISA assesses older students rather than early childhood learners, these findings reinforce the importance of building stronger mathematical foundations from the earliest stages of education. Accordingly, early mathematics instruction requires developmentally appropriate approaches that enable children to construct mathematical understanding through concrete, meaningful, engaging, and contextual experiences.

Rapid developments in digital technology provide opportunities to address these pedagogical challenges by expanding the ways mathematical concepts can be represented and experienced by young learners (Korobkova et al., 2025; C. Wang et al., 2024). Digital technology is increasingly positioned not merely as a supplementary instructional resource but as a means of facilitating interactive, multimodal, and learner-centered experiences (Lindeman et al., 2021). Nevertheless, its integration into early childhood mathematics instruction remains limited, and conventional learning media are still frequently used in ways that provide insufficient interactivity and may not fully accommodate young children's developmental characteristics (Alsaeed & Aladil, 2024; Zhao & Roberts, 2025). This limitation is particularly important because young children tend to construct understanding through concrete experiences, visual representations, storytelling, play, and active interaction (Graven & Jorgensen, 2024; Rahiem, 2021; Savva et al., 2021). Learning media that combine these characteristics may therefore facilitate children's understanding of mathematical concepts that would otherwise remain abstract (Graven & Jorgensen, 2024; Solfiah et al., 2025). Moreover, meaningful and context-based learning can strengthen mathematical conceptual understanding when mathematical ideas are embedded in familiar activities and culturally relevant situations (Putri et al., 2026). Thus, effective digital innovation in early childhood mathematics should not merely digitize conventional instructional content but should create developmentally appropriate environments in which children can experience mathematics through narrative, visualization, interaction, and meaningful contexts.

Interactive digital storybooks represent one promising approach because they integrate narratives, illustrations, animations, audio, and interactive activities within a unified learning environment, thereby potentially strengthening both children's engagement and conceptual understanding (Li et al., 2023; Rahiem, 2021; Son & Butcher, 2024). In parallel, advances in Artificial Intelligence (AI) have expanded the possibilities of digital learning by supporting adaptive experiences, personalized feedback, and individualized learning pathways (Bayly-Castaneda et al., 2024; Farhood et al., 2025; S. Wang et al., 2024). Nevertheless, an important gap remains between these two strands of research. Existing studies have predominantly investigated interactive digital storybooks and AI-supported learning as separate technological and pedagogical approaches, while relatively few studies have systematically integrated them into a single medium specifically designed for the mathematical development of children aged 5–6 years (Utoyo et al., 2025, 2026; Zhang et al., 2026). Moreover, limited attention has been devoted to how AI-supported features can be embedded within interactive picture-story structures while maintaining the concrete, visual, narrative, and developmentally appropriate characteristics required in early childhood learning. Consequently, the research gap concerns not simply the availability of digital media or AI, but the pedagogically coherent integration of foundational mathematics, interactive picture storytelling, and AI-supported learning within a developmentally appropriate learning environment (Nikolopoulou, 2025).

To address this gap, the present study develops an AI-based interactive picture story e-book specifically designed to support the mathematical abilities of children aged 5–6 years. The novelty of the study lies in integrating three interrelated components within a single learning medium: foundational early mathematical concepts, interactive picture-based storytelling, and AI-supported features. Rather than positioning AI as an independent technological intervention, the developed e-book embeds technology within narrative, visual, contextual, and interactive learning experiences that correspond to the developmental characteristics of young children. This integration is expected to extend previous research on digital storybooks and AI-supported education by providing a pedagogically structured medium through which young learners can encounter mathematical concepts in meaningful contexts. Accordingly, this study aims to develop an AI-based interactive picture story e-book for early childhood mathematics learning and to evaluate its validity, practicality, and effectiveness among children aged 5–6 years. Through these objectives, the study seeks to establish both the feasibility of the developed product and its potential contribution to developmentally appropriate technology-enhanced mathematics learning.

Method

This study employed a Research and Development (R&D) approach using the Borg and Gall development model to develop an Artificial Intelligence (AI)-based interactive picture story e-book for improving early childhood mathematics skills. The research was conducted over two years through needs analysis, product development, expert validation, revision, a limited field trial, further revision, and a large-scale field trial. The R&D approach was selected to support systematic development and empirical evaluation of the educational product (Borg & Gall, 1983; Sugiyono, 2022).

