

Teacher-Principal Collaborative Inquiry in AI-Assisted Early Science Learning at PAUD Sekar Nagari

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Abstract

Artificial intelligence (AI) has begun to reshape teachers' professional work, including lesson planning, media design, assessment preparation, and collaborative reflection. However, the integration of AI in early childhood science learning remains pedagogically sensitive because young children require concrete, play-based, sensory, and teacher-mediated inquiry experiences rather than technology-driven instruction. This study examined how teacher-principal collaborative inquiry supported the contextual use of simple AI tools in early science learning at PAUD Sekar Nagari, Universitas Negeri Semarang. Using a qualitative case study design, data were collected from seven participants consisting of one principal, one PAUD coordinator, and five classroom teachers through open-ended online interviews, participant observation, and document analysis. The data were analyzed thematically through data condensation, data display, and conclusion drawing, with trustworthiness strengthened through triangulation, member checking, audit trails, and thick description. The findings reveal five interrelated themes: teachers' cautious but positive initial perceptions of AI, transformational and digital leadership as an enabling condition, collaborative inquiry as AI-mediated professional learning, perceived improvement in teacher creativity and administrative efficiency, and continuing pedagogical-ethical boundaries in AI-assisted early science learning. Simple AI tools supported teachers in transforming science ideas into visual, concrete, and developmentally appropriate learning media, while collaborative inquiry helped them verify, adapt, and contextualize AI outputs. The principal's leadership was decisive in creating psychological safety, facilitating infrastructure, and sustaining a professional learning community. The study concludes that AI can strengthen early science learning when positioned as a teacher-support tool rather than a substitute for hands-on inquiry, direct child observation, and teacher-child interaction.

Keywords: AI-assisted Learning; Collaborative Inquiry; Early Childhood Education; Early Science Learning; Principal Leadership; Teacher Professional Learning

INTRODUCTION

Science learning in early childhood education is not intended to introduce children to complex scientific theories but to cultivate curiosity, observation, questioning, classification, prediction, explanation, and the habit of making sense of everyday phenomena. Early science experiences are important because young children naturally observe, compare, manipulate, and reason about the physical and natural world around them (Eshach & Fried, 2005; French, 2004). In developmentally appropriate science learning, children are invited to touch, smell, compare, test, talk, and represent what they notice through play-based and inquiry-oriented activities. Therefore, early science learning should prioritize process over product and should support holistic development, including cognitive, language, social-emotional, motor, and dispositional dimensions (National Research Council, 2012; Rahayu et al., 2022; Trundle & Sackes, 2015).

In the PAUD context, science learning is especially dependent on the teacher's ability to transform abstract concepts into concrete and meaningful experiences. Teachers need to prepare safe materials, visual media, exploratory questions, simple experiments, and learning

environments that are aligned with children's developmental characteristics. However, many PAUD teachers face practical constraints in designing high-quality science media. These constraints include limited time, limited technological skills, limited infrastructure, heavy administrative workloads, and difficulty converting scientific concepts into concrete learning representations for children aged 3-6 years (Barus & Muzakki, 2024; Ismail, 2010; Mailina & Ali, 2024; Wildanah et al., 2025). As a result, early science learning can remain verbal, routine, and less inquiry-based, even when teachers recognize the importance of exploratory learning.

The rapid growth of artificial intelligence (AI), including generative AI and simple AI-assisted design tools, has opened new possibilities for supporting teacher work. In education, AI can assist teachers in generating ideas, designing materials, organizing lesson plans, developing assessment descriptions, creating visual stories, and personalizing learning resources (Kasneji et al., 2023; Msambwa et al., 2025; UNESCO, 2023; Zawacki-Richter et al., 2019). Recent scholarship suggests that AI can help teachers reduce repetitive administrative burdens and allocate more attention to relational, motivational, and pedagogical aspects of teaching (Ghamrawi et al., 2024; Nurhayati et al., 2024; Xie, 2023). In early childhood education, AI has also been discussed as a resource for introducing young learners to emerging digital realities, provided that its use remains developmentally appropriate and ethically supervised (Riana et al., 2025; Su et al., 2023; Yang, 2022).

