



# AI-Driven Learning Model for Early Childhood Cognitive and Communication Development: An Education for Sustainable Development Approach

Selfi Lailiyatul Iftitah<sup>1\*</sup>, Ardhana Reswari<sup>2</sup>, Danang Prastyo<sup>3</sup>, Lia Fitriana Wahyuni<sup>4</sup>

<sup>1,2,3,4</sup> Universitas Islam Negeri Madura, Pamekasan, Indonesia

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### Abstract

Advances in artificial intelligence (AI) have transformed the landscape of early childhood education; however, research integrating AI, cognitive development, communication skills, and the Education for Sustainable Development (ESD) framework at this level remains very limited. This study aims to identify an AI-based learning model that optimizes the cognitive development and communication skills of young children within the ESD framework at Al Azhar Kindergarten in Pamekasan. This study employed a qualitative approach with a phenomenological design using Interpretative Phenomenological Analysis, involving a school principal, three classroom teachers, and twenty students as informants. Data collection techniques included participant observation, in-depth interviews, and a review of learning documents, conducted from January to March 2026. The findings of the study revealed four main themes: teachers' pedagogical adaptation, improvements in children's logical reasoning, the development of children's verbal communication skills, and the alignment of the learning model with the principles of inclusivity and future orientation within the ESD framework. This study confirms that AI-based learning models are suitable for implementation in early childhood education as a strategic tool for achieving Sustainable Development Goal 4.

[Perkembangan kecerdasan buatan (AI) telah mengubah lanskap pendidikan anak usia dini, namun penelitian yang mengintegrasikan AI, perkembangan kognitif, keterampilan komunikasi, dan kerangka Education for Sustainable Development (ESD) pada jenjang ini masih sangat terbatas. Penelitian ini bertujuan mengidentifikasi model pembelajaran berbasis AI yang mengoptimalkan perkembangan kognitif dan keterampilan komunikasi anak usia dini dalam kerangka ESD di TK Al Azhar Pamekasan. Studi ini menggunakan pendekatan kualitatif dengan desain fenomenologi melalui Interpretative Phenomenological Analysis, melibatkan kepala sekolah, tiga guru kelas, dan dua puluh anak sebagai informan. Teknik pengumpulan data meliputi observasi partisipan, wawancara mendalam, dan telaah dokumen pembelajaran yang dilaksanakan pada Januari hingga Maret 2026. Hasil penelitian mengungkap empat tema utama: adaptasi pedagogis guru, peningkatan penalaran logis anak, perkembangan keterampilan komunikasi verbal anak, serta kesesuaian model pembelajaran dengan prinsip inklusivitas dan orientasi masa depan dalam kerangka ESD. Penelitian ini menegaskan bahwa model pembelajaran berbasis AI layak diterapkan di pendidikan anak usia dini sebagai alat strategis untuk mencapai Tujuan Pembangunan Berkelanjutan ke-4.] © The Authors.

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#### \*Corresponding Author:

Selfi Lailiyatul Iftitah

Universitas Islam Negeri Madura

JL. Raya Panglegur Km 4 Pamekasan 69371 Pamekasan

Email: [siftitah@iainmadura.ac.id](mailto:siftitah@iainmadura.ac.id)

## 1. Introduction

Artificial intelligence has transformed the landscape of education, including early childhood education. This transformation is driven by technology's ability to provide learning experiences that are more adaptive, personalized, and interactive, tailored to each child's needs. Su & Yang [1] shows that the integration of artificial intelligence-based technology into early childhood education increases children's engagement in learning. Abrar et al [2] found that AI-based learning models are more effective at stimulating children's cognitive development than conventional methods. Garzol et al [3] notes that the adoption of AI in education has now become a global trend. As a result, AI-based learning models are becoming an increasingly relevant option in 21st-century education.

There has been a considerable amount of research on cognitive and communication development in early childhood, but most of it focuses on conventional approaches without treating artificial intelligence as a key variable. Therefore, research that specifically examines the role of AI in early childhood development still needs to be developed. Syamsiah et al [4] studying the formation of children's character through parenting patterns without touching the digital aspect at all. Yao [5] discussing children's social skills through a traditional approach without directly considering the role of technology. Hoemann et al [6] raises the emotional development of children, but does not explore the connection between technology and cognitive or communication aspects. From this, the need is seen to study more deeply the artificial intelligence-based learning model for the cognitive and communication development of early childhood.