In the first year, the developed e-book was validated by three experts in media, language, and learning materials and subsequently revised according to their recommendations. A limited field trial was then conducted in one kindergarten involving 11 children aged 5–6 years. The participating kindergarten and children were selected using purposive sampling based on school readiness, teacher willingness to participate, and the availability of facilities required for implementing the digital learning media. The limited field trial employed a one-group pretest–posttest design. The children completed a pretest before participating in learning activities using the AI-based interactive picture story e-book and a posttest after the intervention. In the second year, the revised product was tested in three additional kindergartens involving 45 children aged 5–6 years, with 15 children from each kindergarten. The same one-group pretest–posttest design was applied in the large-scale trial.

The children's mathematics skills were measured using a 10-item assessment instrument covering ten indicators: naming number symbols 1–10, counting objects 1–20, classifying objects by shape, identifying more and less, sequencing daily activities, recognizing geometric shapes, recognizing simple patterns, recognizing size, recognizing time sequence, and identifying object position. Each indicator was represented by one item and assessed using a four-point rating scale. The mathematics assessment was administered as a pretest before the intervention and a posttest after the intervention. The expert validation and teacher practicality instruments were used to evaluate the feasibility and practicality of the developed product, while the mathematics assessment was used to measure changes in children's mathematics performance.

Table 1. Early Childhood Mathematics Skills Assessment Instrument

Mathematics Skill Indicator	Number of Items
Naming number symbols 1–10	1
Counting objects 1–20	1
Classifying objects by shape	1
Identifying more and less	1
Sequencing daily activities	1
Recognizing geometric shapes	1
Recognizing simple patterns	1
Recognizing size	1
Recognizing time sequence	1
Identifying object position	1
Total	10

The validity of the developed e-book was assessed by three experts using a five-point rating scale, while its practicality was assessed through teacher responses using a five-point rating scale. The mathematics assessment used a four-point rating scale. Data were analyzed using descriptive and inferential statistics. Validity and practicality were summarized using percentage scores. Children's mathematics performance was analyzed by comparing pretest and posttest scores. Normality and homogeneity tests were conducted before inferential analysis, followed by the Wilcoxon Signed-Rank Test to examine differences between pretest and posttest scores. Statistical significance was set at $\alpha = 0.05$, and analyses were performed using IBM SPSS Statistics. The study was limited to four kindergartens and children aged 5–6 years; therefore, the findings were interpreted within the participating educational contexts.

Results and Discussions

The development of the AI-based interactive picture story e-book produced a digital learning medium designed to support foundational mathematical abilities among children aged 5–6 years. The product was evaluated through expert validation, practicality assessment, limited field testing, and a large-scale field trial. The evaluation focused on media feasibility, language appropriateness, mathematical content, instructional structure, practicality of implementation, and changes in children's mathematical performance. The overall findings indicate that the developed e-book achieved a high level of feasibility and practicality and was associated with significant differences between children's pretest and posttest mathematical performance.

Table 2. Expert Validation Results of the AI-Based Interactive Picture Story E-Book

Validation Aspect	Percentage (%)	Interpretation
Media	91.11	Highly Feasible
Language	90.00	Highly Feasible
Material	91.11	Highly Feasible
Overall Average	90.74	Highly Feasible

As presented in Table 2, the media validation obtained a score of 91.11%, indicating that the AI-based interactive picture story e-book achieved a high level of feasibility in terms of its visual and technical presentation. The assessment indicates that the developed e-book was appropriate as a learning medium for young children, particularly in relation to its visual presentation, layout, illustrations, typography, color composition, readability, and overall attractiveness. The high validation score suggests that the visual characteristics of the e-book can support children's engagement with the learning content and facilitate the presentation of mathematical concepts through pictures and interactive story contexts.

The language validation obtained a score of 90.00%, as shown in Table 2. This result indicates that the language used in the e-book was considered highly feasible and appropriate for the characteristics of children aged 5–6 years. The language component is important because the e-book presents mathematical concepts through narrative, instructions, questions, and interactions that need to be understood by young learners. Therefore, the high language validation score indicates that the verbal presentation of the learning content was sufficiently clear, understandable, and appropriate to support children's participation in the learning activities.