Nevertheless, AI integration in early childhood classrooms cannot be treated in the same way as AI integration in higher education or secondary schooling. Young children learn science primarily through direct sensory engagement, social interaction, guided play, and hands-on exploration. Therefore, AI should not replace real-world experience, teacher-child dialogue, or inquiry with physical objects. Instead, AI should function as a teacher-support tool that helps educators design better prompts, visual media, learning stories, simple experiments, and reflective documentation (UNESCO, 2024; Yang, 2022). This distinction is essential because AI outputs may contain inaccuracies, biased visual representations, oversimplified explanations, or language that is developmentally inappropriate for young children (Ghamrawi et al., 2024; Kasneji et al., 2023; UNESCO, 2023). The teacher remains the scientific and pedagogical filter who verifies AI-generated content before it reaches children.

From a teacher knowledge perspective, AI-assisted early science learning requires the integration of technological, pedagogical, and content knowledge. The TPACK framework emphasizes that meaningful technology integration occurs when teachers understand not only how to use a tool but also how the tool supports specific pedagogical purposes and subject matter understanding (Mishra & Koehler, 2006; Voogt et al., 2013). For PAUD teachers, this means that AI should be connected to inquiry-based science activities such as observing plants, classifying living and non-living objects, exploring magnets, investigating water, or comparing natural materials. The inquiry cycle itself requires orientation, questioning, investigation, interpretation, conclusion, and reflection (Pedaste et al., 2015). Thus, AI integration becomes meaningful only when it strengthens the inquiry process rather than merely producing attractive digital artifacts.

Collaborative inquiry offers an important mechanism for ensuring that AI use remains pedagogically grounded. Collaborative inquiry positions teachers as reflective practitioners who identify classroom problems, collect evidence, examine practice, test strategies, and reflect collectively on improvement (Dana & Yendol-Hoppey, 2020; Donohoo, 2024; Mockler, 2010). In professional learning communities, teachers do not simply receive training from outside experts; they learn through shared problem solving, peer feedback, collective interpretation of evidence, and sustained reflection (Stoll et al., 2006; Timperley & Alton-Lee, 2008). Previous studies have shown that collaborative and inquiry-based approaches can strengthen analytical thinking, reasoning, engagement, and pedagogical improvement (Juniati & Widiana, 2017; Yu et al., 2024). In the context of AI-assisted learning, collaborative inquiry is particularly valuable because teachers can jointly evaluate AI outputs, discuss ethical concerns, adapt media to children's needs, and prevent uncritical technological dependence.

The role of the principal is equally central. Educational leadership research consistently

indicates that school leadership shapes teacher motivation, professional culture, resource allocation, and the conditions under which innovation can be sustained (Hallinger, [2018](#); Leithwood et al., [2020](#); Nellitawati & Yunistisa, [2022](#)). Transformational leadership is relevant in this context because it involves inspirational motivation, intellectual stimulation, individualized consideration, and the development of shared vision (Bass & Riggio, [2006](#)). More recent research on digital leadership further shows that principals can influence teachers' AI competence by providing infrastructure, facilitating professional development, building learning communities, and developing a supportive culture for experimentation (Ghamrawi et al., [2024](#); Zeng et al., [2025](#)). Teacher performance and motivation are also shaped by recognition, responsibility, work culture, and organizational support (Azizah & Tiadilona, [2023](#); Mailina & Ali, [2024](#); Sanusi et al., [2024](#)).

Despite the growing interest in AI in education, several gaps remain. First, much existing AI-in-education research focuses on higher education, secondary education, or general digital learning, while AI-assisted professional learning in PAUD science remains underexplored (Msambwa et al., [2025](#); Su et al., [2023](#); Zawacki-Richter et al., [2019](#)). Second, studies on AI often emphasize technological affordances but give less attention to leadership, teacher collaboration, and the professional inquiry processes that make AI pedagogically responsible (Ghamrawi et al., [2024](#); UNESCO, [2024](#); Zeng et al., [2025](#)). Third, early science learning requires a careful balance between digital support and concrete hands-on inquiry, yet empirical accounts of how PAUD teachers negotiate this balance remain limited (Eshach & Fried, [2005](#); French, [2004](#); Yang, [2022](#)).

This study addresses these gaps by examining teacher-principal collaborative inquiry in AI-assisted early science learning at PAUD Sekar Nagari. The study does not treat AI as a replacement for teachers or children's direct experience. Instead, it explores AI as a support mechanism within a collaborative professional learning ecosystem. Specifically, the study aims to analyze how simple AI tools are implemented through collaborative inquiry, how the principal's leadership supports teacher performance and professional confidence, and how teachers perceive the opportunities and risks of AI-assisted early science learning. The study is expected to contribute conceptually to the literature on AI-supported teacher professional learning and practically to PAUD institutions seeking to integrate AI in developmentally appropriate, ethical, and science-oriented ways.

