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Exploring Digital Transformation in Early Childhood Education: A Systematic Literature Review

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Abstract

Abstract (English)

This study aims to provide a comprehensive systematic literature review (SLR) of the characteristics, challenges, and pedagogical effectiveness of digital transformation in Early Childhood Education (ECE). The review followed the PRISMA protocol and searched the Scopus database, resulting in 23 articles that met the inclusion criteria from an initial pool of 145 records published between 2016 and 2026. The findings indicate a substantial increase in ECE digital transformation research in 2024, with a primary focus on children aged 4–6 years, a predominance of mixed-methods approaches, and the application of diverse theoretical frameworks, including social constructivism, Bronfenbrenner's ecological systems theory, TPACK, constructionism, and Universal Design for Learning. Key challenges include limited teacher knowledge and confidence, disconnected contexts between home and ECE settings, and insufficient policy guidance. Supporting factors include continuous professional development, active parental involvement, and visionary leadership. Effective pedagogical approaches include hands-on learning, learning-by-teaching, problem-based learning, structured storytelling, and play-based learning. This SLR contributes to the literature by synthesizing empirical evidence and mapping the key factors that shape digital transformation in ECE. The findings highlight the need for a holistic and context-sensitive approach and suggest practical implications for ECE policy and practice, including strengthening teachers' digital competencies, developing clear technology implementation guidelines, and fostering school–family partnerships to support inclusive and sustainable digital transformation.

Keywords: artificial intelligence, digital learning, digital literacy, early childhood education

Penelitian ini bertujuan melakukan systematic literature review (SLR) yang komprehensif mengenai karakteristik, tantangan, dan efektivitas pedagogis transformasi pendidikan digital pada Pendidikan Anak Usia Dini (PAUD). Metode penelitian mengikuti protokol PRISMA dengan pencarian pada basis data Scopus yang menghasilkan 23 artikel yang memenuhi kriteria inklusi dari 145 rekaman awal, mencakup publikasi tahun 2016–2026. Hasil penelitian menunjukkan bahwa kajian transformasi digital PAUD meningkat pesat pada tahun 2024, dengan fokus utama pada anak usia 4–6 tahun, dominasi metode mixed-

method, serta penggunaan berbagai kerangka teoretis seperti konstruktivisme sosial, teori ekologis Bronfenbrenner, TPACK, konstruksionisme, dan Universal Design for Learning. Tantangan utama meliputi rendahnya pengetahuan dan kepercayaan diri guru, kesenjangan konteks rumah dan lembaga PAUD, serta terbatasnya pedoman kebijakan. Faktor pendukung mencakup pengembangan profesional guru, keterlibatan orang tua, dan kepemimpinan visioner. Pendekatan pedagogis yang efektif meliputi hands-on learning, learning-by-teaching, problem-based learning, structured storytelling, dan play-based learning. SLR ini berkontribusi dengan menyintesis bukti empiris dan memetakan faktor-faktor kunci transformasi digital PAUD. Temuan menegaskan perlunya pendekatan holistik dan kontekstual, serta mengimplikasikan pentingnya penguatan kompetensi digital guru, pedoman implementasi teknologi yang jelas, dan kolaborasi sekolah-keluarga untuk mendukung praktik PAUD yang inklusif dan berkelanjutan.

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1. INTRODUCTION

The Fourth Industrial Revolution, driven by the rapid advancement of digital technologies and artificial intelligence (AI), has fundamentally transformed many aspects of human life, including education (Williams et al., 2019). Children growing up in the contemporary digital era are increasingly exposed to smart devices, virtual assistants, intelligent toys, and algorithm-based media, all of which substantially influence how they play, learn, and interact with their surroundings (Su & Zhong, 2022a). Consequently, the field of education, particularly Early Childhood Education (ECE), must critically examine how digital technologies can be integrated into learning environments in ways that are effective, ethical, and developmentally meaningful, rather than merely functioning as supplementary instructional tools (Su et al., 2023).

Despite the growing integration of digital technologies in educational contexts, research concerning the implementation of digital technologies and AI in ECE remains limited compared with studies conducted at secondary and higher education levels. Although previous studies have explored specific aspects of technology use in ECE, such as educational robotics, coding activities, or AI literacy, there remains a lack of comprehensive synthesis that integrates curriculum characteristics, implementation challenges, enabling factors, and pedagogical effectiveness within a single analytical framework. Consequently, current knowledge remains fragmented, making it difficult to formulate evidence-based recommendations for researchers, educators, and policymakers (Yi et al., 2024). This gap is especially important because early childhood is widely recognized as a critical developmental period during which children establish foundational cognitive, socio-emotional, and language abilities. Experiences with digital technologies during this stage may therefore have lasting implications for how children perceive, understand, and engage with technology later in life (Yang et al., 2022).

Despite the increasing integration of digital technologies in Early Childhood Education (ECE), the existing literature remains fragmented. Studies differ substantially in terms of curriculum design, technology applications, target age groups, methodological approaches, and theoretical perspectives, making it difficult to establish a coherent understanding of digital transformation in ECE (Eliasson et al., 2023; Undheim, 2022). Furthermore, implementation remains challenging because many teachers report limited digital competencies, insufficient pedagogical support, and difficulties balancing play-based learning with technology integration. These challenges are often compounded by inconsistent parental

involvement and limited institutional policy support (Eliasson et al., 2023; Hatzigianni et al., 2023; Undheim, 2022).