Education for Sustainable Development is a global framework that promotes the transformation of education to be more relevant, inclusive, and future-oriented. UNESCO has established Education for Sustainable Development as a key strategy for achieving the Sustainable Development Goals, particularly Goal 4 on quality education. González-Salamanca et al [7] shows that Education for Sustainable Development promotes a learning approach that equips children with 21st-century skills. Alsagri, H., & Sohail [8] showing that the integration of technology in Education for Sustainable Development is able to improve the quality of learning. Thus, Education for Sustainable Development becomes a relevant conceptual foundation for developing artificial intelligence-based learning models for early childhood.

Cognitive development and communication skills in early childhood are important foundations for learning success at the next level. This period is known as the golden age, which is very decisive for the quality of a child's growth and development. Rakesh [9] shows that children who receive proper cognitive and communication stimulation at an early age have better academic achievement in later stages. Pietropoli, I., & Gracia [10] shows that a learning environment rich in stimulation has a positive effect on children's cognitive development. Suryaningsih & Aisyah [11] finding that technology-based innovative learning models are able to optimize the communication abilities of early childhood children. On that basis, this research is developed to examine artificial intelligence-based learning models to optimize the cognitive and communication development of early childhood children.

This study aims to identify artificial intelligence-based learning models that are capable of optimizing the cognitive and communication development of early childhood within the framework of Education for Sustainable Development. This is driven by the still limited studies that connect artificial intelligence, early childhood development, and the principles of Education for Sustainable Development in a single integrated study. Ghasemzadeh, A., Kojori, R., Saadat, M., & Alizadeh [12] shows that a structured technological approach has a positive impact on children's overall development. Gligorea et al [13] found that technology-based adaptive learning models are more effective in responding to the individual needs of children. Weber & Greiff [14] shows that proper technological stimulation at an early age has a positive impact on children's cognitive and communication development. This study is expected to enrich the literature on early childhood education and support the implementation of ESD at both local and global levels.

## 2. Method

This research was conducted at Al Azhar Kindergarten Pamekasan from January to March 2026, focusing on children's cognitive and communication development through an AI-based learning model. This school was chosen because it has integrated technology into daily learning processes, making it relevant as a study location. The unit of analysis includes all AI-based learning activities that took place during that period.

A qualitative approach with a phenomenological design was used to understand the direct experiences of teachers and children in the AI-based learning process. This design was chosen because it is suitable for exploring the real experiences of teachers and children in the context of

learning that occurs naturally. Fr chet te et al[15] explaining that phenomenological research aims to describe the essence of the participants' lived experiences related to a particular phenomenon in depth. Alhazmi & Kaufmann[16] explaining that the phenomenological approach produces a deep understanding of how someone interprets their learning experiences. Informants were selected purposively (purposive sampling), namely those directly involved in the learning process based on artificial intelligence. The main informants consisted of the school principal, three classroom teachers, and twenty children along with their respective parents who were directly involved in the learning process. Supporting documents include daily lesson plans, video recordings of learning activities, photos of learning activities, and records of children's development as documented by the teachers periodically. Palinkas et al [17] shows that purposive selection of informants produces data that is rich and relevant to the research focus. Data were collected through three techniques, namely participatory observation, in-depth interviews, and desk review of learning documents. Participatory observation was conducted to observe children's interactions with AI devices in the classroom, in-depth interviews involved principals, teachers, and parents, and desk reviews were conducted on daily learning plan documents and children's development records. These three techniques complement each other so that the data collected is sufficiently rich to answer the research questions. Data analysis used the Interpretative Phenomenological Analysis approach developed by Smith & Osborn [18] through four stages: (1) bracketing (reduction of prejudice); (2) horizontalization (identification of meaningful statements); (3) cluster of meaning (theming); and (4) composite description (combined description) which presents the essence of the informants' experiences as the final research findings.