METHODS

This study employed a qualitative case study design to examine the implementation of teacher-principal collaborative inquiry in AI-assisted early science learning at PAUD Sekar Nagari, Universitas Negeri Semarang. A case study design was selected because the research focused on a bounded system, namely one early childhood education institution in which simple AI tools, collaborative inquiry, and principal leadership interacted within a specific organizational culture (Merriam & Tisdell, [2016](#); Yin, [2018](#)). The qualitative approach allowed the researchers to explore participants' perceptions, experiences, meanings, and contextual dynamics in depth rather than measuring AI adoption only through predetermined indicators.

The participants consisted of seven respondents who were directly involved in the implementation process: one principal, one PAUD coordinator, and five classroom teachers. These participants were selected purposively because they had direct experience with school-based collaborative inquiry, simple AI tools, and early science learning activities. The institutional context was relevant because PAUD Sekar Nagari had begun to encourage teachers to use simple AI tools such as ChatGPT, Google Gemini, Canva AI, and other accessible applications to support lesson planning, visual media development, story generation, song creation, and reflective documentation.

Data were collected through three main techniques. First, open-ended online interviews were administered to obtain participants' perceptions of AI, leadership support, collaborative inquiry processes, perceived impacts, and implementation barriers. Second, participant observation was conducted during teacher learning community activities and selected classroom

science learning practices. Third, document analysis was conducted on lesson plans, teacher reflections, AI-assisted learning media, meeting notes, and documentation of science activities. The combination of these techniques enabled the researchers to compare what participants reported, what was observed, and what was documented in school artifacts.

Data were analyzed thematically following the interactive logic of data condensation, data display, and conclusion drawing/verification (Miles et al., 2014). The researchers first read all interview responses, observation notes, and documents repeatedly to become familiar with the data. Initial codes were then generated to capture meaningful statements related to AI perception, principal leadership, collaborative inquiry, teacher performance, children's responses, supporting factors, and challenges. These codes were clustered into broader themes, refined through iterative comparison, and interpreted in relation to theories of early science learning, collaborative inquiry, professional learning communities, digital leadership, and TPACK.

Trustworthiness was strengthened through triangulation of data sources and techniques, member checking, peer discussion, and audit trail documentation (Lincoln & Guba, 1985; Patton, 2015). Triangulation was conducted by comparing interview data with classroom observations and school documents. Member checking was conducted by confirming key interpretations with participants. Ethical considerations were addressed by explaining the research purpose, requesting participant consent, protecting participant identity through codes, and ensuring that all data were used only for academic purposes.

Table 1. Participant Profile

Code	Role	Primary Involvement	Data Source
KS-01	Principal	Digital leadership, infrastructure support, policy direction	Interview, observation, documents
KO-01	PAUD Coordinator	Teacher community facilitation, pedagogical mentoring	Interview, observation, documents
GR-01	Classroom teacher	AI-assisted science media design and classroom use	Interview, observation, documents
GR-02	Classroom teacher	Collaborative reflection and AI-assisted planning	Interview, observation, documents
GR-03	Classroom teacher	Learning media development and student engagement	Interview, observation, documents
GR-04	Classroom teacher	Use of AI for stories, visual media, and activities	Interview, observation, documents
GR-05	Classroom teacher	AI-supported lesson planning and assessment notes	Interview, observation, documents

Result

The findings were derived from open-ended online interview responses, participant observation, and documentation involving seven respondents at PAUD Sekar Nagari UNNES: one principal, one PAUD coordinator, and five classroom teachers. The analysis shows that the implementation of AI-assisted collaborative inquiry was not a single technological intervention, but a school-level professional learning process shaped by leadership support, peer collaboration, teacher motivation, and practical classroom needs.

Initial perceptions of AI among teachers

Before the collaborative inquiry program was strengthened, participants' perceptions of AI varied. Five respondents expressed positive attitudes while still showing hesitation, mainly because they were unsure whether simple AI tools such as ChatGPT, Google Gemini, and Canva Magic Studio were appropriate for early childhood learning. Two teachers initially reported skepticism and low confidence because of limited digital competence. One teacher stated, "At first, I was afraid of making mistakes and worried that AI would not be suitable for PAUD children because I had never used it before."

