SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Artificial Intelligence-Supported Innovation in Early Childhood Education: A Literature-Based Review of Development Pathways and Challenges

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ARTICLE INFO

Article history:
Received 1 May 2026
Received in revised form 6 Jun 2026
Accepted 20 July 2026
Available online 13 August 2026

Keywords:

Artificial intelligence; early childhood education; AI LIteracy; personalized learning; ethical governance

ABSTRACT

Artificial intelligence (AI) has increasingly influenced early childhood education by reshaping curriculum design, learning environments, assessment practices, and teacher professional development. However, existing studies often examine technological applications, learning outcomes, or ethical concerns separately, providing limited understanding of how these dimensions interact within a broader educational transformation process. This study aims to identify the major research themes, challenges, and future development pathways of AI-supported early childhood education through a literature-based review. Twenty representative studies published between 2008 and 2026 were analyzed using thematic synthesis to examine recurring patterns and relationships among existing research findings. The results reveal four interconnected dimensions: AI-supported learning and curriculum innovation, teacher readiness and AI literacy, personalized learning and assessment, and ethical governance. Based on these findings, this review proposes a child-centered conceptual framework integrating technological innovation, pedagogical transformation, and ethical responsibility. The framework provides theoretical insights and practical guidance for promoting sustainable and developmentally appropriate AI implementation in early childhood education.

1. Introduction

Artificial intelligence (AI) may suggest that it has become an increasingly important topic in modern education. Moreover, the significant findings from advances in machine learning, natural language processing, learning analytics, and generative AI could indicate that new possibilities for teaching, learning, and educational administration have emerged. Furthermore, the evidence may suggest that AI is no longer viewed merely as a technical tool but could demonstrate its capacity to influence curriculum design, learning environments, assessment practices, and educational decision-making [16]. In light of these developments, researchers and educators might indicate that they are beginning to explore the educational potential of AI across different stages of learning. AI shapes education broadly.

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https://doi.org/10.37934/araset.62.5.1838

Early childhood is widely regarded as a critical period for cognitive, social, emotional, and language development. Additionally, the significant evidence may suggest that educational experiences during this stage could demonstrate a substantial influence on later academic achievement and lifelong learning. Given that the unique developmental characteristics of young children appear relevant, the important findings could indicate that educational innovations introduced into early childhood settings require careful examination. Notwithstanding these developmental considerations, the results may suggest that technology adoption at this level should support children's holistic development while improving learning outcomes [3,19]. Research shows AI supports these goals.

Thus, the rapid expansion of AI applications in education may suggest that interest in their use within early childhood contexts has grown considerably. Moreover, Chen [3] could indicate that research on AI in early childhood education has expanded to cover significant topics including learning support, curriculum development, teacher education, digital literacy, ethical governance, and educational policy. Furthermore, the key findings may suggest that this trend could demonstrate a growing recognition that AI technologies appear likely to shape future educational practices. Nevertheless, the evidence might indicate that concerns regarding developmentally appropriate implementation remain important. Concerns persist across contexts.

The significant results may suggest that AI could support children's learning through multiple pathways. Additionally, the key findings might indicate that AI systems could demonstrate the capacity to analyze learning data and adapt instructional content according to children's needs and developmental progress. Given that such capabilities appear relevant, the evidence may suggest that educators could address individual differences more effectively and provide learning experiences responsive to children's abilities and interests [5]. Considering these results, the important findings could indicate that personalized learning appears particularly significant in early childhood settings because developmental differences among children may be substantial. Personalization shows clear benefits.

Moreover, the significant findings may suggest that curriculum innovation could demonstrate an area of growing interest. Furthermore, the evidence might indicate that researchers have argued that AI technologies should complement rather than replace the important principles of play-based learning, social interaction, and hands-on experiences. Therefore, Su and Zhong [19] could suggest that AI-supported curriculum design should demonstrate a focus on promoting creativity, exploration, and problem-solving while maintaining developmentally appropriate educational practices. Notwithstanding these established principles, the key results may suggest that technological tools appear to support inquiry-based learning and children's active engagement in knowledge construction [17]. STEM findings support this.

However, the significant emergence of generative AI may suggest that the scope of educational innovation could demonstrate further expansion. Additionally, the important findings might indicate that generative AI tools could support teachers in preparing instructional materials, designing learning activities, and creating personalized educational resources. Given that large language models appear relevant to educational processes, the evidence may suggest that their implementation could demonstrate important challenges related to accuracy, bias, and ethical responsibility [9]. Considering these significant challenges, the results might indicate that concerns regarding children's developmental needs and exposure to AI-generated content appear unresolved [8,15]. Generative AI needs careful use.

Furthermore, the significant findings may suggest that AI could demonstrate a meaningful influence on educational assessment. Moreover, the important evidence might indicate that AI-assisted assessment systems could process large amounts of learning data and provide timely

information to educators. Thus, Chen and Perez [5] may suggest that AI could demonstrate the potential to improve both assessment efficiency and personalized learning support. Notwithstanding these possibilities, the key results might indicate that the evidence appears consistent with broader educational discussions emphasizing the importance of formative assessment, feedback, and learner-centered evaluation practices [6]. Assessment benefits look substantial.

The significant findings may suggest that AI could demonstrate important applications within embodied learning environments. Additionally, the important evidence might indicate that AI-supported embodied learning could increase children's engagement and participation by encouraging active interaction between learners and learning environments. Given that Yang *et al*., [20] appear to demonstrate these results, the key findings may suggest that AI applications in early childhood education could support meaningful learning through physical exploration and social interaction. Considering these results, the evidence might indicate that AI need not be limited to virtual environments but could demonstrate broader educational relevance. Embodied learning shows engagement gains.

Nevertheless, the significant findings may suggest that successful implementation of AI could depend heavily on teachers. Moreover, the important evidence might indicate that teachers' beliefs, knowledge, and professional competencies could demonstrate a key influence on how educational technologies are used in practice. Furthermore, the key results may suggest that Lim [11] could demonstrate that pre-service early childhood teachers' perceptions of AI education appear significantly associated with their levels of digital literacy and self-efficacy. Therefore, the evidence might indicate that teachers who possessed stronger technological confidence could demonstrate greater willingness to integrate AI into educational settings. Teacher confidence shapes adoption.

The significant findings may suggest that AI literacy could demonstrate an increasingly important concept within educational research. Additionally, the important evidence might indicate that AI literacy refers to the knowledge, skills, and critical understanding necessary for individuals to interact effectively with AI technologies [14]. Given that this concept appears relevant beyond teachers, the key results may suggest that curriculum developers, school leaders, and policymakers could demonstrate a need for sufficient understanding of AI capabilities and limitations. Notwithstanding this broad relevance, the findings might indicate that educational stakeholders may struggle to make informed decisions regarding technology adoption without such understanding. Literacy gaps limit decisions.