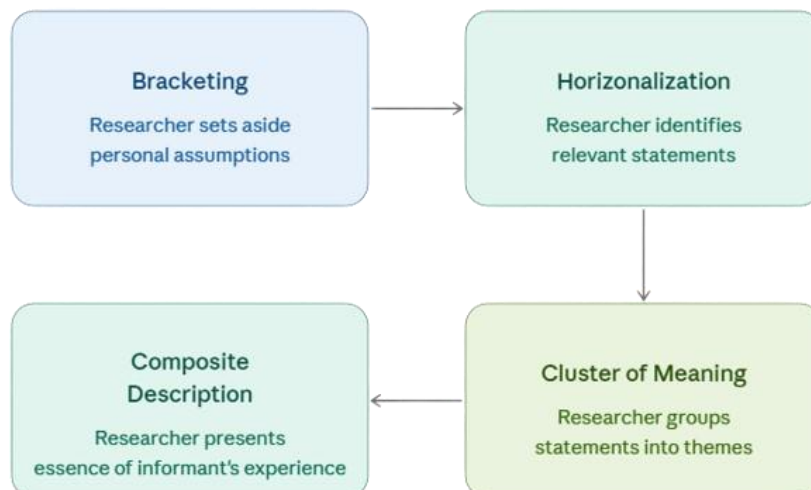


Figure 1. Stages of Interpretative Phenomenological Analysis

### 3. Results

This study produced four main themes obtained through Interpretative Phenomenological Analysis (IPA) of observation data, in-depth interviews, and document desk review of learning at Al Azhar Kindergarten Pamekasan during the period from January to March 2026. The four themes include: (1) teachers' experiences in integrating learning models based on artificial intelligence; (2) children's cognitive development through artificial intelligence-based learning; (3) improvement of children's communication skills through interaction with artificial intelligence devices; and (4) the relevance of implementing this learning model with the principles of Education for Sustainable Development (ESD). Each theme is described based on meaningful statements (horizontalization) identified from the informants' utterances and behaviors.

Prior to presenting the four themes, Table 1 below summarizes the field observation data collected across eight weeks of participatory observation sessions at Al Azhar Kindergarten Pamekasan. These observation records document the AI learning experience as it occurred naturally in the classroom, capturing children's behavioral responses, AI tool usage, and teacher facilitation patterns that formed the empirical basis for the thematic analysis.

Table 1. Summary of Field Observation Data on AI Learning Experience at Al Azhar Kindergarten Pamekasan (January–March 2026)

Session	Date	AI Tool Used	Children's Observed Behavior	Teacher Facilitation Notes
1	January 13, 2026	Canva for Education	Children observed pointing at visual story cards on the screen; 14 out of 20 children appeared attentive throughout the session	Teacher used Canva templates to display thematic visual boards; guided children to name objects shown on screen
2	January 20, 2026	Quizlet	Children in small groups responded to picture-based questions; several children retried incorrect answers independently without teacher prompting	Teacher facilitated group rotation; encouraged children to discuss answer choices before selecting
3	February 3, 2026	Speeko Kids	A previously quiet child repeated a speaking prompt three times before producing a full sentence; peers listened attentively and applauded	Teacher created a supportive atmosphere by allowing children to practice individually before speaking in front of the group
4	February 10, 2026	Google Read Along	Children took turns reading aloud; the app provided immediate pronunciation feedback; 16 children attempted re-reading after receiving feedback	Teacher monitored individual progress and recorded children who showed improved fluency compared to the previous session
5	February 17, 2026	Scratch Jr.	Children attempted to arrange character movement sequences; 11 children successfully completed a 3-step instruction pattern independently	Teacher demonstrated each step on the classroom screen before children practiced individually on tablets
6	February 24, 2026	Quizlet + Canva for Education	Combined session; children matched visual cards to quiz answers; engagement noticeably higher than Session 1; spontaneous peer discussion observed	Teacher integrated both tools in a single lesson plan; designed visual prompts to support quiz comprehension
7	March 3, 2026	Speeko Kids + Scratch Jr.	Children verbally described the Scratch Jr. sequences they had built; 15 children participated voluntarily in storytelling activity	Teacher connected both tools by asking children to narrate their Scratch Jr. creations using Speeko Kids speaking prompts
8	March 17, 2026	All five AI tools (integrated session)	All 20 children participated actively; children demonstrated confident verbal expression, sequential reasoning, and cooperative interaction with peers	Teacher conducted a closing reflection session, asking children to describe what they learned; responses documented in children's development records