After being involved in the collaborative inquiry process, all seven respondents expressed

positive perceptions of AI. However, their positivity was not uncritical. The principal and PAUD coordinator viewed AI as a strategic opportunity to make learning more adaptive, while several teachers positioned AI as a supportive tool that still required teacher judgment, verification, and pedagogical adaptation. This pattern indicates that the school had a constructive readiness base for implementing AI-assisted collaborative inquiry, although teachers still needed mentoring, examples, and safe opportunities for experimentation. This finding is consistent with Riana et al. (2025), who reported that PAUD teachers generally perceived AI positively while still facing challenges related to infrastructure, technical skills, and readiness.

Table 2. Summary of Respondents' Initial Perceptions of AI

Code	Position	Initial Perception
KS-01	Principal	Positive: AI makes learning more varied and attractive.
KO-01	Coordinator	Positive-transformative: AI is viewed as an opportunity for adaptive educational transformation.
GR-01	Classroom teacher	Cautious but open: initially curious and uncertain, but later felt supported by AI.
GR-02	Classroom teacher	Critical-constructive: AI is accepted as a teaching aid, not as a replacement for teachers.
GR-03	Classroom teacher	Positive-transformative: AI helps make learning more interesting and easier to prepare.
GR-04	Teacher	Positive: feels assisted by AI use.
GR-05	Teacher	Positive: feels assisted by AI use.

Principal and coordinator leadership in supporting AI adoption

Data from all respondents consistently indicate that the leadership of the principal and PAUD coordinator was the most frequently mentioned determinant of AI adoption at PAUD Sekar Nagari UNNES. Leadership support appeared through four interrelated dimensions: facilitative support, motivational support, collaborative support, and vision-building. These dimensions did not operate separately; rather, they created a psychologically safe and practically enabling environment for teachers to test AI tools, revise their outputs, and integrate them into early science learning.

In the motivational dimension, the principal and coordinator gave teachers freedom to create and permission to learn through trial and error. Four of the five classroom teachers described "freedom to create" as the most meaningful form of support. One respondent explained that the coordinator cultivated a healthy digital culture in which teachers were allowed to try, make mistakes, and learn again without fear of negative judgment. This indicates that leadership worked not only through formal instruction, but also through psychological safety and recognition of teacher agency.

In the facilitative dimension, the school provided basic technological support, including laptop access, classroom internet, and simple AI platforms. Teachers reported that the availability of devices and internet access made it easier for them to try various AI applications for teaching. They also received basic internal training and were encouraged to explore AI-based media design. This supports Zeng et al. (2025), who emphasize that principals' digital leadership functions as a bridge and catalyst for identifying barriers, developing support mechanisms, and stimulating teachers' motivation to integrate AI.

In the collaborative dimension, the principal and coordinator encouraged professional learning through teacher learning communities, AI workshops, prompt-engineering practice, Canva AI exploration, and informal sharing sessions. These leadership practices reflect the dimensions of transformational leadership proposed by Bass and Riggio (2006), particularly inspirational motivation, intellectual stimulation, and individualized consideration. In this study, transformational leadership was translated into concrete PAUD practices: providing facilities, encouraging experimentation, organizing collaboration, and framing AI as part of teachers' professional growth.

Table 3. Dimensions of Leadership Support

Leadership Dimension	Concrete Form
Facilitative	Provision of laptops, tablets, internet access, and learning devices.
Motivational	Freedom to create, trial-and-error culture, and psychological safety.
Collaborative	AI workshops, prompt-engineering training, and teacher learning communities.
Vision and inspiration	Encouragement to adopt technology as part of professional development.

AI-assisted collaborative inquiry among teachers

The collaborative inquiry process at PAUD Sekar Nagari UNNES developed as an organic form of professional learning. It took place through a teacher learning community locally referred to as a regular teachers' meeting, as well as through flexible peer discussions. The process enabled teachers to use AI not merely for producing media, but also for solving pedagogical and administrative problems collaboratively.

The inquiry process involved six recurring stages. First, teachers identified classroom or administrative problems, such as difficulty designing science media, lesson plans, play ideas, assessment descriptions, or child-development reports. Second, teachers collected and organized relevant data, while AI helped summarize long notes and group information. Third, teachers engaged in collaborative analysis to interpret the problem, while AI was used to identify patterns and possible causes. Fourth, teachers formulated solutions, and AI helped generate alternative action designs. Fifth, teachers implemented the agreed solutions in classroom practice or administrative work. Sixth, teachers conducted reflection and evaluation, with AI supporting report writing and follow-up suggestions.

Collaborative inquiry occurred through two patterns. Formal meetings were held twice in one semester with structured agendas, such as sharing AI-generated media and conducting joint reflection. Informal meetings were more dominant and flexible, occurring through WhatsApp groups, discussions in the teacher room, and exchanges after classroom activities. This flexible pattern made teachers more comfortable sharing problems, asking for help, and revising AI-generated outputs without feeling judged.