Moreover, the significant findings may suggest that teachers could demonstrate diverse perceptions regarding AI. Furthermore, the important evidence might indicate that Lim [12] could suggest that pre-service teachers often use a variety of metaphors to describe AI, reflecting both optimism and uncertainty. Thus, Kölemen and Yıldırım [10] may suggest that teachers generally recognized the educational benefits of AI while the results could demonstrate concerns regarding professional preparedness, ethical issues, and the possible reduction of human interaction within educational settings. Considering these significant findings, the evidence might indicate that teacher attitudes toward AI appear complex and cannot be understood solely through measures of technological competence. Attitudes reflect complex concerns.

However, the significant findings may suggest that ethical concerns could demonstrate a central issue in discussions of AI-supported early childhood education. Additionally, the important evidence might indicate that the collection and analysis of children's learning data could raise key questions regarding privacy and data protection. Given that algorithmic bias, transparency, accountability, and fairness appear relevant, the results may suggest that these concerns could demonstrate particular significance in early childhood settings because young children may be less capable of understanding how digital systems operate [15]. Notwithstanding these promising applications, the key findings

might indicate that ethical governance could demonstrate an essential component of responsible AI implementation. Ethics shapes responsible practice.

Furthermore, the significant findings may suggest that equity and inclusion could demonstrate important considerations in AI-supported education. Moreover, the important evidence might indicate that Chen and Delaney [4] could suggest that effective AI implementation should demonstrate grounding in educational equity, AI literacy, and ethical responsibility. Therefore, the key results may suggest that the digital divide could demonstrate a relevant concern, as unequal access to digital resources appears likely to increase existing educational disparities [2]. Considering these significant challenges, the evidence might indicate that ensuring equitable access could demonstrate an important challenge for policymakers and educators. Access gaps persist significantly.

However, the significant findings may suggest that emerging forms of AI-supported learning environments could demonstrate increasing attention in recent years. Additionally, the important evidence might indicate that Hwang and Chien [7] could suggest that AI may demonstrate an important role in future metaverse learning environments by supporting interaction, personalization, and immersive learning experiences. Given that digital companion technologies appear relevant, the key results may suggest that such tools could demonstrate the capacity to facilitate communication, engagement, and learning support in early childhood contexts [18]. Notwithstanding these developments, the findings might indicate that long-term educational implications appear unclear. Emerging applications need more study.

Moreover, the significant findings may suggest that the current literature could demonstrate important fragmentation across research areas. Furthermore, the important evidence might indicate that research on curriculum innovation, teacher readiness, AI literacy, personalized learning, and ethical governance could develop independently, suggesting that limited attention appears to have been paid to the relationships among these dimensions. Thus, the key results may suggest that existing research could demonstrate a tendency to explain what AI can do rather than how AI contributes to broader educational transformation. Considering these significant limitations, the findings might indicate that current studies rarely examine technological innovation, pedagogical transformation, and ethical governance within a unified analytical framework. Fragmentation limits understanding.

However, the existing literature also reveals several limitations. Although previous studies have examined AI applications in early childhood education from different perspectives, including curriculum innovation, teacher development, personalized learning, and ethical considerations, these research areas often remain relatively separate. Current studies tend to focus on what AI technologies can achieve in specific educational contexts, while less attention has been given to how technological innovation, pedagogical transformation, and ethical governance interact to support sustainable educational development. As a result, a more integrated understanding of AI-supported early childhood education remains insufficiently developed.

Therefore, this study addresses three related research questions: (1) What major themes characterize current research on AI-supported early childhood education? (2) What challenges influence the effective integration of AI into early childhood settings? and (3) How can existing research findings inform future development pathways for AI-supported early childhood education? To answer these questions, this review synthesizes twenty representative studies published between 2020 and 2025 through thematic analysis. Based on the identified patterns, this study proposes an integrated conceptual framework connecting technological innovation, pedagogical transformation, and ethical governance from a child-centered perspective.

This study contributes to existing research in two ways. First, it provides a systematic synthesis of recent research trends and challenges in AI-supported early childhood education rather than examining individual technological applications separately. Second, it develops a conceptual framework that explains how AI can contribute to educational innovation while maintaining developmental appropriateness, ethical responsibility, and children's holistic development. This perspective provides theoretical insights for researchers and practical implications for educators and policymakers seeking responsible AI implementation in early childhood education.

2. Methodology

2.1 Research Design

This study adopts a literature-based review design to examine the innovative development pathways of early childhood education supported by artificial intelligence (AI). A literature-based approach is appropriate for this study because research on AI in early childhood education has expanded across multiple areas, including curriculum innovation, teacher preparation, personalized learning, assessment practices, and ethical considerations [3,19].

Rather than examining a single application of AI, this review focuses on the relationships among technological development, educational practice, and governance issues. Previous studies have demonstrated that AI applications in education involve not only technological functions but also changes in teaching approaches, teacher competencies, and learning environments [14,16]. Therefore, this study analyzes existing literature to identify common research themes, major challenges, and possible future development directions for AI-supported early childhood education.

2.2 Literature Selection

The reviewed literature was selected according to its relevance to AI-supported early childhood education. Twenty representative Studies published between 2008 and 2026 were included in the review. These studies were selected because they addressed key aspects of AI integration in early childhood contexts, including curriculum development, teacher readiness, AI literacy, personalized learning, assessment improvement, and ethical governance [3,5,11,15].

The selection process considered both educational relevance and research contribution. Studies were included when they examined AI applications, theoretical discussions, or practical implications related to early childhood education. Research focusing only on technical AI development without educational relevance, or studies conducted in educational stages unrelated to early childhood, was excluded. The criteria used for literature selection are presented in Table 1.

Table 1
Literature selection criteria

Criteria	Inclusion Criteria	Exclusion Criteria
Publication period	Studies published between 2020 and 2025	Studies published before 2020
Research focus	AI applications and implications in early childhood education	AI research unrelated to educational contexts
Publication type	Peer-reviewed academic publications	Non-academic materials
Language	English-language studies	Publications in other languages
Research themes	Curriculum innovation, teacher readiness, AI literacy, personalized learning, assessment, and ethical governance	Studies focusing only on AI technology development without educational implications

Research themes Curriculum innovation, teacher readiness, AI literacy, personalized learning, assessment, and ethical governance Studies focusing only on AI technology development without educational implications

The criteria presented in Table 1 define the scope of the literature review and ensure that the selected studies are directly related to AI-supported early childhood education. The publication period was limited to 2020–2025 to capture recent developments in AI technologies and their emerging applications in educational contexts. The review focused on peer-reviewed journal articles to maintain academic quality and excluded studies that lacked direct relevance to early childhood education.