The material validation obtained a score of 91.11%, indicating a high level of feasibility of the mathematical content presented in the e-book. This result demonstrates that the mathematical material was considered appropriate for the learning objectives and characteristics of children aged 5–6 years. The high material validation score also indicates that the mathematical concepts incorporated into the interactive picture story were considered suitable for supporting children's foundational mathematical abilities. The material was presented through meaningful story situations, visual representations, and interactive activities, allowing mathematical concepts to be introduced in a contextual and developmentally appropriate manner.

Overall, as shown in Table 2, the three validation aspects obtained consistently high scores, namely 91.11% for media, 90.00% for language, and 91.11% for material, resulting in an overall average score of 90.74%. These results indicate that the AI-based interactive picture story e-book achieved a high level of overall feasibility. The consistency of the scores across the three aspects suggests that the product was appropriately designed not only from the perspective of its visual and technical characteristics but also in terms of language and mathematical content. Therefore, the developed e-book can be considered feasible for further implementation and field testing in early childhood mathematics learning.

Table 3. Mathematical Indicators Integrated into the Interactive Picture Story E-Book

No.	Mathematical Indicator
1	Naming number symbols 1–10
2	Counting objects 1–20
3	Classifying objects by shape
4	Identifying more and less
5	Sequencing daily activities
6	Recognizing geometric shapes
7	Recognizing simple patterns
8	Recognizing size
9	Recognizing time sequence
10	Identifying object position

The mathematical content was deliberately oriented toward foundational mathematical concepts rather than formal arithmetic operations. As shown in Table 3, the e-book addresses number-symbol recognition, counting, classification, comparison, sequencing, geometry, patterns, size, temporal sequence, and spatial position. The assessment consisted of ten indicators represented by ten items. This composition reflects a broad conception of early mathematics in which children develop mathematical understanding through number concepts, relationships, patterns, classification, spatial awareness, and everyday situations.

The selection of these mathematical domains is supported by international research on early mathematics and educational technology.A systematic review of 54 studies indicated that educational technology can support young children's mathematical competencies, while its effectiveness is influenced by implementation

characteristics, including teacher support and children's prior knowledge. Consistent with this perspective, the present study positioned technology within an integrated pedagogical structure rather than treating it as an independent learning mechanism (Chen, 2026; Clements et al., 2025; Verbruggen et al., 2021).

The use of interactive storytelling is also supported by recent research that specifically examined early childhood mathematics. The use of interactive storytelling is also supported by recent research on mathematics education. Sihombing et al (2026) incorporated mathematical domains including number concepts, patterns, geometry, measurement, and simple data representation into an interactive storybook and reported significant improvement in children's mathematical abilities. Similarly, Deslis et al (2025) found that digital storytelling can support mathematics learning by promoting mathematical understanding, engagement, reasoning, and problem-solving.

Table 4. Overall Practicality Result of the AI-Based Interactive Picture Story E-Book

Assessment	Percentage
Overall practicality	92,84%.

The developed e-book obtained an overall practicality score of 92,84 %, indicating that the product was considered practical for use in early childhood learning. This finding indicates that the product was sufficiently understandable and implementable within the learning context. Practicality is particularly important in early childhood education because a technologically sophisticated product may not be useful if teachers encounter difficulties in operating it or if its activities are not aligned with classroom routines.

The findings of this study reinforce the perspective that practicality is one of the key prerequisites for integrating AI-based technology into early childhood mathematics education. Utoyo et al (2026) demonstrate that AI-based e-books can support mathematics learning when the technology used has a clear connection to learning needs, ease of use, clarity of presentation, assessment, and interactivity. Recent systematic evidence further indicates that effective AI integration requires alignment between technological affordances, pedagogical approaches, and learners' needs (Aravantinos et al., 2024). In mathematics education, the effectiveness of AI integration is likewise influenced by pedagogical design and teacher readiness rather than by technological features alone (Manto et al., 2026). In the context of this study, practicality not only indicates that the product is usable but also reflects the alignment between the technology's characteristics, teachers' needs, and the developmental characteristics of early childhood students. Therefore, AI in early childhood mathematics learning should be positioned as a tool that reinforces meaningful and interactive learning experiences appropriate to children's developmental stages (Utoyo et al., 2026).

The present finding further reinforces the emerging role of digital media as a pedagogical component in mathematics learning. Digital learning media can be meaningfully integrated into mathematics instruction when technological affordances are aligned with instructional objectives and learner engagement. Building on this perspective, the present study extended the use of digital media to early childhood mathematics by embedding foundational mathematical concepts within an AI-based interactive picture story. Such integration shifts the function of digital technology from merely delivering learning content toward creating contextualized, visual, and interactive learning experiences that are more consistent with the developmental characteristics of young children (Engelbrecht & Borba, 2024; Romadiastri et al., 2025).