The content of collaborative inquiry covered both technical and pedagogical issues. Technically, teachers learned how to write effective prompts so that AI could produce more appropriate teaching materials. Pedagogically, teachers discussed how AI-generated ideas should be adapted to PAUD learning principles, children's developmental stages, curriculum themes, and the need for direct exploration. ChatGPT and Google Gemini were used to generate lesson ideas, reflections, and assessment narratives; Canva was used to design picture cards, storybooks, and visual materials; and Suno was used to create theme-based children's songs. Importantly, teachers emphasized that AI remained an assistant for problem solving and administration, while the teacher's role in guiding children could not be replaced.

Perceived impacts on teacher performance and children's early science engagement

Participants reported positive impacts of AI-assisted collaborative inquiry on teacher performance. Six of the seven respondents stated that AI helped transform early science concepts into more concrete and visual learning media, such as materials for classifying living and non-living things, the water cycle, and simple magnet experiments. Five respondents also reported that AI shortened the time needed to prepare learning media and lesson plans. Teachers described AI as a tool that improved creativity, administrative efficiency, digital competence, and professional confidence.

One respondent explained, "AI helps increase teacher productivity and job satisfaction. AI simplifies administrative tasks such as preparing lesson plans, making learning media, and creating assessments automatically. With AI handling technical tasks, teachers can focus on roles that machines cannot replace: building emotional relationships, motivation, and children's character." Another respondent stated that AI-assisted learning made school activities more varied, attractive, and less monotonous.

The perceived impact on children was also positive. Observation data and teacher reports

showed that children became more enthusiastic, focused, and active in observing and asking questions when teachers used colorful and visually rich AI-assisted media. Teachers reported that the frequency of science activities increased from an average of two activities to seven or eight activities per semester. One teacher stated, "The children are now more excited. They ask more questions and observe more often because the media are more attractive and colorful."

These findings suggest that AI-assisted collaborative inquiry supported early science learning indirectly by strengthening teachers' capacity to design concrete, visual, and engaging learning experiences. However, the results also show that AI was most beneficial when integrated with teacher facilitation and hands-on exploration, rather than used as a substitute for children's direct interaction with real objects and phenomena.

Table 4. Perceived Impacts of AI-Assisted Collaborative Inquiry Based on Respondent Data

Code	Impact on Teacher Performance	Impact on Children
KS-01	Learning became more varied and innovative.	Learning was perceived as less monotonous.
KO-01	Productivity increased and the teacher role shifted more strongly toward facilitation.	Children became more active, independent, and critical in learning.
GR-01	Teaching performance increased and teachers became more creative.	Children were happier and more interested.
GR-02	Performance improved through the use of more appropriate media.	Children became enthusiastic, focused, and active participants.
GR-03	Learning became more innovative.	Children responded positively and found learning enjoyable.
GR-04	Teachers became more creative in developing learning media.	Children were enthusiastic and liked AI-assisted media.
GR-05	Teachers became more creative and felt assisted.	Children became active, focused, and willing to try new things.

Supporting factors and main challenges

The implementation of AI-assisted collaborative inquiry was supported by five major factors. First, leadership support was the most dominant factor and was mentioned by six of the seven respondents. It included device facilitation, training, encouragement, and space for creativity. Second, the teacher learning community and sharing culture were identified by five respondents as a strong internal support system. Third, simple AI tools were technically accessible because they could be used through smartphones without requiring expensive infrastructure. Fourth, teachers' intrinsic motivation to keep learning and follow technological developments encouraged exploration. Fifth, AI was perceived as improving work efficiency by helping teachers prepare lesson plans, media, play ideas, assessment descriptions, reflection notes, and follow-up actions.

Although the implementation was generally positive, three main challenges remained. The first was uneven digital competence among teachers, especially in operating AI tools and writing effective prompts. The second was technical infrastructure, particularly unstable internet connections and unequal access to devices, which sometimes required teachers to use personal equipment. The third was limited time due to administrative workload, which reduced opportunities for deeper inquiry, planning, reflection, and evaluation. In addition to these operational constraints, several teachers expressed pedagogical concern that excessive dependence on AI might weaken children's reasoning, creativity, and critical thinking. Therefore, AI use in PAUD science learning must remain teacher-mediated, developmentally appropriate, and balanced with direct hands-on experiences.