Source: Participatory observation field notes, Al Azhar Kindergarten Pamekasan, January–March 2026

### 3.1 Teacher Experience in Integrating Artificial Intelligence-Based Learning Models

Teachers at Al Azhar Pamekasan Kindergarten undergo a pedagogical adaptation process that takes place gradually in integrating artificial intelligence tools into daily learning activities. This adaptation occurs because the teachers do not have a technical background in the field of artificial intelligence, so the introduction to the tools is done independently through exploration and guidance from the school principal. Observational results show that all teachers utilize artificial intelligence-based applications such as Canva for Education, Quizlet, and Speeko Kids to create engaging and interactive teaching materials. As presented in Table 1, these five AI devices are used with varying frequencies, ranging from daily use to once per week, reflecting a structures and intentional, integration of technology into the learning process. The most frequently used tool canva for eduaction, was observed to be actively operatde by teachers during morning preparation session, where they designed visual story cards and thematic learning boards tailopred to the daily topic. Meanwhile, quizlet sessions were

observed to take place in small group setting, where children responded to picture-based question displayed on a classroom screen, with teachers guiding the activity interactively. In-depth interviews with three classroom teachers revealed that artificial intelligence tools facilitate the preparation of daily lesson plans because there are templates that can be customized to the children's needs. One teacher noted that the availability of ready to use visual templates in canva for education significantly reduced preparation time, allowing more focus on observing and responding to children's learning behaviors during class. Another teacher highlighted that speeko kids provided structured speaking prompts that helped children who were initially reluctant to speak voluntarily begin to participate more actively in verbal activities. Notes on children's development documented by teachers periodically show that the intensity of children's engagement in learning increased after artificial intelligence tools were used regularly. Field observations recorded that child displayed higher levels of enthusiasm. Longer attention spans, and more frequent voluntary participation during AI-assisted sessions compared to conventional learning activities. The teachers' experience indicates that AI-based pedagogical adaptation occurs naturally at Al Azhar Pamekasan Kindergarten.

These experiences were further confirmed through in-depth interviews. One teacher explicitly stated: "At first I didn't know how to use these applications at all. But after trying them little by little on my own, I realized that children become much more enthusiastic when the learning materials are visually appealing and interactive. It saves my preparation time, so I can focus more on observing and responding to the children during class." (Teacher A). Another teacher shared a similar sentiment regarding Speeko Kids: "Before we used Speeko Kids, some children were very reluctant to speak, even just to answer simple questions. After a few sessions, they started raising their hands on their own. I was quite surprised by how quickly they changed." (Teacher B). The school principal also confirmed the gradual but meaningful shift in teachers' confidence: "In the beginning, the teachers were hesitant. But once they saw how the children responded positively to the AI tools, they became more motivated to explore and integrate these tools more creatively into their lesson plans." (School Principal).

Table 2. Artificial Intelligence Devices Used by Teachers in Learning

No.	AI Device Name	Main Function	Frequency of Use
1.	Canva for Education	Preparation of interactive visual media	Every day
2.	Quizlet	Child response-based adaptive quiz	3 times per week
3.	Speeko Kids	Stimulation of speaking ability	2x times per week
4.	Google Read Along	Interactive reading practice	2x times per week
5.	Scratch Jr.	Introduction to basic programming logic	1x times per week

Table 2 shows the five artificial intelligence tools used by teachers in learning activities at Al Azhar Kindergarten in Pamekasan, along with their primary functions and frequency of use. The selection of these tools is tailored to learning objectives and the developmental stages of young children. Canva for Education is used daily as it serves as the primary tool for creating visually engaging and child-friendly teaching materials. This daily use indicates that teachers have integrated the tool into their lesson preparation. Additionally, Quizlet is used three times a week to assess children's understanding through interactive quizzes that adjust difficulty levels based on their responses, thereby supporting the development of logical thinking skills. Speeko Kids and Google Read Along are each used twice a week. Speeko Kids focuses on developing children's speaking skills, while Google Read Along is used to support interactive reading practice. Both tools have been shown to make a tangible contribution to improving children's verbal communication skills. Scratch Jr. is used once a week as a tool to introduce children to basic programming logic, aiming to build systematic thinking skills from an early age in accordance with the future-oriented principles within the framework of Education for Sustainable Development. Overall, the usage patterns of these five AI tools reflect that teachers have designed learning in a structured and targeted manner, taking into account the balance between children's cognitive development and communication skills within the context of sustainable education