In addition, evidence regarding the effectiveness of pedagogical approaches for fostering digital and AI literacy remains scattered across individual studies. Although approaches such as hands-on learning, problem-based learning, and storytelling have shown promise, their overall effectiveness and implications for inclusive and sustainable curriculum development have not been systematically synthesized. Emerging concerns related to generative AI, ethical issues, data privacy, algorithmic bias, and children's understanding of AI technologies further highlight the need for a comprehensive review of current evidence (Damjanovic & Branson, 2025; Kanders, 2024; Luo et al., 2024).

Moreover, current evidence is predominantly derived from specific geographical and socio-economic contexts, limiting the generalizability of findings across diverse educational settings. Important dimensions such as ethical awareness, sustainability, and broader understandings of technology within society also remain underrepresented in existing ECE digital curricula (Druga et al., 2019; Ljungcrantz, 2026; Ljungcrantz, 2026).

Accordingly, this study aims to conduct a comprehensive systematic literature review to identify, analyze, and synthesize the characteristics, challenges, and pedagogical effectiveness of digital transformation in Early Childhood Education based on empirical and conceptual evidence from the international literature. Specifically, the study seeks to: (1) examine the characteristics and research trends of digital transformation in ECE in relation to curriculum design, types of technology, children's age groups, research methodologies, and theoretical frameworks (RQ1); (2) identify the primary challenges and enabling factors associated with implementing digital transformation in ECE, particularly in relation to teacher competencies, parental involvement, and institutional policies (RQ2); and (3) evaluate the effectiveness of various pedagogical approaches in fostering young children's digital and AI literacy while formulating implications for the development of inclusive and sustainable digital curricula (RQ3).

This study addresses these gaps by providing a comprehensive systematic review of research on digital transformation in ECE published between 2015 and 2026. Unlike previous reviews that focused on specific technologies or isolated themes, this study integrates evidence on curriculum design, technology implementation, pedagogical effectiveness, and stakeholder perspectives to provide a more holistic understanding of digital transformation in ECE (Ljungcrantz, 2026). Furthermore, this study provides a theoretical contribution by integrating several frameworks—such as Technological Pedagogical Content Knowledge (TPACK), Ecological Systems Theory, Universal Design for Learning (UDL), and Constructionism—into a coherent analytical framework. From a practical perspective, the study also offers recommendations for developing inclusive, sustainable, and developmentally appropriate digital curricula for ECE. Based on these objectives, the study addresses the following research questions: (RQ1) What are the characteristics and research trends of digital transformation in ECE in terms of curriculum design, technology integration, target age groups, research methodologies, and theoretical frameworks? (RQ2) What are the major challenges and enabling factors influencing the implementation of digital transformation in ECE, particularly regarding teacher competencies, parental involvement, and institutional policies? and (RQ3) How effective are various pedagogical approaches in fostering young children's digital and AI literacy?

2. METHODS

This study adopted a systematic literature review (SLR) design guided by the PRISMA 2020 Statement (Page et al., 2021). The PRISMA framework was employed to ensure transparency, consistency, and methodological rigor throughout the processes of identifying, screening, evaluating, and synthesizing studies related to digital transformation in Early Childhood Education (ECE). The SLR approach was selected because it enables the systematic identification, appraisal, and synthesis of evidence across studies, thereby providing a comprehensive understanding of research trends, knowledge gaps, and future research directions (Page et al., 2021). Therefore, this method was

considered appropriate for addressing the research questions concerning the characteristics, challenges, and pedagogical effectiveness of digital transformation in ECE.