Discussion

The findings of this study indicate that the integration of simple AI tools through teacher-principal collaborative inquiry did not function merely as a technological innovation, but as a professional learning mechanism that reshaped how teachers planned, represented, and

reflected on early science learning. The empirical data show that teachers initially approached AI with caution, uncertainty, and uneven digital confidence, yet gradually moved toward more positive and constructive use when AI was mediated by collegial inquiry and supportive leadership. This pattern suggests that the effectiveness of AI in PAUD science learning depends less on the sophistication of the technology itself and more on the pedagogical judgment, collaborative culture, and leadership conditions that frame its use (Bass & Riggio, [2006](#); Dana & Yendol-Hoppey, [2020](#); Mishra & Koehler, [2006](#); Zeng et al., [2025](#)). The discussion below interprets the findings through five interrelated dimensions: early scientific thinking, technology-enhanced science pedagogy, collaborative inquiry as teacher professional learning, leadership-supported professional ecosystems, and the scientific-pedagogical risks of AI use in early childhood settings.

Developing Early Scientific Thinking through AI-Supported Media

The results show that AI-assisted media helped teachers increase the frequency and quality of science activities, from an average of approximately two activities to seven or eight activities per semester. This improvement is important because early childhood science learning is not primarily concerned with memorizing scientific facts, but with cultivating curiosity, observation, classification, prediction, questioning, and simple explanation. These science process skills are central to developmentally appropriate early science education because young children construct scientific understanding through sensory exploration, concrete manipulation, social interaction, and language-mediated reasoning (Eshach & Fried, [2005](#); French, [2004](#); National Research Council, [2012](#); Trundle & Sackes, [2015](#)).

In this study, AI supported early scientific thinking by helping teachers transform abstract or underdeveloped ideas into visual, concrete, and child-friendly learning media. Examples reported by respondents included media for classifying living and non-living things, explaining the water cycle, designing simple magnet activities, creating illustrated stories, and composing theme-based songs. These materials appeared to increase children's enthusiasm, focus, and willingness to observe and ask questions. In this sense, AI functioned as an instructional amplifier: it strengthened teachers' ability to prepare attractive representations that invited children into inquiry. However, this does not mean that AI itself generated scientific understanding. Rather, the media became meaningful only when teachers used them to initiate hands-on observation, questioning, dialogue, and experimentation. This finding reinforces the view that young children can engage in scientific reasoning when learning environments provide rich, concrete, and socially supported opportunities for exploration (National Research Council, [2012](#); Trundle & Sackes, [2015](#)).

Technology-Enhanced, Not Technology-Replaced, Science Pedagogy

A central implication of the findings is that AI should be positioned as a tool that enhances early science pedagogy, not as a substitute for children's direct encounters with the physical world. The data show that teachers used AI mainly to develop visual media, story prompts, song lyrics, play ideas, assessment descriptions, and administrative documents. These uses are pedagogically valuable because they reduce preparation barriers and help teachers move beyond verbal explanation toward more concrete and visual science learning. From the perspective of Technological Pedagogical Content Knowledge (TPACK), the study illustrates an emerging integration of technological knowledge, pedagogical knowledge, and science content knowledge in PAUD practice (Mishra & Koehler, [2006](#); Voogt et al., [2013](#)).

Nevertheless, early science learning requires direct sensory engagement. Children need to touch leaves, compare textures, observe water movement, test magnets, classify real objects, and communicate what they notice. AI-generated images, stories, and songs can prepare or enrich these experiences, but they cannot replace them. If AI output becomes the primary source of scientific knowledge, children may receive visually attractive but superficial understanding. Therefore, the principle emerging from this study is "technology-enhanced, not technology-

replaced.” AI should support teachers in designing more engaging inquiry activities, while the core of PAUD science learning must remain hands-on experience, teacher-child interaction, peer discussion, and exploration of real phenomena (French, [2004](#); National Research Council, [2012](#); Yang, [2022](#)).

Collaborative Inquiry as a Mechanism of Teacher Professional Learning

The study also demonstrates that collaborative inquiry was not merely a forum for sharing AI-generated products. It developed into a professional learning space where teachers collectively identified classroom problems, experimented with AI prompts, reviewed media quality, discussed children’s responses, adapted learning activities, and reflected on follow-up actions. This process aligns with the concept of teacher inquiry, in which teachers investigate their own practice through systematic reflection, collegial dialogue, and evidence-informed improvement (Dana & Yendol-Hoppey, [2020](#); Donohoo, [2024](#); Timperley & Alton-Lee, [2008](#)).