The selected themes were designed to reflect the main dimensions of AI integration in early childhood education, including technological applications, educational practices, teacher development, and ethical considerations. Therefore, the literature selection process aimed to provide a balanced understanding of both the opportunities and challenges associated with AI-supported educational innovation.

2.3 Data Analysis and Thematic Synthesis

The selected studies were analyzed through thematic synthesis to identify recurring concepts and relationships across the literature. This analytical approach was used because existing research on AI-supported early childhood education covers diverse areas, and a thematic perspective helps reveal connections among different research concerns.

The analysis focused on several recurring issues identified in previous studies, including the role of AI in curriculum transformation, the influence of teacher AI literacy on implementation, the potential of adaptive systems for personalized learning, and ethical challenges related to privacy and equity [2,5,14,15].

During the synthesis process, concepts with similar meanings were grouped together and examined across studies. Research discussing AI-supported learning environments and curriculum design was integrated into the theme of curriculum innovation [17,19]. Studies focusing on teacher competence and professional preparation were analyzed under teacher readiness and AI literacy [11,12]. Literature addressing adaptive learning and AI-assisted assessment was organized around personalized learning and assessment [5,13]. Ethical issues, including privacy protection, fairness, and digital inequality, were synthesized as ethical governance concerns [4,8].

Through this process, four interconnected themes were identified: AI-supported learning and curriculum innovation, teacher readiness and AI literacy, personalized learning and assessment, and ethical challenges and governance. These themes provide the analytical basis for the subsequent Results and Discussion sections.

3. Results

The review of twenty representative studies published between 2020 and 2025 reveals that artificial intelligence (AI) has become an increasingly important research topic in early childhood education. Existing studies have examined AI applications from multiple perspectives, including curriculum innovation, teacher development, personalized learning, educational assessment, and ethical governance [3,16]. Although these studies differ in their research purposes and analytical approaches, they share a common concern regarding how AI can contribute to educational improvement while maintaining the developmental characteristics and educational values of early childhood education.

A synthesis of the reviewed literature identified four major themes: AI-supported learning and curriculum innovation, teacher readiness and AI literacy, personalized learning and assessment, and ethical challenges and governance. These themes reflect the main directions of current research and demonstrate that AI integration in early childhood education involves not only technological applications but also pedagogical transformation and institutional responsibility [4,14,19].

The identified themes are interconnected rather than isolated. Research on curriculum innovation focuses on how AI reshapes learning experiences and instructional practices, whereas studies on teacher readiness emphasize the human capacity required for effective implementation [3,11]. Similarly, personalized learning research highlights the instructional possibilities provided by AI-supported assessment systems, while ethical governance studies examine the conditions necessary to ensure responsible and equitable use of technology [5,15]. The major themes and representative studies are summarized in Table 2.

Table 2
Major themes identified in the reviewed literature

Theme	Focus	Representative Studies
AI-Supported Learning and Curriculum Innovation	Curriculum design, STEM learning, embodied learning, inquiry-based learning	Chen (2024); Su and Zhong (2022); Yang *et al*., (2024); Ozturk (2025)
Teacher Readiness and AI Literacy	Digital literacy, AI literacy, teacher competence, professional development	Ng et al. (2021); Lim (2023); Lim (2024); Kölemen and Yıldırım (2025)
Personalized Learning and Assessment	Adaptive learning, learning analytics, assessment support	Chen and Perez (2023); Harris and Brown (2013); Nan (2020)
Ethical Challenges and Governance	Privacy, equity, digital divide, child-centered AI	Chen and Delaney (2026); Nikolopoulou (2025); Kanders e*t al*., (2024); Özdemir Beceren et al. (2025)

Note. The themes were developed through comparative analysis and thematic synthesis of the twenty studies included in this review.

Table 2 demonstrates that current research on AI-supported early childhood education has gradually expanded from a technology-centered perspective toward a more comprehensive educational perspective. The identified themes show that AI integration involves multiple dimensions, including curriculum development, teacher capacity, learning personalization, and ethical responsibility.

The four themes are closely interconnected rather than independent. Curriculum innovation provides the educational context in which AI technologies are applied, while teacher readiness determines whether these technologies can be effectively integrated into classroom practice. Personalized learning and assessment reflect the instructional possibilities enabled by AI, whereas ethical governance addresses the conditions required for responsible and sustainable implementation.

Taken together, the thematic structure indicates that AI-supported early childhood education should be understood as an integrated process involving technological innovation, pedagogical transformation, and educational responsibility. This perspective provides the analytical foundation for the following sections.

3.1 AI-Supported Learning and Curriculum Innovation

AI-supported learning and curriculum innovation represents one of the most frequently discussed themes in research on artificial intelligence in early childhood education. Existing studies indicate that AI is gradually shifting from being viewed as a supplementary technological tool toward becoming a means of supporting curriculum transformation, learning experience design, and educational innovation [3,19]. Rather than focusing only on the functional capabilities of AI systems, recent research has increasingly examined how intelligent technologies can be integrated into developmentally appropriate learning environments while maintaining the child-centered principles of early childhood education.

Curriculum innovation supported by AI is primarily reflected in the design of adaptive and interactive learning environments. Chen [3] argues that AI technologies provide new possibilities for curriculum development by enabling more flexible learning arrangements and supporting teachers in understanding children's individual learning needs. Through data-based analysis and intelligent feedback mechanisms, AI systems can assist educators in adjusting instructional strategies and creating more responsive learning experiences. Similarly, Chen and Perez [5] highlight that AI-supported systems can contribute to personalized educational planning by providing information that helps teachers better understand children's learning progress.

However, existing studies also emphasize that AI integration should not be understood as a replacement for traditional early childhood pedagogical practices. Su and Zhong [19] argue that effective AI-supported curriculum innovation should maintain alignment with play-based learning, exploration, and social interaction, which remain fundamental characteristics of early childhood education. From this perspective, the educational value of AI depends on whether technology can enhance children's active participation and creativity rather than simply increase the use of digital tools in classrooms.