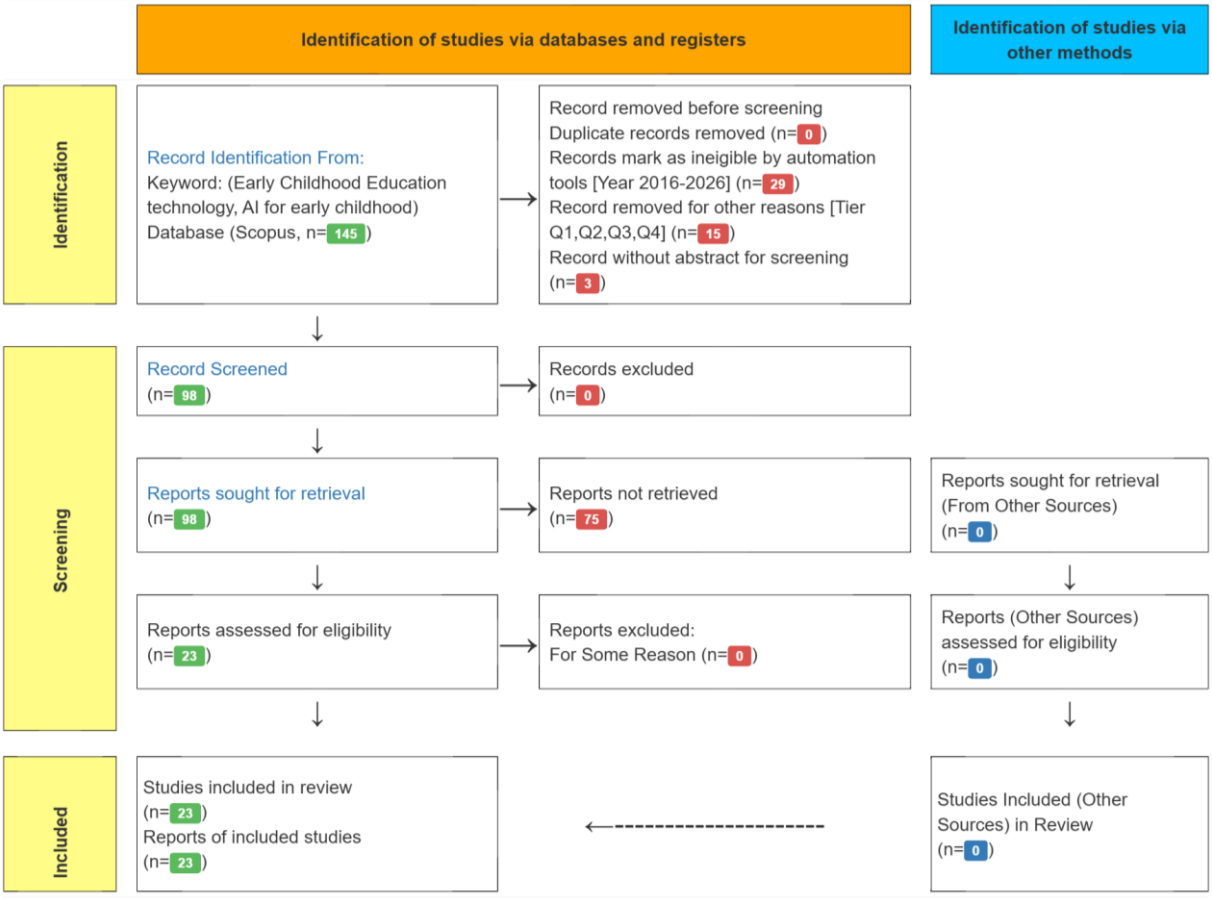

Figure 1. PRISMA Flow Diagram

Figure 1 presents the PRISMA study selection process. A total of 145 records were initially identified through a search of the Scopus database using the keywords “early childhood education technology” and “AI for early childhood. ” During the identification stage, 29 records were excluded because they fell outside the publication period of 2016–2026, and 3 records were excluded because they lacked abstracts required for screening. Journal quartile rankings (Q1–Q4) were recorded for descriptive purposes to characterize publication quality and distribution; however, quartile status was not used as an exclusion criterion during the study selection process. During the screening stage, no records were excluded; therefore, all 98 records proceeded to the retrieval stage. However, 75 reports could not be retrieved in full text and were excluded from further consideration. The remaining 23 reports were assessed for eligibility. No studies were excluded during the eligibility assessment, and all 23 articles satisfied the inclusion criteria. Consequently, 23 studies were included in the final systematic literature review. These studies form the basis for the analysis of research trends, challenges, enabling factors, and pedagogical approaches related to digital transformation in Early Childhood Education (ECE) between 2016 and 2026.

a. Study Identification and Selection Process

The literature identification process was conducted through a systematic search of the Scopus database using combinations of keywords related to early childhood education, digital technology, artificial intelligence, robotics, machine learning, and pedagogical approaches. The selection of these keywords was aligned with the three research questions formulated in this study and was refined through preliminary database searches to ensure comprehensive coverage of the literature on digital transformation in Early Childhood Education. The initial search yielded 145 article records. Subsequently, an automatic filtering process based on the publication period from 2016 to 2026 was applied, resulting in the exclusion of 29 records.