### 3.2 Children's Cognitive Development through Artificial Intelligence-Based Learning

The cognitive development of children at Al Azhar Kindergarten Pamekasan shows improvement in three aspects: logical reasoning, the ability to solve simple problems, and memory. This improvement occurs because of artificial intelligence tools that can adjust the

difficulty level of the material according to each child's ability, so that every child receives stimuli according to their own developmental level. Participatory observation results over eight weeks show that children who routinely use Scratch Jr. are able to follow instructions in sequence correctly, such as moving characters according to predetermined patterns. Interviews with parents reveal that children practice again the ways of playing learned from these artificial intelligence tools when at home. Meanwhile, video recordings of learning activities show that when children make mistakes while playing Quizlet, they immediately try again without waiting for instructions from the teacher. These findings indicate that artificial intelligence-based learning provides structured cognitive stimulation that is appropriate for the developmental stage of young children.

These behavioral observations were further supported by accounts from parents during interviews. One parent noted: "At home, my child often asks to play the same game he does at school. He even tries to teach his younger sibling the sequences he learned from Scratch Jr. I didn't expect him to remember all the steps." (Parent of Child 7). A classroom teacher described a specific incident that captured children's developing logical reasoning: "One day, a child who used to give up easily when making mistakes in Quizlet started saying 'let me try again' on his own. That was a big moment for me, because it showed that he was not only learning the content, but also learning how to think through problems." (Teacher C).

Table 3. Indicators of Children's Cognitive Development Based on Teacher Observations and Documentation

No.	Cognitive Indicator	Initial Condition (January 2026)	Final Condition (March 2026)
1.	Ability to sequence simple steps	12 out of 20 children	18 out of 20 children
2.	Ability to identify patterns	10 out of 20 children	17 out of 20 children
3.	Ability to solve simple problems	9 out of 20 children	16 out of 20 children
4.	Ability to remember instructions	8 out of 20 children	15 out of 20 children

Source: Notes on child development documented by the teacher at Al Azhar Pamekasan Kindergarten, 2026

Table 3 presents the cognitive development of children based on observations and documentation by teachers during AI-based learning implementation, which was carried out in two measurement stages, namely in January 2026 as the initial condition and in March 2026 as the final condition. Overall, the four observed cognitive indicators showed significant improvement during this period. For the indicator of the ability to sequence simple steps, there was an increase from 12 children to 18 children, equivalent to a 30 percent rise. This improvement indicates that AI-based learning is able to help children understand the logical sequence of a process better. The indicator of pattern recognition ability increased from 10 children to 17 children. This shows that the use of AI tools such as Quizlet and Scratch Jr. is effective in stimulating children's ability to recognize relationships between concepts. Meanwhile, the ability to solve simple problems increased from 9 children to 16 children, reflecting the gradual development of children's critical thinking skills through technology-based learning experiences. As for the indicator of the ability to remember instructions, it showed an increase from 8 children to 15 children. Although the initial condition was the lowest among the four indicators, the increase that occurred was quite significant, namely 7 children or equivalent to 35 percent. The pattern of improvement in all these indicators consistently shows that the AI-based learning model implemented at Al Azhar Pamekasan Kindergarten has a positive impact on the cognitive development of early childhood, particularly in the aspects of logical reasoning and systematic thinking skills relevant to the goals of sustainable education.