The role of AI in STEM-related curriculum development has received increasing attention in recent research. Ozturk [17] examines the application of AI-supported learning approaches in STEM education and suggests that intelligent technologies can provide opportunities for young children to engage in inquiry-based learning, problem-solving activities, and early computational thinking. Rather than introducing complex technological concepts directly, AI-supported STEM environments can encourage children to explore relationships, test ideas, and develop reasoning abilities through meaningful learning activities. Su and Zhong [19] similarly emphasize that technology-supported learning should be integrated with children's developmental characteristics and educational experiences rather than being separated from existing curriculum goals.

Another important direction concerns embodied and experiential learning. Yang *et al*., [20] demonstrate that AI-supported embodied learning environments can strengthen children's engagement by combining digital interaction with physical exploration. Their research highlights that AI applications can expand children's learning opportunities when technology relates to movement, communication, and collaborative activities. This perspective challenges the assumption that digital technologies necessarily reduce children's direct experiences and instead emphasizes the potential of AI to enrich interactive learning contexts.

The reviewed studies also reveal that successful AI-supported curriculum innovation requires careful consideration of teachers' pedagogical roles. Although AI can provide learning resources, adaptive support, and analytical information, teachers remain responsible for interpreting children's needs and designing meaningful learning activities [3,19]. In early childhood education, where emotional interaction, social development, and contextual understanding are particularly important, AI functions most effectively when it supports rather than replaces teachers' professional judgment.

Taken together, research on AI-supported learning and curriculum innovation demonstrates that the contribution of AI lies not simply in introducing advanced technologies into educational settings but in reshaping how learning experiences are designed and delivered. The reviewed studies suggest that sustainable curriculum innovation requires a balance between technological possibilities and established principles of early childhood education. AI can expand learning opportunities, but its educational significance depends on child-centered curriculum design, meaningful teacher involvement, and developmentally appropriate implementation.

3.2 Teacher Readiness and AI Literacy

Teacher readiness and AI literacy represent another central theme identified in the reviewed literature. While AI technologies provide new opportunities for improving educational practices, their effectiveness largely depends on teachers' ability to understand, evaluate, and appropriately integrate these technologies into early childhood education. Existing studies increasingly emphasize that successful AI implementation requires not only access to digital tools but also teachers' professional knowledge, technological competence, and pedagogical decision-making abilities [11,14].

AI literacy has become an important component of teachers' professional competence in the digital era. Ng *et al*., [14] argue that teachers need more than basic digital skills; they must develop an understanding of how AI systems operate, how educational data are generated and interpreted, and how intelligent technologies influence teaching and learning processes. Without sufficient AI literacy, teachers may experience difficulties in evaluating the educational value of AI applications or making appropriate decisions regarding their classroom use.

Recent research further indicates that teacher readiness involves multiple dimensions, including technological confidence, pedagogical adaptation, and professional learning capacity. Lim [11] highlights that teachers' willingness and ability to adopt AI-supported practices are influenced by their perceptions of technology, access to professional development opportunities, and understanding of AI-related educational applications. In early childhood settings, these factors are particularly important because teachers must balance technological possibilities with children's developmental needs and learning characteristics.

Professional development has therefore become a critical condition for sustainable AI integration. Lim [12] emphasizes that teacher training should move beyond technical instruction and focus on helping educators develop critical and reflective approaches toward AI use. Effective professional learning should enable teachers to understand when and how AI can support children's learning while also recognizing its limitations. This perspective suggests that teacher preparation should combine technological knowledge with pedagogical reasoning rather than treating AI competence as a separate technical skill.

The importance of teacher competence is also reflected in research examining educators' attitudes and preparedness toward AI adoption. Kölemen and Yıldırım [10] indicate that teachers' perceptions of AI influence their willingness to incorporate intelligent technologies into educational activities. Positive perceptions, together with adequate institutional support, can encourage teachers to explore innovative teaching approaches, whereas insufficient knowledge or uncertainty about AI may limit meaningful implementation.

Although AI can provide automated feedback, learning resources, and analytical support, the reviewed studies consistently emphasize that teachers remain central actors in early childhood education. AI systems cannot independently understand children's emotions, social interactions, and developmental contexts in the same way that teachers can. Therefore, the role of teachers is not

reduced by AI integration; instead, it is transformed toward greater emphasis on interpretation, instructional design, and ethical decision-making [11,14].

The reviewed literature also suggests that teacher readiness is closely connected with broader educational conditions. Individual competence alone is insufficient if schools lack professional development mechanisms, technical support, or organizational encouragement for AI experimentation. Sustainable AI implementation requires an environment in which teachers can continuously improve their AI-related knowledge and integrate technological tools into meaningful educational practices.

Overall, research on teacher readiness and AI literacy demonstrates that teachers represent the key link between technological innovation and educational practice. AI integration in early childhood education should therefore focus not only on providing intelligent tools but also on developing teachers' capacity to critically and creatively apply these tools. Strengthening teacher AI literacy is essential for ensuring that AI-supported education remains pedagogically meaningful, developmentally appropriate, and aligned with the goals of early childhood education.

3.3 Personalized Learning and Assessment

Personalized learning and assessment represent an important theme in research on AI-supported early childhood education. Existing studies emphasize that children's developmental differences create challenges for traditional instructional and assessment approaches, particularly when teachers need to respond to diverse learning needs within classroom settings [5,13]. AI technologies have therefore attracted attention because of their ability to analyze learning information and provide adaptive support for individual learners.

AI-supported personalized learning is mainly associated with adaptive systems that collect and process learning-related information. Chen and Perez [5] argue that AI-assisted educational systems can provide teachers with insights into children's learning progress and developmental patterns, allowing instructional strategies to be adjusted according to individual needs. Similarly, Nan [13] suggests that AI technologies can modify learning content and instructional approaches based on learners' performance and responses, creating more flexible learning experiences.

In early childhood education, this adaptive capacity is particularly relevant because children differ substantially in language development, cognitive abilities, attention patterns, and learning pace. AI-supported systems may help educators identify these differences and provide targeted learning opportunities [5,13]. However, the effectiveness of personalized learning depends not only on technological adjustment but also on teachers' interpretation of children's developmental contexts.

AI has also influenced discussions of educational assessment. Chen and Perez [5] highlight that AI-assisted assessment systems can process learning data efficiently and provide timely information to support instructional decisions. Compared with traditional assessment approaches that often rely on limited observation periods, AI-supported assessment may provide more continuous information regarding children's learning processes.

Nevertheless, assessment quality cannot be determined solely by the amount of data generated by intelligent systems. Harris and Brown [6] emphasize that effective assessment should support learning through meaningful feedback rather than simply measure achievement. This principle remains important in AI-supported environments because teachers continue to play a central role in interpreting assessment information and transforming data into appropriate educational responses.