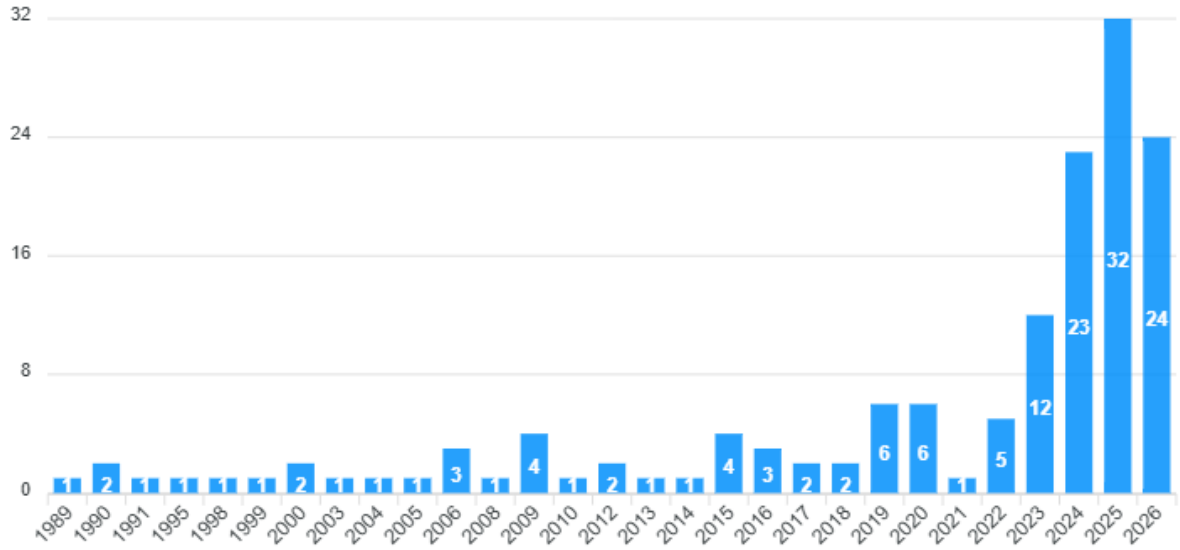

Figure 2. Distribution of Publications Identified Based on Publication Year

Subsequently, duplicate records, articles without abstracts, and studies that did not satisfy the predefined inclusion criteria were removed. Journal quartile rankings (Q1–Q4) were recorded for descriptive purposes to characterize publication quality and distribution; however, quartile status was not used as an exclusion criterion during the study selection process (Ljungcrantz, 2026). During the screening stage, the titles and abstracts of all retrieved articles were independently reviewed by two researchers according to the predefined inclusion and exclusion criteria. Studies deemed potentially relevant were retained for full-text assessment. Any disagreements between reviewers were discussed until consensus was achieved. However, 75 articles could not be accessed in full text (full-text not retrieved), leaving only 23 articles eligible for the eligibility assessment stage, all of which met the inclusion criteria and were subsequently included in the final review (Damjanovic & Branson, 2025; Hatzigianni et al., 2023). The entire study selection process was documented using the PRISMA flow diagram, which consists of four main stages: identification, screening, eligibility, and inclusion. This procedure ensured that every inclusion and exclusion decision could be systematically traced and transparently reported in accordance with the PRISMA 2020 guidelines (Page et al., 2021).

The screening process was conducted independently by two reviewers. During the title and abstract screening stage, both reviewers assessed the relevance of each study based on the predefined inclusion and exclusion criteria. Any disagreements regarding study eligibility were discussed until consensus was reached. When consensus could not be achieved immediately, the article was re-examined jointly and a final decision was made through discussion. The same procedure was applied during the full-text eligibility assessment stage. This process was implemented to reduce selection bias and enhance the reliability of study inclusion decisions.

b. Inclusion and Exclusion Criteria

The inclusion and exclusion criteria were established prior to the literature search and screening process to ensure consistency and minimize subjective decision-making. The inclusion criteria consisted of articles published in peer-reviewed English-language journals between 2016 and 2026. The selected studies focused on the implementation of digital technologies or artificial intelligence (AI) in the context of Early Childhood Education (ECE) for children aged 0–8 years. Furthermore, the included articles were required to report empirical findings derived from quantitative, qualitative, or mixed-methods research designs, or to present conceptual frameworks related to digital transformation in ECE. In addition, each study had to address at least one of the three primary areas of investigation: characteristics of digital curricula, challenges and enabling factors in implementation, or the effectiveness of pedagogical approaches in promoting digital and AI literacy (Su & Zhong, 2022; Williams et al., 2019; Yang et al., 2022).

The exclusion criteria comprised articles that were unavailable in full-text format, studies discussing digital technology without direct relevance to the ECE context, and research conducted in secondary or higher education settings. Moreover, opinion papers, editorials, commentaries, and conference proceedings lacking rigorous peer-review processes were excluded because they did not sufficiently meet the academic quality standards required for a systematic literature review (Eliasson et al., 2023; Samuelsson, 2025). All inclusion and exclusion criteria were established prior to the literature search and screening process to ensure consistency and minimize subjective decision-making during study selection.

c. Instruments and Data Collection Procedures

The primary instrument employed in this study was a structured data extraction form developed in accordance with systematic literature review (SLR) methodological guidelines. A sample of the extraction form is presented in Appendix A. The form included the following categories: author(s), publication year, country, participant characteristics, age group, research design, technology type, theoretical framework, implementation challenges, enabling factors, pedagogical approaches, key findings, and study limitations. The form was designed to systematically document essential information from each selected study, including bibliographic details, characteristics of digital curricula, technologies utilized, participant age groups, research designs, theoretical frameworks, implementation challenges, enabling factors, pedagogical approaches, key findings, and study limitations.

The data collection procedure was conducted through several stages. First, a comprehensive literature search was carried out in the Scopus database using predetermined keywords. Second, article titles and abstracts were screened according to the established inclusion and exclusion criteria. Third, studies that met the eligibility requirements were reviewed in full-text format. Fourth, relevant data were extracted and systematically recorded in the prepared extraction form. Finally, all extracted data were independently reviewed by the two researchers to ensure the accuracy, consistency, and completeness of the extracted information prior to thematic analysis. Any discrepancies in extracted information were discussed and resolved through consensus to minimize bias and reduce interpretative errors (Haas et al., 2022; Kanders, 2024).

d. Data Analysis Techniques

Data analysis in this study employed a combination of thematic analysis, content analysis, and narrative synthesis to integrate findings from studies with diverse research designs, methodologies, and contexts. The thematic analysis procedure followed the reflexive thematic analysis framework developed (Braun & Clarke, 2021), which emphasizes familiarization with the data, systematic coding, theme development, theme review, and iterative interpretation. For RQ1, the analysis focused on curriculum design characteristics, types of technologies used, children's age groups, research methodologies, and the theoretical frameworks underpinning the studies (Ljungcrantz, 2026; Undheim, 2022).

For RQ2, the analysis examined major implementation challenges, including limited teacher competence, gaps between home and school contexts, and inadequate policy support, while also identifying enabling factors such as collaborative professional development, parental involvement, and digital leadership (Luo et al., 2024). For RQ3, the analysis evaluated the effectiveness of various pedagogical approaches, including hands-on learning, problem-based learning, structured storytelling, and learning-by-teaching, based on available empirical evidence. In addition, the analysis explored implications for the development of inclusive and sustainable digital curricula by referring to the principles of Universal Design for Learning (UDL) and educational sustainability (Damjanovic & Branson, 2025).

To enhance reliability, an initial coding framework was developed deductively from the three research questions and consisted of five categories: (1) curriculum characteristics, (2) technology types, (3) implementation challenges, (4) enabling factors, and (5) pedagogical approaches. Additional subthemes were generated inductively as recurring patterns emerged from the reviewed studies. The complete coding framework is presented Table 1.