Table 5. Pretest and Posttest Statistical Results of the Limited Field Trial

Comparison	Z	Asymp. Sig. (2-tailed)	Statistical Test
Posttest – Pretest	−2.705	.007	Wilcoxon Signed-Rank Test

The limited field trial involved 11 children aged 5–6 years. The children's initial mathematical performance showed considerable variation, with pretest scores ranging from 25% to 80%. The Shapiro–Wilk results produced significance values of .002 for the pretest and .019 for the posttest, indicating that the data did not consistently meet the normality assumption. Therefore, the Wilcoxon Signed-Rank Test was employed. The analysis produced $Z = -2.705$ and $p = .007$, indicating a statistically significant difference between pretest and posttest performance.

The significant difference provides preliminary empirical evidence that children's mathematical performance changed following the implementation of the developed e-book. The result should be interpreted in relation to the learning characteristics of the product. Mathematical concepts were presented through stories, illustrations, and interactive activities, allowing children to encounter mathematical ideas through contextualized experiences rather than through isolated exercises. Such an approach may help children connect mathematical representations with familiar situations and observable objects.

Findings from limited pilot studies indicate that the integration of digital technology into early childhood mathematics education needs to be understood within a broader pedagogical framework. Chen (2026) states that digital technology has positive potential for early mathematics learning, but its effectiveness is influenced by the characteristics of its implementation and the learning context. These findings are relevant to this study because the e-book developed does not rely on AI technology as the sole source of the learning experience. Instead, AI is integrated with stories, illustrations, interactive activities, basic mathematical concepts, and teacher facilitation to create a contextual learning experience aligned with the developmental characteristics of 5–6-year-olds. Therefore, the differences in mathematical abilities observed after using the product are better understood as an indication of the potential of integrated technology-based instructional design rather than as an effect of AI technology alone. This perspective underscores that technological innovation in early childhood education should focus on enhancing the quality of learning experiences rather than merely adding digital features (Chen, 2026; Hu et al., 2024; Papavlasopoulou et al., 2026).

Table 6. Statistical Results of the Large-Scale Field Trial

Comparison	Z	Asymp. Sig. (2-tailed)	Statistical Test
Posttest – Pretest	−5.865	0.000	Wilcoxon Signed-Rank Test

The large-scale field trial involved 45 children aged 5–6 years from three educational institutions: TK Pembangunan Laboratorium UNP, TK Delima Bandara, and TK Islam H RJ Rasuna Said Maninjau, each located in a different regency or city. This diversity of locations provided a broader implementation context for testing the use of AI-based interactive picture story e-books in early childhood mathematics education. The results of the Wilcoxon Signed-Rank Test indicated a significant difference in the children's mathematical abilities before and after the implementation of the e-book ($Z = -5.865$; $p < .001$). These findings suggest that the use of the developed e-book has the potential to support the development of mathematical abilities in 5–6-year-olds through contextual, visual, and interactive learning experiences.

The available posttest data also indicate relatively high levels of mathematical performance. The distribution suggests that many children achieved high levels of performance after the intervention, although individual differences remained. These differences are important because children's mathematical readiness and prior experiences are not uniform. Consequently, the effectiveness of a digital learning medium should be considered in relation to children's initial abilities as well as the quality of the learning environment.

The findings of this study reinforce the growing evidence that digital storytelling can provide a meaningful pedagogical environment for early childhood mathematics learning. By combining mathematical concepts with narratives, visual representations, and interactive activities, digital storybooks may enable young children to encounter mathematical ideas within contexts that are more concrete, engaging, and developmentally appropriate. Solfiah et al. (2025) demonstrated that embedding mathematical concepts in interactive storybooks can promote children's engagement while providing meaningful opportunities for developing early mathematical skills. This interpretation is consistent with the systematic review conducted by Deslis et al. (2025), which indicated that digital storytelling in mathematics education has the potential to enhance conceptual understanding and learner engagement while facilitating more contextualized learning experiences. Thus, the observed improvement in children's mathematical performance in the present study may be understood within a broader pedagogical framework in which storytelling provides meaningful contexts for children to recognize, interpret, and apply foundational mathematical concepts.