The reviewed literature also indicates that AI-supported personalization should maintain a balance between technological assistance and human interaction. While adaptive systems can provide individualized recommendations, early childhood education remains deeply dependent on

communication, emotional support, and teacher-child relationships [5,6]. Therefore, AI should be viewed as a supportive resource that enhances teachers' capacity rather than replacing professional judgment.

Although existing research has demonstrated the potential of AI-supported personalization and assessment, current studies have mainly focused on technological functions and immediate learning support. Less attention has been given to the long-term influence of AI-based personalization on children's social development, creativity, and emotional growth.

Overall, the reviewed studies suggest that AI can strengthen personalized learning and assessment by improving educational responsiveness and supporting teachers' understanding of children's learning processes. However, meaningful personalization requires the combination of intelligent technologies, professional interpretation, and child-centered pedagogical practices.

3.4 Ethical Challenges and Governance

While artificial intelligence (AI) provides new opportunities for innovation in early childhood education, the reviewed studies also highlight a range of ethical challenges associated with its implementation. Compared with other educational contexts, AI applications in early childhood education involve younger learners who have limited awareness of data collection, algorithmic decision-making, and potential digital risks. Therefore, ethical governance has become an essential dimension in ensuring that AI development remains consistent with children's rights, educational equity, and child-centered educational principles [4,15].

Privacy and data protection represent one of the most frequently discussed ethical concerns in existing research. AI-supported educational systems often collect and analyze children's learning behaviors, interaction patterns, and developmental information to provide personalized learning support. Nikolopoulou [15] emphasizes that protecting children's personal information is particularly important because young learners may not fully understand how their data are collected, processed, and applied. Therefore, educational institutions need appropriate mechanisms to ensure transparency, accountability, and responsible management of children's educational data.

Beyond privacy issues, existing studies have also examined concerns related to fairness and algorithmic bias. AI systems generate recommendations and assessments based on available datasets, meaning that incomplete or biased information may influence educational outcomes. Kanders *et al*., [8] argue that emerging AI technologies, particularly generative AI applications, require attention not only to technological performance but also to broader issues of fairness, reliability, and accountability. In early childhood education, biased AI systems may influence learning recommendations, assessment results, or access to educational opportunities.

Educational equity represents another important governance concern. Although AI technologies have the potential to expand access to learning resources and provide additional educational support, differences in digital infrastructure, technological accessibility, and institutional capacity may affect whether children can benefit from these innovations. Berson *et al*., [2] highlight that unequal access to digital resources remains an important challenge in technology-supported education. Without sufficient attention to these conditions, AI implementation may unintentionally reinforce existing educational inequalities.

Recent research further suggests that ethical AI governance requires consideration of children's developmental characteristics and educational needs. Chen and Delaney [4] emphasize that responsible AI integration should involve AI literacy development, educational equity, and appropriate governance mechanisms. This perspective indicates that AI governance cannot rely only

on technical regulation but requires cooperation among teachers, schools, policymakers, families, and technology developers.

Emerging AI applications, including digital companions and generative AI tools, introduce additional ethical considerations. Özdemir Beceren *et al*., [18] discuss the potential of digital companions to support children's communication and engagement while also raising questions regarding emotional attachment, dependence on intelligent systems, and the appropriate boundaries between technological assistance and human interaction. Similarly, Kanders *et al*., [8] highlight that generative AI applications require careful evaluation regarding content accuracy, transparency, and responsible use, particularly when young children interact with AI-generated information.

The reviewed literature demonstrates that ethical governance in AI-supported early childhood education extends beyond privacy protection alone. It involves broader considerations related to fairness, accountability, children's developmental rights, and the appropriate relationship between technology and human interaction. Effective governance therefore requires a balanced approach that encourages educational innovation while preventing potential risks associated with uncontrolled technological adoption.

To further illustrate how different AI applications contribute to educational practices and their associated values, Table 3 summarizes the major AI applications identified in the reviewed studies and their corresponding educational functions.

Table 3
Relationships between AI applications and educational values

AI Application	Educational Value	Representative Studies
Adaptive learning systems	Individualized learning support and responsive instruction	Chen and Perez (2023); Nan (2020)
AI-assisted assessment	Timely feedback and developmental monitoring	Chen and Perez (2023); Harris and Brown (2013)
Generative AI tools	Instructional resource development and teaching support	Kasneci *et al*., (2023); Kanders *et al*., (2024)
Embodied learning environments	Active engagement, exploration, and experiential learning	Yang *et al*., (2024)
AI-supported STEM learning	Problem-solving, inquiry skills, and computational thinking	Ozturk (2025); Su and Zhong (2022)
Digital companions	Communication support and learning engagement	Özdemir Beceren *et al*., (2025)

Note. The table was developed through thematic synthesis of the twenty reviewed studies to illustrate the relationship between AI applications and their educational functions in early childhood education.

Table 3 illustrates that AI applications in early childhood education serve different educational purposes rather than representing a single technological function. Adaptive learning systems and AI-assisted assessment mainly support individualized instruction by helping teachers understand children's learning progress and developmental needs. Generative AI tools extend AI applications toward teacher support through instructional resource development and learning material preparation.

Other applications emphasize children's active engagement and experiential learning. Embodied learning environments and AI-supported STEM activities focus on exploration, inquiry, and problem-solving, reflecting the importance of active participation in early childhood education. Digital companions represent an emerging application area that expands AI-supported interaction while also requiring careful consideration of children's emotional development and human relationships.

The distribution of AI applications shown in Table 3 demonstrates that technological innovation and educational value are closely connected. AI does not improve education simply through automation; rather, its contribution depends on how effectively technologies are integrated into meaningful pedagogical contexts. Sustainable AI implementation requires alignment among technological capabilities, teachers' professional practices, children's developmental characteristics, and ethical governance mechanisms.

4. Discussion

The findings of this review indicate that artificial intelligence (AI)-supported early childhood education should not be understood as a simple process of technology adoption. Instead, AI integration represents a broader transformation involving curriculum design, teacher professional capacity, personalized learning approaches, and ethical governance. While previous studies have demonstrated the potential of AI in improving educational efficiency and supporting learning innovation, the reviewed literature suggests that the educational value of AI depends largely on whether technological development remains aligned with child-centered educational principles [3, 19].

The discussion therefore extends beyond identifying applications of AI and examines the conditions under which AI can contribute to sustainable educational development. Based on the thematic synthesis, this study proposes that effective AI integration requires coordination among three interconnected dimensions: technological innovation, pedagogical transformation, and ethical responsibility. The relationship among these dimensions is illustrated in Figure 1.