Table 1. Coding Framework Used in the Thematic Analysis

Category	Description
Curriculum Characteristics	Digital curriculum features and learning activities
Technology Types	AI, robotics, apps, tablets, digital media
Challenges	Teacher competence, infrastructure, policy issues
Enabling Factors	Leadership, parental involvement, professional development
Pedagogical Approaches	Play-based learning, storytelling, PBL, learning-by-teaching

To enhance reliability, an initial coding framework was developed deductively from the three research questions and consisted of five categories: 1) curriculum characteristics, 2) technology types, 3) implementation challenges, 4) enabling factors, and 5) pedagogical approaches. Additional subthemes were generated inductively as recurring patterns emerged from the reviewed studies. Two researchers independently coded all included studies, compared coding outcomes, and resolved discrepancies through consensus discussions. When disagreements occurred, the relevant article was jointly re-examined until agreement was achieved. Because the review included a relatively small number of studies (n = 23), consensus coding was employed rather than calculating formal inter-rater reliability statistics. Coding discrepancies were discussed during regular consensus meetings. Where differences in interpretation occurred, the relevant article was re-examined and the coding framework was refined when necessary. The final coding structure was agreed upon by both reviewers before thematic synthesis was undertaken. The use of the PRISMA flow diagram also ensured that the article selection process was systematically documented and academically accountable (Eliasson et al., 2023; Yang et al., 2022). Reference management was conducted using software such as Mendeley and Zotero, while extracted data and thematic analyses were organized using spreadsheets (Dogan & Gogus, 2025). Through the use of a predefined search strategy, explicit inclusion and exclusion criteria, independent screening and coding by two reviewers, documented consensus procedures, standardized data extraction procedures, and a transparent coding framework presented in the appendices, this review was designed to enhance methodological transparency, analytical rigor, and replicability for future research.

3. RESULTS

Based on the systematic literature review of 23 articles that met the inclusion criteria from a total of 145 initial records identified through the Scopus database, this study provides a comprehensive synthesis of the characteristics and trends of digital transformation in Early Childhood Education (ECE) during the 2016–2026 period. During the initial identification stage, 29 records were excluded because they fell outside the predetermined publication period of 2016–2026. Subsequently, 15 records were removed based on journal ranking criteria, while an additional 3 records were excluded due to the absence of adequate abstracts for the screening process (Gestiardi, 2025). After screening the remaining 98 records, all articles were considered relevant and proceeded to the retrieval stage. However, 75 articles could not be accessed in full text (full-text not retrieved), leaving only 23 articles eligible for further assessment, all of which met the inclusion criteria and were ultimately included in the review (Ljungcrantz, 2026).

As illustrated in Figure 2, research on digital transformation in ECE has increased substantially over the past five years. The highest publication growth occurred in 2024 with 32 publications, followed by 24 publications in 2025 and 23 publications in 2023. In contrast, publications between 1989 and 2019 remained relatively limited, with significantly lower numbers compared to the post-COVID-19 period. These findings indicate that the pandemic served as a major catalyst accelerating the integration of digital technologies into education, including ECE, thereby increasing scholarly attention toward digital literacy, artificial intelligence (AI), and technology-based learning for young children (Haas et al., 2022).

In terms of digital curriculum design for ECE, the synthesis identified three dominant curriculum models commonly adopted in the literature. The first model is the structured AI curriculum developed by (Su & Zhong, 2022a), which consists of four main modules: Introduction to AI, Machine Learning, Speech Recognition, and Flaws and Biases of AI. This curriculum was specifically designed for children aged 5–7 years using Scott's curriculum framework, which includes learning objectives, content, instructional methods, and assessment procedures. The second model is the social robot–based curriculum, such as PopBots, developed by (Williams et al., 2019). This curriculum introduces

foundational AI concepts, including knowledge-based systems, supervised machine learning, and generative AI, to children aged 4–7 years through a hands-on learning approach using robots as interactive learning companions. The third model is the conversational agent–based curriculum, such as Zhorai, developed by (Lin et al., 2020), which employs mind-map and histogram visualizations to help children understand machine learning concepts through a learning-by-teaching approach. In addition, (Luo et al., 2024) proposed the SIACC AI literacy framework (Safety, Identity, Attitude, Cognition, and Capability), which provides a conceptual foundation for developing more holistic AI literacy curricula. Another innovative approach was introduced by (Lu et al., 2024) through structured storytelling supported by generative AI tools such as ChatGPT to teach sustainability and urban mining concepts to children aged 5–6 years.

Table 1. Dominant Digital Curriculum Models in ECE Research

Curriculum Model	Developer(s)	Learning Focus	Pedagogical Approach
Structured AI Curriculum	Su & Zhong (2022)	AI, machine learning, speech recognition	Structured modules
PopBots	Williams et al. (2019)	Foundational AI concepts	Robot-based hands-on learning
Zhorai	Lin et al. (2020)	Machine learning	Learning-by-teaching
SIACC Framework	Luo et al. (2024)	Holistic AI literacy	Grounded theory
Structured AI Storytelling	Lu et al. (2024)	Sustainability and AI literacy	AI-supported storytelling

Regarding the technologies used, the findings indicate that digital transformation in ECE encompasses a broad spectrum of technologies, ranging from simple digital tools to sophisticated AI-based systems. (Yi et al., 2024b) identified numerous intelligent robots utilized in ECE contexts, including iRobiQ, NAO, KASPAR, Keepon, AIBO, IROMEC, iCat, Paro, Probo, PaPeRo, EngKey, and RUBI. These robots perform diverse functions, such as emotion recognition, social interaction, and therapeutic support for children with special needs (Purnomo et al., 2024). Beyond robotics, the literature also highlights the growing use of conversational agents such as Zhorai and generative AI chatbots such as ChatGPT in ECE settings, although research on generative AI for young children remains limited (Kanders, 2024; Luo et al., 2024). Other commonly used technologies include pedagogical documentation platforms such as Storypark and Kindyhub, Web 2.0 applications such as Wordwall, Powtoon, Canva, Kahoot!, and Storyjumper, as well as tangible coding devices such as Cubetto, Bee-Bot, and Matatalab for robotics and computational learning (Damjanovic & Branson, 2025; Dogan & Gogus, 2025; Samuelsson, 2025).