The collaborative inquiry process at PAUD Sekar Nagari operated through both formal and informal patterns. Formal meetings were held twice per semester with structured agendas, while informal discussions occurred through WhatsApp groups, teacher-room conversations, and spontaneous sharing after classroom activities. This dual structure is important because professional learning in early childhood institutions often occurs through everyday collegial interaction rather than only through formal training. The teachers did not simply ask AI to generate materials individually; they negotiated whether the outputs were safe, developmentally appropriate, visually accurate, and aligned with the theme and learning objectives. In this way, collaborative inquiry functioned as a pedagogical filter and quality-control mechanism that reduced the risk of uncritical AI adoption (Stoll et al., [2006](#); UNESCO, [2023](#)).

The findings further suggest that AI helped teachers with cognitive offloading, particularly in administrative tasks such as lesson planning, assessment descriptions, reflection notes, and report drafting. This enabled teachers to redirect attention toward pedagogical roles that cannot be automated: building emotional relationships, encouraging children’s curiosity, guiding observation, interpreting children’s questions, and sustaining classroom dialogue. Thus, AI-assisted collaborative inquiry contributed to professional agency rather than technological dependency when teachers remained active evaluators and adapters of AI-generated output.

Leadership-Supported Professional Ecosystem

The strongest contextual factor in the findings is the role of the principal and PAUD coordinator. All respondents agreed that leadership support was decisive in enabling AI adoption. The support took the form of internet quota, laptop access, basic internal training, permission to experiment, and encouragement to learn from mistakes. These actions created psychological safety, allowing teachers to move from fear and hesitation toward trial, reflection, and improvement. This finding is consistent with transformational leadership theory, which emphasizes idealized influence, inspirational motivation, intellectual stimulation, and individualized consideration as mechanisms for enabling professional growth (Bass & Riggio, [2006](#)).

The findings also support recent research on digital leadership, which argues that principals can act as bridges and catalysts in educational technology integration by allocating resources, developing a supportive culture, and stimulating teacher motivation (Ghamrawi et al., [2024](#); Zeng et al., [2025](#)). In this case, leadership was not limited to infrastructure provision. It involved building a culture of experimentation, legitimizing teacher learning, and connecting AI use with the broader goal of improving early science learning. The principal’s repeated encouragement—“try first; if it is wrong, we will improve it together”—became a practical expression of psychological safety. Such leadership is particularly important in PAUD contexts, where teacher confidence, collegial trust, and relational support often shape whether innovation is sustained.

This study therefore enriches the literature on AI in education by showing that

responsible AI integration in PAUD requires an ecosystem, not only access to tools. The ecosystem includes leadership vision, teacher motivation, peer collaboration, digital infrastructure, ethical awareness, and sustained professional learning. Without these conditions, AI may remain a technical novelty. With them, AI can become part of a reflective professional culture that strengthens teachers' ability to design more meaningful science learning experiences.

Scientific and Pedagogical Risks of AI Use in PAUD Science Learning

Although the findings show clear perceived benefits, they also reveal several scientific and pedagogical risks that must be addressed carefully. First, AI may generate inaccurate information or misleading scientific explanations. In the context of early childhood science, such inaccuracies are especially problematic because young children are still forming foundational concepts about natural phenomena. Teachers must therefore verify AI-generated content before using it in class. Second, AI-generated visuals may contain bias, stereotypes, unrealistic representations, or oversimplified images of natural objects. If these visuals are not critically reviewed, children may develop distorted perceptions of scientific phenomena such as animal forms, plant structures, colours, textures, or environmental processes (UNESCO, [2023](#); UNESCO, [2024](#)).

Third, AI often produces language that is too abstract, complex, or adult-oriented for children aged three to six. Respondents' concern about children becoming dependent on instant answers reflects a broader pedagogical issue: AI should not shortcut children's reasoning process. Early science learning requires children to wonder, try, fail, compare, ask again, and revise their thinking. If AI is used to deliver immediate answers rather than support inquiry, it may weaken the very habits of mind that science education seeks to cultivate. This concern resonates with broader debates on teacher agency and AI, where educators worry that AI may reduce professional autonomy or shift attention away from human judgment if adopted uncritically (Ghamrawi et al., [2024](#); Zawacki-Richter et al., [2019](#)).

For this reason, the teacher remains the central scientific and pedagogical filter. Teachers must evaluate whether AI-generated materials are scientifically accurate, developmentally appropriate, safe, culturally relevant, and capable of leading children toward direct exploration. AI should be used to support planning, media design, documentation, and reflection, but not to replace teachers' interpretive role or children's engagement with real-world phenomena. The findings therefore support a balanced model of AI-assisted PAUD science learning: AI can accelerate preparation and expand creative possibilities, but responsible use requires teacher verification, collaborative review, and hands-on inquiry as the pedagogical core.