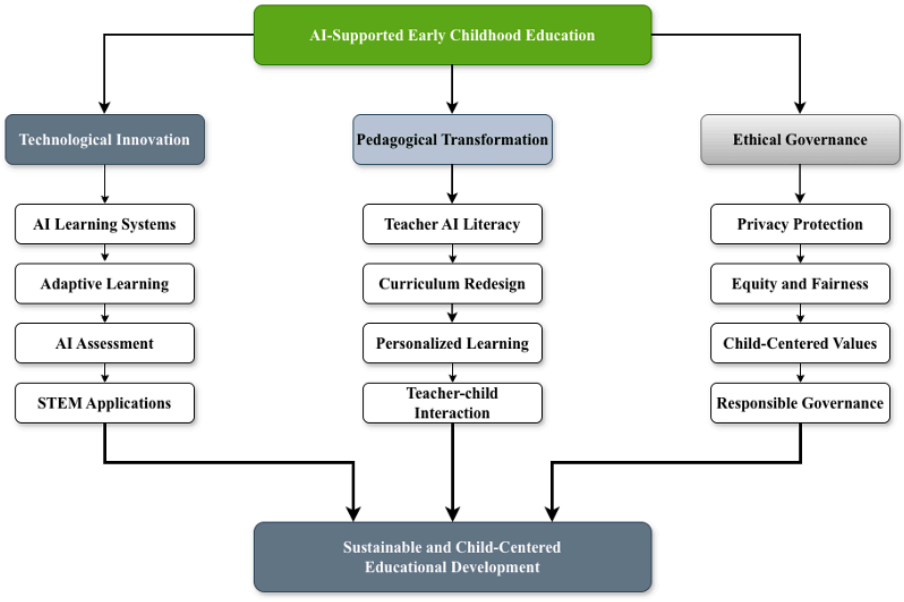

Fig. 1. A Conceptual framework for AI-supported early childhood education

Figure 1 presents the conceptual framework developed from the thematic synthesis of the reviewed literature. The framework highlights three interconnected dimensions of AI-supported early childhood education: technological innovation, pedagogical transformation, and ethical governance.

Technological innovation provides new possibilities for learning support, while pedagogical transformation determines how AI is integrated into curriculum design, teacher practice, and

personalized learning. Ethical governance ensures that AI applications remain responsible, equitable, and aligned with child-centered educational principles.

Overall, the framework suggests that sustainable AI integration requires coordination among technological development, educational practice, and ethical responsibility rather than focusing solely on technological advancement.

4.1 Reconsidering AI Integration from a Child-Centered Educational Perspective

The findings of this review challenge a technology-centered understanding of AI implementation in early childhood education. Although AI provides new possibilities for adaptive learning, curriculum innovation, and educational support, its contribution should not be evaluated solely according to technological capabilities. Instead, AI should be examined according to how effectively it enhances children's learning experiences while maintaining the developmental and social characteristics of early childhood education [3,19].

Previous research has emphasized that early childhood education is fundamentally based on interaction, exploration, play, and children's active participation. Su and Zhong [19] argue that AI should function as a supportive resource rather than replace traditional pedagogical approaches. Similarly, Chen [3] highlights that AI-supported learning environments can improve educational responsiveness when technologies are integrated with appropriate curriculum design and teachers' professional judgment. These perspectives indicate that the central question is not whether AI should be introduced into early childhood classrooms, but rather how AI can be meaningfully incorporated without weakening child-centered educational values.

The findings also extend previous discussions by highlighting the relationship between technological innovation and pedagogical transformation. Research on AI-supported STEM learning and embodied learning demonstrates that AI can expand children's opportunities for inquiry, exploration, and problem-solving when technology is embedded within meaningful learning activities [17,20]. Rather than promoting passive interaction with digital systems, effective AI applications encourage children to actively construct knowledge through exploration and collaboration.

However, the implementation of AI also requires attention to potential tensions between technological efficiency and educational authenticity. AI systems are capable of processing large amounts of learning information and generating instructional recommendations, but they cannot fully understand children's emotions, social relationships, and developmental contexts. Therefore, AI should enhance teachers' ability to design learning experiences rather than reduce education to automated processes [5,14].

From a theoretical perspective, this study extends existing AI-in-education research by proposing that early childhood AI integration should be viewed through a combined technological-pedagogical-governance framework. Previous studies have often examined AI applications from specific perspectives, such as adaptive learning or digital literacy, whereas the present review highlights the importance of connecting technological possibilities with educational purposes and ethical considerations [4,16].

Overall, AI-supported early childhood education should be understood as a process of educational transformation rather than technological replacement. The sustainable value of AI depends on whether technology strengthens children's learning experiences, supports teachers' professional practices, and remains consistent with the fundamental principles of child-centered education.

4.2 Strengthening Teacher Capacity as the Key Condition for AI Implementation

The findings of this review demonstrate that teacher capacity represents a critical condition determining whether AI can be effectively integrated into early childhood education. Although AI technologies provide new possibilities for curriculum innovation, personalized learning, and assessment support, their educational value depends largely on teachers' ability to interpret, adapt, and apply these technologies within meaningful pedagogical contexts. Therefore, AI implementation should not be understood as a process driven only by technological advancement but as a transformation requiring changes in teachers' professional knowledge and educational practices.

Previous research has emphasized that AI literacy is becoming an essential component of teachers' professional competence in the digital era. Ng *et al*., [14] argue that teachers need to develop an understanding of AI functions, data interpretation, and the implications of intelligent technologies for teaching and learning. This perspective extends traditional views of digital competence, which often focus mainly on operational skills. In AI-supported educational environments, teachers must also evaluate the appropriateness of AI applications, recognize potential limitations, and make informed pedagogical decisions.

The findings further indicate that teacher readiness involves both individual competence and institutional support. Lim [11] highlights that teachers' willingness to adopt AI is influenced by their confidence, previous technology experiences, and access to professional learning opportunities. Similarly, Lim [12] emphasizes that effective teacher development should move beyond technical training and focus on reflective understanding of how AI can support educational goals. These findings suggest that professional development programs should not simply teach teachers how to use AI tools but should help them integrate AI into curriculum planning, classroom interaction, and assessment practices.

This perspective is particularly important in early childhood education because teachers play a central role in interpreting children's behaviors, emotions, and developmental needs. While AI systems can provide learning data and instructional recommendations, they cannot fully replace teachers' understanding of children's social and emotional development. Ouyang and Jiao [16] argue that human-AI collaboration represents a more appropriate direction for educational transformation, where AI enhances teachers' decision-making rather than replacing professional judgment.