### 3.3 Enhancing Children's Communication Skills through Interaction with Artificial Intelligence Devices

The communication skills of children at Al Azhar Pamekasan Kindergarten show development in three aspects, namely verbal expression, vocabulary mastery, and the courage to speak in front of peers. This development is inseparable from the role of artificial intelligence devices such as Speeko Kids and Google Read Along, which consistently provide direct feedback on the pronunciation and fluency of children's speech. Feedback provided repeatedly becomes one of the factors that encourage children to continue practicing without fear of making mistakes. Participatory observation results show that children are more enthusiastic about speaking after receiving voice responses from the devices used. This condition occurs because

of these devices, which provide opportunities for children to express themselves verbally. This aligns with the results of in-depth interviews with classroom teachers, which revealed that children who were previously passive in storytelling activities began to be brave in expressing their experiences sequentially after regularly interacting with voice-based devices. These changes were also documented in the children's development records, where the average vocabulary of children increased from 47 words to 83 words over an 8-week period. These findings indicate that children's interaction with voice-based artificial intelligence devices contributes significantly to the development of communication skills in early childhood.

This development was vividly described by one classroom teacher during the interview: "There is one child who used to just sit quietly during storytelling time. He would not say a single word even when asked directly. But after several weeks of using Speeko Kids, he started telling his own story in front of the class not perfectly, but he spoke. That was something I had not seen before." (Teacher A). A parent also observed noticeable changes in their child's verbal behavior at home: "My daughter now talks a lot more than before. She uses words I did not even teach her at home. When I asked where she learned them, she said 'from the reading game at school.' I think whatever they are doing at school is working." (Parent of Child 3).

Table 4. Development of Children's Communication Skills Based on Teacher's Notes

No.	Communication Indicator	Initial Condition (January 2026)	Final Condition (March 2026)
1.	Courage to speak in front of friends	11 out of 20 children	18 out of 20 children
2.	Fluency in expressing ideas	10 out of 20 children	17 out of 20 children
3.	Average active vocabulary (words)	47 words	83 words
4.	Ability to tell stories coherently	8 out of 20 children	15 out of 20 children

Source: Notes on child development documented by the AI Azhar Pamekasan kindergarten teacher, 2026

Table 4 presents the development of children's communication skills based on teacher records during the implementation of AI-based learning, measured at two points in time, namely the initial condition in January 2026 and the final condition in March 2026. All four observed communication indicators showed significant improvement over the two-month period. For the indicator of courage to speak in front of friends, there was an increase from 11 children to 18 children. This increase indicates that the use of AI devices such as Speeko Kids successfully created a learning atmosphere that encouraged children to be more confident in expressing themselves verbally in front of others. The indicator of fluency in expressing ideas increased from 10 children to 17 children. This indicates that children's interaction with AI-based devices consistently trains their ability to organize and convey ideas in a more structured and directed manner. The most notable increase was seen in the indicator of children's average active vocabulary, which rose from 47 words to 83 words. This surge of 36 words reflects that exposure to AI-based content, particularly through Google Read Along and Speeko Kids, effectively enriches children's vocabulary in a relatively short period of time. The ability to tell stories sequentially increased from 8 children to 15 children. Although this indicator had the lowest initial achievement, the increase is considered significant and reflects the development of children's ability to build a logical and coherent narrative. Overall, the data in Table 3 reinforces the research findings that the AI-based learning model implemented at TK AI Azhar Pamekasan provides a tangible contribution to the development of verbal communication skills in early childhood, which aligns with the principles of inclusivity and future orientation within the framework of Education for Sustainable Development.

### 3.4 The Relevance of Artificial Intelligence-Based Learning Models with the Principles of Education for Sustainable Development

The artificial intelligence-based learning model implemented at AI Azhar Pamekasan Kindergarten shows alignment with the three main principles of Education for Sustainable Development (ESD), namely inclusivity, future orientation, and competency-based. This alignment is identified because each learning component designed by the teacher refers to the individual needs of the child, rather than normative uniform achievement. Participatory observation shows that the artificial intelligence tools used are able to automatically adjust the difficulty level of the material based on the child's responses, so that each child learns according to their own capacity. A desk review of the daily lesson plan implementation shows that teachers consistently formulate learning objectives oriented towards life skills, not merely memorization abilities. Interviews with the school principal revealed that the implementation of artificial

intelligence-based learning models has become part of the school's vision to prepare children to face future challenges. These findings indicate that the artificial intelligence-based learning model at Al Azhar Pamekasan Kindergarten is aligned with the ESD framework established by UNESCO (2020) as a strategy to achieve the fourth Sustainable Development Goal.