The synthesis further revealed that children aged 4–6 years constituted the most dominant participant group in the reviewed studies, with a median age of approximately five years and six-year-old children being the most frequently studied group (Ljungcrantz, 2026). Four-year-old children tended to demonstrate lower levels of understanding of AI concepts requiring multi-step reasoning compared to children aged five and six years (Williams et al., 2019). Studies involving children aged 2–3 years remain scarce and generally focus on simple technological concepts such as wheel mechanisms or remote STEAM-based learning (Eliasson et al., 2023; Haas et al., 2022). Similarly, research involving children aged 7–11 years is relatively limited, with one notable example being (Lin et al., 2020) through the Zhorai platform. In addition to children, several studies also involved ECE teachers, preservice teachers, school principals, parents, educational supervisors, and AI or robotics experts as research participants (Hatzigianni et al., 2023).

From a methodological perspective, mixed-methods approaches emerged as the most dominant research design in studies on digital transformation in ECE, followed by qualitative, experimental, and quantitative approaches (Ljungcrantz, 2026). The increasing use of mixed-methods research over time suggests that digital transformation in ECE is increasingly recognized as a complex phenomenon requiring the integration of quantitative and qualitative data to achieve a more comprehensive understanding (Creswell & Clark, 2011). Common qualitative methods included ethnography, case studies, grounded theory, action research, interaction analysis, and participant observation (Damjanovic & Branson, 2025). Meanwhile, experimental studies generally employed pretest–posttest designs with control groups to evaluate the effectiveness of AI and digital technology interventions for young children (Lu et al., 2024; Williams et al., 2019).

The theoretical frameworks underpinning research on digital transformation in ECE also demonstrated substantial diversity and multidisciplinary integration. Vygotsky's social constructivist theory was among the most frequently adopted frameworks for explaining the importance of social interaction in young children's digital learning (Eliasson et al., 2023; Undheim, 2022). Bronfenbrenner's ecological systems theory was widely used to analyze how multiple systemic levels influence the successful implementation of technology in ECE settings (Hatzigianni et al., 2023; Samuelsson, 2025). In addition, the TPACK framework (Technological Pedagogical Content Knowledge) developed by Mishra and Koehler was employed to examine teachers' competencies in integrating technology into pedagogical practices (Dogan & Gogus, 2025; Yang et al., 2022). Papert's constructionism theory provided the foundation for robot-based and learning-by-teaching approaches, such as PopBots and Zhorai (Williams et al., 2019; Lin et al., 2020). Furthermore, the principles of Universal Design for Learning (UDL) developed by CAST were frequently applied to ensure the accessibility of digital technologies for all children, including those with special educational needs (Damjanovic & Branson, 2025).

Overall, the findings indicate that digital transformation in ECE is developing rapidly and increasingly moving toward the integration of AI technologies, robotics, and interactive collaborative digital pedagogies. Nevertheless, significant challenges remain, particularly concerning teacher competence, technology accessibility, policy support, and curriculum readiness to adapt to rapid technological advancements. Therefore, future development of digital transformation in ECE requires a multidisciplinary approach that not only emphasizes technological innovation but also carefully considers pedagogical, social, cultural, and ethical dimensions in a balanced manner.

4. DISCUSSION

a. Characteristics and Trends in Research on Digital Transformation in Early Childhood Education

The findings of this study indicate that research on digital transformation in Early Childhood Education (ECE) has grown substantially in recent years, particularly with a notable surge in publications in 2024, which accounted for the highest number of publications within the analyzed dataset (Ljungcrantz, 2026). This finding is consistent with recent studies reporting that research on artificial intelligence (AI), digital pedagogy, and technology integration in ECE has increased significantly alongside rapid technological advancement and the growing global emphasis on digital learning environments (Su & Zhong, 2022; Zhai et al., 2024). The expansion of research activity is strongly associated with the impact of the COVID-19 pandemic, which accelerated the adoption of digital technologies across educational sectors, including ECE. During the pandemic, teachers and parents were required to adapt quickly to digital platforms and online learning systems in order to maintain learning continuity for young children (Dong et al., 2020; Kewalramani et al., 2021).

The synthesis also revealed a significant paradigm shift regarding young children's capacity to understand digital technologies and AI. Whereas young children were previously perceived as unprepared to engage with complex technological concepts, recent evidence demonstrates that children are capable of developing foundational AI and computational thinking skills when instruction is aligned with their developmental characteristics (Su & Zhong, 2022b). Bers (2021) demonstrated that coding and robotics activities positively support computational thinking, creativity, and collaboration among preschool children (Bers, 2021). Similarly, found that AI-integrated storytelling activities increased children's engagement and conceptual understanding of intelligent systems through playful interaction (Relkin et al., 2021). These findings are consistent with earlier studies emphasizing hands-on learning, experimentation, and play-based pedagogies as effective approaches within digital ECE environments (Williams et al., 2019; Lin et al., 2020).