The reviewed literature also reveals that teacher capacity development requires organizational and policy support. Kölemen and Yıldırım [10] indicate that teachers' attitudes toward AI adoption are closely related to their knowledge, confidence, and perceived support environment. Without adequate training opportunities, technical assistance, and institutional encouragement, teachers may experience uncertainty or resistance toward AI implementation. Therefore, schools should establish continuous professional development mechanisms that allow teachers to explore AI applications while critically reflecting on their educational implications.

From a theoretical perspective, the role of teachers highlights an important shift in AI education research. Rather than viewing technology adoption as a direct relationship between AI tools and learning outcomes, this review suggests that teachers function as an essential mediating factor between technological innovation and educational improvement. This perspective expands existing discussions by emphasizing that AI effectiveness depends not only on technological capability but also on teachers' professional agency and pedagogical interpretation.

From a practical perspective, strengthening teacher capacity requires a comprehensive approach. Professional development should combine AI literacy education, pedagogical application, ethical awareness, and opportunities for classroom-based experimentation. Such an approach can enable

teachers to become active designers of AI-supported learning environments rather than passive users of technological systems.

Overall, teacher capacity represents the bridge connecting AI innovation with educational practice. Sustainable AI integration in early childhood education requires not only advanced technologies but also teachers who possess the knowledge, confidence, and critical understanding necessary to apply these technologies in child-centered ways.

4.3 Balancing Professionalization Benefits and Human-Centered Assessment

The findings of this review indicate that AI-supported personalized learning provides important opportunities for improving educational responsiveness in early childhood education. However, the educational value of personalization should not be evaluated only through technological efficiency. A key challenge is maintaining a balance between AI-driven adaptive support and the human-centered characteristics of early childhood assessment, where teachers' professional judgment and interaction with children remain essential.

Previous research has highlighted the potential of AI systems to support personalized learning by analyzing learning information and providing adaptive recommendations. Chen and Perez [5] argue that AI-assisted systems can help teachers identify children's learning patterns, monitor developmental progress, and adjust instructional strategies according to individual needs. Similarly, Nan [13] emphasizes that adaptive learning technologies can modify learning content and provide differentiated support based on learners' responses. These findings demonstrate that AI can strengthen teachers' ability to respond to individual differences among children.

However, the implementation of AI-supported professionalization also raises questions regarding the meaning of assessment in early childhood education. Traditional assessment approaches emphasize observation, interaction, and understanding children's developmental processes rather than simply measuring learning outcomes. Harris and Brown [6] argue that effective assessment should support learning through meaningful feedback and reflection. This perspective remains important in AI-supported environments because data generated by intelligent systems require professional interpretation before they can contribute to educational decisions.

The discussion of AI-supported assessment therefore requires a distinction between data-based support and automated decision-making. AI can improve the efficiency of collecting and organizing learning information, but it cannot fully understand children's emotions, social relationships, cultural backgrounds, and contextual experiences. Chen [3] suggests that AI should enhance educational responsiveness rather than replace the professional roles of educators. In early childhood settings, teachers continue to serve as the primary interpreters of children's development and the designers of meaningful learning experiences.

The findings also extend existing discussions by highlighting the potential tension between professionalization and holistic development. Although AI systems can provide individualized recommendations, excessive dependence on algorithmic professionalization may narrow children's learning experiences by emphasizing measurable patterns over creativity, exploration, and social interaction. Therefore, personalized learning should not be understood as providing different digital content to each child alone, but as creating supportive learning environments that recognize children's diverse developmental pathways.

From a theoretical perspective, this review contributes to AI-in-education research by emphasizing that personalization is not merely a technological function but a pedagogical process. Previous studies have often focused on adaptive algorithms and learning paralytics, while the findings

of this review highlight the importance of connecting AI capabilities with educational purposes, teacher expertise, and developmental principles.

From a practical perspective, schools should consider AI-supported assessment as a complementary resource rather than an alternative to teacher observation and professional judgment. Effective implementation requires teachers to critically interpret AI-generated information and combine technological feedback with direct interaction and contextual understanding of children's needs.

Overall, AI-supported overspecialization offers valuable opportunities for improving individualized learning and assessment practices. Nevertheless, sustainable implementation requires maintaining a balance between technological assistance and human-centered education. AI can expand teachers' capacity to understand children's learning processes, but meaningful overspecialization ultimately depends on professional judgment, emotional interaction, and child-centered pedagogical practice.

4.4 Establishing Ethical Governance for Sustainable AI Adoption

The findings of this review indicate that ethical governance is not an additional consideration after AI implementation but a fundamental condition for sustainable AI adoption in early childhood education. Although AI technologies provide opportunities for improving learning support, assessment, and educational innovation, their application also introduces challenges related to privacy, fairness, transparency, and children's rights. Therefore, AI integration requires governance mechanisms that consider not only technological effectiveness but also educational responsibility and social implications.

Previous studies have highlighted that ethical concerns are particularly significant in early childhood education because young children have limited ability to understand data practices and evaluate technological decisions. Nikolopoulou [15] emphasizes that responsible AI implementation requires careful consideration of children's privacy, data protection, and the appropriate boundaries of technology use. Unlike adult learners, young children may not be able to provide meaningful consent regarding the collection and use of their educational data, making institutional responsibility essential.

The issue of fairness represents another important dimension of AI governance. AI systems often rely on existing datasets to generate recommendations, feedback, or assessments, which means that biased or incomplete data may influence educational outcomes. Kanders *et al*., [8] argue that emerging AI technologies, particularly generative AI, require attention to algorithmic accountability, reliability, and ethical use. In early childhood education, these concerns are closely related to whether AI systems can support diverse learners without reinforcing existing inequalities.

The reviewed literature also demonstrates that ethical governance should address the digital divide and unequal access to AI-supported educational resources. Berson *et al*., [2] highlight that differences in technological infrastructure and digital access continue to shape educational opportunities. Therefore, schools and policymakers need to consider whether AI implementation strategies provide equitable benefits for children from different social and educational backgrounds. Without appropriate support mechanisms, AI may unintentionally widen existing educational gaps.

In addition to institutional and technological issues, ethical governance requires attention to the relationship between AI and human interaction. Emerging applications such as digital companions demonstrate both the opportunities and challenges of AI-supported communication. Özdemir Beceren *et al*., [18] suggest that digital companions may provide new forms of learning engagement, but their use also requires consideration of children's emotional development and the importance of

human relationships in early childhood education. Similarly, Kasneci *et al*., [9] emphasize that generative AI applications require careful evaluation regarding accuracy, transparency, and responsible use.