The principal elaborated on this vision during the interview: "We believe that preparing children for the future does not only mean teaching them academic content. It means helping them become comfortable with technology, confident in expressing themselves, and capable of solving problems creatively. That is what we are trying to build through this AI-based learning approach." (School Principal). One teacher also reflected on how the learning model resonated with inclusive principles: "What I appreciate most about using these tools is that every child can learn at their own pace. I do not have to wait for the slower children or hold back the faster ones. The applications adjust on their own, and that makes my job easier and fairer for all the children." (Teacher B).

Table 5. Suitability of AI-Based Learning Models with ESD Principles

No.	ESD Principles	Implementation at Al Azhar Kindergarten	Evidence Found
1.	Inclusivity	Adaptive material according to each child's needs	Observation & teaching module
2.	Future-oriented	Development of digital life skills	Interview with the principal
3.	Competency-based	Assessment of the process, not memorization	Child development notes
4.	Participatory	Children as active subjects of learning	Activity video recordings

Source: Field data of Al Azhar Pamekasan Kindergarten, January-March 2026

Table 5 presents the suitability of the artificial intelligence-based learning model implemented at Al Azhar Pamekasan Kindergarten with the four main principles of Education for Sustainable Development (ESD). The data were obtained from various sources of evidence, including observations, teaching modules, interviews, children's development records, and video recordings of learning activities. The first principle, inclusivity, is realized through the adaptation of learning materials to the needs of each child. The AI tools used allow teachers to modify the level of difficulty and type of content according to the individual child's abilities, so that each child can access learning equally. This is evidenced by direct observation results and the review of teaching modules, which show content differentiation in each learning session. The second principle, which is future orientation, is implemented through the development of digital life skills from an early age. Based on interviews with the school principal, introducing AI devices to children is viewed as a long-term investment in preparing a generation that is adaptive and technologically literate, in line with the demands of the 21st century. The third principle, which is competency-based, is reflected in the assessment approach that emphasizes the child's learning process, not just memorization skills. The child's development notes show that teachers assess the child's progress based on their ability to think, communicate, and solve problems in real everyday activities. The fourth principle, which is participatory, is reflected in the position of children as active subjects in the learning process. Video recordings of learning activities show that children are directly involved in each AI-based session, ranging from responding to interactive quizzes, practicing speaking, to exploring simple programming logic through Scratch Jr. Overall, Table 5 confirms that the AI-based learning model implemented at TK Al Azhar Pamekasan is not only technologically relevant but also conceptually aligned with the principles of ESD, making it a suitable model for sustainable learning that focuses on holistic child development.

#### 4. Discussion

This research proves that the learning model based on artificial intelligence at Al Azhar Pamekasan Kindergarten is able to optimize the cognitive development and communication skills of early childhood within the framework of Education for Sustainable Development (ESD). This evidence is obtained because observation data, in-depth interviews, and desk reviews consistently show improvement in all indicators observed during the period from January to March 2026. Children who previously demonstrated limited ability to solve simple problems developed to be able to solve challenges independently by the end of the observation. Children's vocabulary increased, children became brave to speak in front of peers, increasing from rarely to almost seen in every learning session. These findings are in line with Su & Yang[1] found

that the integration of artificial intelligence-based technology in early childhood education increases children's learning engagement. This study shows that artificial intelligence-based learning models can be applied at the early childhood education level.

The improvement of children's cognitive development at TK AI Azhar Pamekasan occurs because artificial intelligence tools provide learning stimulation that is adaptive and responsive to the individual needs of each child. This adaptability mechanism works through algorithms that automatically adjust the difficulty level, so that children do not experience boredom due to material being too easy or frustration due to material exceeding their capacity. Wang, F., Du, Z. and Wang [19] found that artificial intelligence-based learning models stimulate children's cognitive development more effectively compared to conventional methods because the system's responses are personalized. Farah et al.[20] adding that a learning environment rich in stimulation has a direct impact on the optimal cognitive development of children. Children who routinely use Scratch Jr. in this study are able to complete layered instructions independently, which is a clear indicator of the development of logical reasoning in early childhood. These findings broaden the argument. Dong et al [21] explaining that innovative technology-based learning models optimize children's cognitive capacity in a structured and sustainable manner.