The dominance of children aged 4–6 years as research participants suggests that this developmental period is widely considered the most appropriate stage for introducing foundational digital and AI literacy (Ljungcrantz, 2026). At this age, children's cognitive, linguistic, and social development are sufficiently advanced to support engagement with digital learning activities through developmentally appropriate pedagogical approaches (Su & Yang, 2022). Nevertheless, studies involving children aged 1–3 years remain limited, likely due to ethical considerations, methodological challenges, and concerns regarding technology exposure for very young children (Eliasson et al., 2024). Despite

these limitations, recent studies suggest that early exposure to developmentally appropriate digital experiences during the first years of life may contribute positively to children's emerging digital literacy and cognitive development (Luo et al., 2024; Samuelsson, 2025).

From a methodological perspective, mixed-methods research was identified as the dominant approach in studies of digital transformation in ECE. This tendency reflects researchers' growing recognition that digital transformation is a complex phenomenon that cannot be adequately explained through quantitative or qualitative approaches alone (Luo et al., 2024)). Mixed-methods designs enable researchers to combine quantitative evidence regarding the effectiveness of digital technologies with qualitative insights into children's experiences, interactions, and learning processes. In addition to mixed-methods research, ethnographic studies, case studies, grounded theory, and action research were frequently used to explore the contextual and sociocultural dimensions of technology implementation in ECE settings ((Damjanovic & Branson, 2025; Samuelsson, 2025).

Recent studies also reinforce the importance of digital play, multimodal literacy, and inquiry-based learning within contemporary ECE contexts. Digital play practices expanded rapidly among young children during and after the pandemic, reshaping early childhood literacy and interaction patterns (Marsh et al., 2021). Likewise, Bird and Edwards (2021) reported that inquiry-oriented digital projects encourage children to become active creators rather than passive users of technology. Interactive digital storybooks effectively support emergent literacy development when integrated with guided teacher interaction and dialogic reading strategies (Neumann, 2020).

Overall, the findings of this study provide an important contribution to the field of ECE by offering a comprehensive and systematic overview of current trends in digital transformation. Unlike earlier reviews that focused primarily on isolated aspects such as robotics or AI literacy (Su et al., 2023; Yi et al., 2024), this study integrates multiple dimensions, including curriculum design, technological tools, participant age groups, pedagogical approaches, ethical considerations, and research methodologies. Consequently, the findings may serve as both a conceptual and empirical foundation for future research and for the development of more adaptive, inclusive, and sustainable digital transformation policies in ECE.

b. Major Challenges and Supporting Factors in the Digital Transformation of Early Childhood Education

The findings of this study indicate that the challenges associated with implementing digital transformation in ECE can be categorized into three interconnected levels: the micro level (teachers), the meso level (parents and partnerships), and the macro level (policy and institutions). These three levels are closely interrelated and collectively influence the success of digital transformation initiatives in early childhood education settings.

At the micro level, the primary challenge concerns teachers' limited competence, pedagogical skills, and confidence in integrating digital technologies and AI into learning practices. Recent studies indicate that many early childhood teachers still experience uncertainty regarding the pedagogical use of digital technologies despite possessing basic technical skills (Nikolopoulou, 2022). This finding highlights the gap between technological competence and pedagogical digital competence. In addition, insufficient training opportunities, limited instructional guidance, and inadequate curriculum support continue to hinder teachers' readiness to implement digital transformation effectively (Su & Yang, 2022; Dogan & Gogus, 2025). Research further suggests that short-term and theory-oriented training programs are insufficient for developing sustainable pedagogical digital competence among teachers.

At the meso level, the main challenge relates to weak connections between children's digital experiences at home and within ECE institutions. Previous studies have identified the existence of disconnected digital contexts between home and school environments (Aldhafeeri et al., 2016). Teachers are often unfamiliar with the digital platforms, games, and media that children use at home, thereby limiting opportunities to integrate children's informal digital experiences into classroom learning. Moreover, parental technological competence varies considerably and is strongly influenced by socioeconomic background. Similarly, (Livingstone & Blum-Ross, 2020) found that unequal access to devices, internet connectivity, and parental mediation contributes to widening digital inequality among young children. Nevertheless, collaborative partnerships between families and educational institutions

have been shown to strengthen digital learning ecosystems and support more coherent and meaningful learning experiences for children across home and school settings (Arnott & Yelland, 2021).

At the macro level, challenges are associated with insufficient policy support, unclear institutional guidelines, and gaps between policy and classroom implementation. Although many educational systems encourage digital innovation in ECE, teachers frequently encounter difficulties due to limited infrastructure, inadequate professional development opportunities, and the absence of practical implementation models (Yang et al., 2022). In several contexts, national ECE quality standards still do not explicitly regulate the role of digital technologies within educational quality frameworks (Hatzigianni et al., 2023). These findings highlight the persistent gap between macro-level educational policy and practical implementation in classrooms. Therefore, successful digital transformation in ECE requires systemic support, including infrastructure development, equitable access to technology, clear policy guidelines, continuous teacher development, and sustainable monitoring and evaluation systems (Luo et al., 2024; OECD, 2021).