The pedagogical value of the developed e-book is not limited to its digital format but also derives from the integration of narrative, illustrations, mathematical content, and opportunities for interaction. Previous research has demonstrated that the textual and visual characteristics of mathematics storybooks can stimulate diverse mathematical conversations between adults and children, thereby creating opportunities for children to explore mathematical ideas through meaningful interactions (Björklund & Palmér, 2022; Maričić & Stakić, 2023). Similarly, the use of stories as a context for mathematics learning can facilitate mathematical communication between children and educators (Splinter et al., 2023), while appropriate combinations of text and illustrations can encourage a wider range of mathematics-related discussions during learning activities (Turker-Biber et al., 2021). These findings suggest that the educational value of interactive storybooks emerges from the interaction among their pedagogical components rather than from visualization or digital presentation alone. In the present study, the combination of narrative, visual representation, interactive activities, and foundational mathematical concepts therefore provided an integrated environment through which children could engage with mathematics in developmentally meaningful ways.

The integration of AI further extends the functionality of the interactive picture-story e-book; however, its contribution should be interpreted within the broader instructional design rather than as an independent technological effect. The effectiveness of digital technology in early mathematics education is influenced by how

the technology is implemented and supported by teachers, rather than simply by the presence of technological features (Verbruggen et al., 2021). In the present study, AI-supported features were embedded within stories, visual representations, interactive activities, mathematical content, and teacher-facilitated learning. Consequently, the differences observed between pretest and posttest performance should not be interpreted as evidence of a causal effect attributable exclusively to AI. Instead, they indicate the potential of an integrated technology-supported instructional design in which AI functions as one component of a broader pedagogical environment. This interpretation is particularly important in early childhood education, where technological innovation should remain aligned with children's developmental characteristics and should complement, rather than replace, meaningful interaction between children, teachers, and learning materials.

The present study extends previous work on storytelling-based mathematics learning by integrating foundational mathematical concepts with interactive picture stories and AI-supported features within a single digital learning medium. Previous evidence indicates that integrating stories, games, and interactive activities can support the mathematical abilities of children aged 5–6 years (Solfiah et al., 2025). Building on this evidence, the contribution of the present study can be conceptualized through three interconnected dimensions. First, the e-book emphasizes foundational mathematical concepts rather than formal arithmetic operations, thereby aligning its content with the developmental needs of young children. Second, these concepts are embedded within interactive picture stories, enabling children to encounter mathematics through narratives, illustrations, contextual situations, and interactive activities. Third, AI-supported features are incorporated into this pedagogical structure, extending conventional digital storybooks toward a more interactive technology-supported learning environment. Accordingly, the novelty of the developed product lies not merely in the use of AI, but in the pedagogically coherent integration of foundational mathematics, interactive storytelling, visual representation, contextual learning, and AI-supported features.

Overall, the findings indicate that the developed AI-based interactive picture-story e-book is a feasible and practical learning medium and that its implementation was accompanied by improved mathematical performance among participating children. These findings support the potential of combining basic mathematical concepts, narrative, visualization, interactivity, and AI-supported technology within a unified and developmentally appropriate learning experience. Nevertheless, the observed pretest–posttest differences should be interpreted cautiously because they demonstrate improvement following implementation rather than establishing that AI itself caused the improvement. The educational contribution of the product therefore lies primarily in its integrated pedagogical design, which provides children with opportunities to experience mathematical concepts through meaningful, visual, narrative, and interactive contexts. Future research should further examine this potential through more rigorous comparative designs that distinguish the contribution of AI-supported features from those of storytelling, teacher facilitation, and other interactive components, thereby providing stronger evidence regarding the specific mechanisms through which AI-enhanced digital storybooks may support early childhood mathematics learning.

Conclusions

This study developed an AI-based interactive picture story e-book to support mathematics learning among children aged 5–6 years. The developed product demonstrated high feasibility (90.74%) and practicality (92.84%) and integrated foundational mathematical concepts into interactive, visual, and developmentally appropriate learning experiences. Significant differences between pretest and posttest performance were observed in both the limited field trial involving 11 children ($Z = -2.705$; $p = .007$) and the large-scale field trial involving 45 children ($Z = -5.865$; $p < .001$), indicating promising potential for supporting early mathematical development. Overall, the findings suggest that the e-book provides a feasible and practical learning medium that integrates foundational mathematics, interactive storytelling, visual representation, and AI-supported technology within a developmentally appropriate learning environment.

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