Children's communication skills at TK AI Azhar Pamekasan develop because voice-based tools such as Speeko Kids and Google Read Along function as conversational partners that provide immediate feedback without social pressure. This pressure-free condition is important for young children because the fear of speaking incorrectly in front of adults or peers often becomes a major barrier to the development of children's verbal communication. Ramsook et al [22] showing that proper communication stimulation at an early age affects children's academic achievement in subsequent levels. Farzana et al [23] shows that a structured technological approach has a positive impact on child development, including aspects of communication. Children who were previously passive and less confident in speaking in front of the class gradually demonstrate the courage to express ideas coherently. This change emerges along with the intensity of their interactions with voice-based artificial intelligence devices, which occur routinely and consistently. These changes in communication behavior indicate that artificial intelligence-based interactions accelerate the development of communication skills observed qualitatively.

The findings of this study are in line with a number of previous studies, but also show a novelty that has not been specifically discussed in the previous literature. This novelty lies in the simultaneous integration of artificial intelligence, early childhood development, and the ESD framework in a single phenomenological study centered on the real experiences of teachers and children. Arabiat et al[24] only examines child development through a conventional approach without incorporating the technology dimension at all, so the findings of this study fill that gap in the literature. Khosibah et al [25] noting that the adoption of artificial intelligence in education has become a global trend, however studies at the early childhood education level in Indonesia are still very limited. Emi et al [26] demonstrates that the right technological stimulation at an early age has a positive impact on children's cognitive and communication development simultaneously, which aligns with the pattern of findings at AI Azhar Pamekasan Kindergarten. This study strengthens and expands the empirical foundation built by those studies in the context of early childhood education in Indonesia.

Artificial intelligence-based learning models implemented at TK AI Azhar Pamekasan are in line with the three core principles of ESD, namely inclusivity, future orientation, and competency-based learning. This alignment is realized because every learning component is designed to respond to the individual needs of children, equip them with digital life skills, and encourage them to be active subjects in the learning process. Nayak[27] shows that ESD promotes learning approaches that equip children with 21st-century competencies, and artificial intelligence-based learning models meet these expectations in practice. Bonilla-Jurado, D., Zumba, E., Lucio-Quintana, A., Yerbabuena-Torres, C., Ramírez-Casco, A., & Guevara [28] shows that the integration of technology in ESD significantly improves the quality of learning. Crisostomo & Reinertsen[29] menunjukkan bahwa transformasi pendidikan anak usia dini melalui teknologi sejalan dengan arah pembangunan berkelanjutan, dan temuan di TK AI Azhar Pamekasan mendukung pandangan tersebut. Penelitian ini menunjukkan bahwa ESD tidak hanya bersifat konseptual, tetapi dapat diwujudkan melalui model pembelajaran berbasis kecerdasan buatan pada jenjang pendidikan anak usia dini.

## 5. Conclusion

This research proves that the artificial intelligence-based learning model at TK AI Azhar Pamekasan successfully optimizes cognitive development and communication skills in early childhood. The application of adaptive AI devices provides personalized learning stimulation that matches the individual needs and capacities of each child, making the learning process more meaningful. Children who were previously passive in storytelling activities gradually demonstrated courage in expressing ideas coherently after consistent interaction with voice-based devices, while those who regularly used Scratch Jr. showed measurable improvements in logical reasoning and independent task completion. Teachers also underwent a gradual yet significant pedagogical adaptation process, evolving from unfamiliarity with AI tools to independently designing interactive and inclusive learning experiences. These findings confirm that an AI-based learning model is not only technologically relevant but also conceptually aligned with the principles of inclusivity, future orientation, and participatory learning within the Education for Sustainable Development framework.

This study offers a new conceptual contribution by simultaneously integrating artificial intelligence, child development, and the ESD framework within a single phenomenological study, addressing a gap that previous research has not yet explored. However, this study acknowledges its limitations, particularly in terms of its single-school scope, which restricts the generalizability of findings across diverse early childhood education settings in Indonesia. Further research is recommended to expand the scope of study locations across regions with varied social characteristics and infrastructure, employing a mixed methods approach that combines qualitative phenomenology with quantitative experimentation, in order to produce a more holistic and nationally applicable AI-based learning model.

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