These findings extend previous AI-in-education research by suggesting that governance should move beyond controlling technological risks toward establishing an integrated educational governance framework. Chen and Delaney [4] argue that responsible AI development requires attention to AI literacy, equity, and ethical responsibility. In the context of early childhood education, this means that teachers, schools, families, policymakers, and technology developers should share responsibility for ensuring that AI applications remain aligned with educational goals and children's developmental needs.

From a practical perspective, sustainable AI adoption requires clear institutional guidelines, teacher preparation, and continuous evaluation mechanisms. Schools should establish procedures for data protection, responsible technology selection, and monitoring of AI-supported educational practices. At the policy level, governance frameworks should balance innovation with protection by ensuring that AI development serves educational improvement rather than technological expansion alone.

Overall, ethical governance provides the foundation for ensuring that AI-supported early childhood education develops in a responsible and sustainable direction. The future of AI integration depends not only on improving technological capabilities but also on establishing educational systems that protect children's rights, promote equity, and maintain the human-centered nature of early childhood education.

4.5 Theoretical and Practical Implications

The findings of this review contribute to existing discussions of AI-supported early childhood education in both theoretical and practical ways. From a theoretical perspective, this study extends current understandings of AI integration by moving beyond a technology-adoption perspective. Previous research has often focused on specific AI functions, such as adaptive learning systems, digital tools, or intelligent assessment. In contrast, the present review proposes that AI-supported early childhood education should be understood as an interconnected process involving technological innovation, pedagogical transformation, teacher capacity, and ethical governance.

The conceptual framework developed in this study contributes to AI-in-education research by emphasizing the mediating role of educational practice. Rather than assuming that technological advancement directly leads to educational improvement, the framework highlights that teachers, curriculum design, and governance mechanisms determine how AI technologies are interpreted and applied in educational contexts. This perspective extends existing discussions by positioning teachers and educational values as central components of AI implementation rather than secondary considerations [4,14].

From a practical perspective, the findings highlight several challenges that need to be addressed before AI can be effectively integrated into early childhood education. One major challenge concerns teacher preparation. Although AI provides new opportunities for instructional support and personalized learning, insufficient AI literacy and limited professional development opportunities may restrict teachers' ability to use these technologies effectively [11,12]. Therefore, professional development should focus not only on operational skills but also on critical understanding of AI applications, ethical considerations, and pedagogical integration.

Another practical challenge relates to institutional capacity and implementation conditions. Schools require appropriate technological infrastructure, organizational support, and clear guidelines

for responsible AI use. Without sufficient resources and governance mechanisms, AI adoption may increase educational inequalities rather than promote inclusive development. This issue is particularly important in early childhood education, where differences in access, resources, and teacher expertise can significantly influence children's learning experiences [2].

At the policy level, the findings suggest that AI development in early childhood education requires a balanced governance approach. Policymakers should support technological innovation while establishing standards related to data protection, fairness, transparency, and children's rights. Effective policies should not only encourage the adoption of AI technologies but also ensure that implementation remains aligned with child-centered educational objectives [4,15].

Overall, the theoretical and practical implications of this review indicate that sustainable AI integration requires coordination among technology developers, educators, institutions, and policymakers. The future development of AI-supported early childhood education depends not only on improving technological capabilities but also on creating educational systems capable of applying AI responsibly, effectively, and ethically.

5. Conclusion

This review examined the development pathways and challenges of artificial intelligence (AI)-supported early childhood education through a thematic synthesis of recent literature. The findings indicate that AI integration in early childhood education is not merely a process of introducing technological tools into educational settings, but a broader transformation involving curriculum innovation, teacher professional development, personalized learning, assessment practices, and ethical governance.

The review identifies four interconnected dimensions shaping AI-supported early childhood education: AI-supported learning and curriculum innovation, teacher readiness and AI literacy, personalized learning and assessment, and ethical governance. These dimensions demonstrate that the educational value of AI depends not only on technological capabilities but also on how effectively AI is integrated with child-centered pedagogical practices. Teachers remain central actors in this process because their professional knowledge, AI literacy, and pedagogical judgment determine whether technological applications can genuinely support children's development.

This study contributes to existing research by proposing an integrated perspective that connects technological innovation, pedagogical transformation, and ethical responsibility. Rather than viewing AI as an independent solution for improving educational outcomes, this review highlights that sustainable AI adoption requires coordination among children, teachers, educational institutions, families, policymakers, and technology developers. Such a perspective provides a more comprehensive understanding of how AI can support early childhood education while maintaining developmental appropriateness and educational equity.

Future research should further investigate AI implementation in authentic early childhood settings through empirical studies with diverse populations and contexts. Greater attention should also be given to long-term effects of AI-supported learning on children's cognitive, social, and emotional development, as well as effective strategies for teacher preparation and ethical governance. Continued interdisciplinary collaboration will be essential to ensure that AI contributes to educational innovation while preserving the human-centered nature of early childhood education.

Acknowledgements
The author would like to thank the researchers whose studies contributed to this review.

Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this study.

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APPENDIX A

Summary of reviewed literature

Table A1 presents the main characteristics of the twenty studies included in this review

Author(s)	Year	Research Focus	Research Type
Chen	2024	AI affordances in ECE	Scoping Review
Chen and Delaney	2026	AI ethics and equity	Conceptual Analysis
Hwang and Chien	2022	Metaverse and AI in education	Theoretical Review
Kanders *et al*.,	2024	Generative AI and child development	Perspective Paper
Kasneci *et al*.,	2023	ChatGPT in education	Review
Lim	2023	Teacher AI literacy	Survey
Lim	2024	Teachers' perceptions of AI	Qualitative Study
Ng *et al*.,	2021	AI literacy framework	Literature Review
Nikolopoulou	2025	Child-centered AI	Conceptual Analysis
Ouyang and Jiao	2021	Three paradigms of AI in education	Review
Kölemen and Yıldırım	2025	Teachers' opinions on AI	Qualitative Study
Özdemir Beceren *et al*.,	2025	Digital companions	Scoping Review
Ozturk	2025	AI in STEM education	Review
Chen and Perez	2023	Assessment and personalized learning	Conceptual Analysis
Yang *et al*.,	2024	Embodied learning	Case Study
Berson *et al*.,	2022	Digital divide	Commentary
Su and Zhong	2022	Curriculum design	Review
Barron and Darling-Hammond	2008	Inquiry learning	Literature Review
Harris and Brown	2013	Assessment practices	Case Study
Nan	2020	AI applications in preschool education	Conference Paper