Conceptually, this study contributes to the literature by proposing a three-level analytical framework—micro, meso, and macro—for understanding the challenges and supporting factors associated with digital transformation in ECE more comprehensively. This framework may serve as a foundation for designing interventions, professional development programs, and educational policies that are more contextually responsive and aligned with actual implementation conditions.

c. Effectiveness of Pedagogical Approaches and Implications for Inclusive and Sustainable Curricula

The synthesis findings indicate that the most effective pedagogical approaches for developing digital and AI literacy among young children include hands-on learning, learning-by-teaching, problem-based learning, structured storytelling, play-based learning, inquiry-based learning, and collaborative learning. Williams et al., (2019) demonstrated that hands-on learning activities involving educational robotics significantly improved children's understanding of foundational technological concepts because children actively participated in building, experimenting, programming, and interacting with technological systems. Similarly, Lin et al., (2020) found that learning-by-teaching approaches encouraged children to act as instructors for AI agents, thereby fostering metacognitive awareness and deeper conceptual understanding. Problem-based learning approaches also provide meaningful opportunities for children to engage in authentic problem-solving experiences through contextualized and collaborative activities (Su & Zhong, 2022).

In addition, structured storytelling supported by generative AI technologies has been found to strengthen children's language development, creativity, imagination, and multimodal literacy skills. (Lu et al., (2024) reported that AI-assisted storytelling environments significantly enhanced children's narrative abilities and creative engagement. Likewise, Kucirkova & Flewitt, (2022) explained that AI-supported storytelling can strengthen multimodal literacy when appropriately guided by teachers and parents. These findings suggest that young children possess greater capacities for learning technological concepts than previously assumed, provided that instruction is designed according to their developmental stages and learning characteristics (Su & Yang, 2022).

Consequently, the development of digital curricula in ECE should incorporate the principles of Universal Design for Learning (UDL) in order to ensure equitable learning opportunities for all children, including those with special educational needs (Damjanovic & Branson, 2025). Digital curricula should integrate play-based learning, robotics, generative AI, digital storytelling, and tangible coding activities so that children become active participants in technological exploration and creation rather than passive consumers of technology (Bers, 2021). Inquiry-based and collaborative learning environments are also important because they encourage creativity, communication, social interaction, and critical thinking (Bird & Edwards, 2021; Papadakis et al., 2021).

Beyond pedagogical considerations, the findings also emphasize the importance of integrating ethical and sustainability dimensions into digital ECE curricula. Ethical literacy related to AI and digital technology should be introduced from an early age through age-appropriate activities that encourage empathy, responsibility, critical thinking, and awareness of data privacy and algorithmic bias ((Crescenzi-Lanna & Grané-Oró, 2021; (Holmes et al., 2019). Sustainability should also be addressed both in terms of environmental awareness and the long-term sustainability of digital educational practices. Recent

studies have shown that AI-supported learning activities can be integrated with sustainability themes such as digital waste reduction and responsible technology use (Lu et al., 2024).

Furthermore, the development of digital curricula in ECE should involve collaboration among multiple stakeholders, including teachers, parents, school leaders, academics, technology developers, and policymakers (Damjanovic & Branson, 2025; Hatzigianni et al., 2023). Digital curricula should function as living curricula that are continuously evaluated and revised in response to technological advancements, emerging research findings, and evolving societal needs (Su & Yang, 2022). Through such an approach, digital transformation in ECE is expected to foster learning systems that are inclusive, adaptive, sustainable, ethical, and responsive to the challenges of twenty-first-century education.

5. CONCLUSION

This study concludes that digital transformation in Early Childhood Education (ECE) has experienced significant development over the past decade, particularly with the growing number of publications in recent years. The findings indicate that digital transformation in ECE has become an increasingly important and widely discussed topic in educational research. The systematic literature review identified three major dimensions, namely: (1) research characteristics and trends, (2) implementation challenges and supporting factors, and (3) the effectiveness of pedagogical approaches in developing children's digital and AI literacy.

The review revealed that children aged 4–6 years were the most frequently studied participants, while mixed-methods research was the dominant methodological approach. Various theoretical perspectives were applied across the studies, including social constructivism, ecological theory, Technological Pedagogical Content Knowledge (TPACK), constructionism, and Universal Design for Learning (UDL). These findings demonstrate that digital transformation in ECE is increasingly approached through interdisciplinary, contextual, and developmentally appropriate perspectives that integrate pedagogical, technological, social, and ecological dimensions.

In terms of implementation, the study identified several interconnected challenges at the teacher, family, and institutional levels. Major challenges included teachers' limited digital competence and confidence, disparities between children's digital experiences at home and in educational settings, socioeconomic inequalities affecting technology access, and the lack of clear institutional or policy guidelines. At the same time, several supporting factors were consistently highlighted, including continuous professional development for teachers, active parental involvement, and visionary institutional leadership that supports innovation and collaboration.

Regarding pedagogical effectiveness, the findings indicate that approaches such as hands-on learning, learning-by-teaching, problem-based learning, structured storytelling, play-based learning, inquiry-based learning, and collaborative learning are effective in fostering digital and AI literacy among young children. These approaches are particularly effective when aligned with children's cognitive developmental stages and supported by meaningful, interactive, and engaging learning experiences. The review also suggests that young children are capable of understanding technological concepts when learning activities are designed in ways that are appropriate, contextual, and child-centered.

Another important finding is that the historical, ethical, and sustainability dimensions of technology remain underrepresented in digital ECE curricula. Therefore, future curriculum development should not only focus on digital competence and AI literacy but also integrate broader humanistic and ethical perspectives to help children understand technology as part of social and cultural development.

Overall, this study provides a comprehensive overview of the current state of digital transformation in ECE and highlights important research gaps and future directions. The findings emphasize the importance of adopting holistic, collaborative, inclusive, and context-sensitive approaches to ensure that digital transformation in ECE supports not only technological competence, but also ethical awareness, sustainability, inclusivity, and meaningful child-centered learning experiences.

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