Practical Implications and Limitations

The practical implication of this study is that PAUD institutions wishing to adopt AI should begin with simple, accessible, and low-cost tools that teachers can use through existing devices. However, tool access must be accompanied by professional learning. Training should not focus only on technical operation, but also on prompt design, science content verification, developmental appropriateness, media safety, bias awareness, and strategies for converting AI-generated ideas into hands-on inquiry activities. Schools also need collaborative routines in which teachers can share AI outputs, test their suitability, revise them collectively, and document classroom responses.

For principals and PAUD coordinators, the findings suggest that leadership should combine facilitation, motivation, and collaboration. Providing devices and internet access is important, but equally important is creating a culture in which teachers feel safe to experiment, make mistakes, and improve together. AI integration becomes more sustainable when it is embedded in a learning community rather than imposed as an individual technical requirement.

CONCLUSION

This study concludes that teacher-principal collaborative inquiry can support the responsible implementation of simple AI tools in early childhood science learning. At PAUD Sekar Nagari, AI-assisted collaborative inquiry helped teachers develop more creative visual media, reduce administrative workload, and increase children's engagement in science activities. However, the success of this implementation was not determined by AI alone. It depended on transformational and digital leadership, psychological safety, peer collaboration, teacher motivation, and the careful adaptation of AI outputs to children's developmental needs. AI should therefore be positioned as a teacher-support tool that strengthens planning, media design, documentation, and reflection, while hands-on exploration, teacher-child interaction, and direct sensory experience remain the core of PAUD science learning. The study recommends sustained teacher professional development, school-based AI ethics guidelines, basic infrastructure support, and collaborative inquiry cycles that help teachers verify and contextualize AI outputs before they are used in classrooms.

REFERENCES

- Azizah, A. L., & Tiadilona, W. (2023). Kepemimpinan kepala sekolah dalam meningkatkan kinerja guru: Systematic literature review. *Jurnal Manajemen Mutu Pendidikan*, 11(2), 53-62.
- Barus, Y. K., & Muzakki, F. I. (2024). Pengenalan kecerdasan buatan untuk ide kreatif mengajar bagi guru sekolah dasar. *Jurnal Pengabdian Kepada Masyarakat*.
- Bass, B. M., & Riggio, R. E. (2006). *Transformational leadership* (2nd ed.). Psychology Press. <https://doi.org/10.4324/9781410617095>
- Dana, N. F., & Yendol-Hoppey, D. (2020). *The reflective educator's guide to classroom research: Learning to teach and teaching to learn through practitioner inquiry* (4th ed.). Corwin.
- Donohoo, J. (2024). *Collaborative inquiry for educators: A facilitator's guide to school improvement*. Corwin.
- Eshach, H., & Fried, M. N. (2005). Should science be taught in early childhood? *Journal of Science Education and Technology*, 14(3), 315-336. <https://doi.org/10.1007/s10956-005-7198-9>
- Fajriati, A., Wisroni, W., & Handrianto, C. (2024). Pemanfaatan teknologi artificial intelligence (AI) dalam pembelajaran berbasis peserta didik di era digital. *Jurnal Pendidikan*, 6(2).
- French, L. (2004). Science as the center of a coherent, integrated early childhood curriculum. *Early Childhood Research Quarterly*, 19(1), 138-149. <https://doi.org/10.1016/j.ecresq.2004.01.004>
- Ghamrawi, N., Shal, T., & Ghamrawi, N. A. R. (2024). Exploring the impact of AI on teacher leadership: Regressing or expanding? *Education and Information Technologies*, 29, 8415-8433. <https://doi.org/10.1007/s10639-023-12174-w>
- Hallinger, P. (2018). Bringing context out of the shadows of leadership. *Educational Management Administration & Leadership*, 46(1), 5-24. <https://doi.org/10.1177/1741143216670652>
- Ismail, M. I. (2010). Kinerja dan kompetensi guru dalam pembelajaran. *Lentera Pendidikan: Jurnal Ilmu Tarbiyah dan Keguruan*, 13(1), 44-63. <https://doi.org/10.24252/lp.2010v13n1a4>
- Juniati, N. W., & Widiana, I. W. (2017). Penerapan model pembelajaran inkuiri untuk meningkatkan hasil belajar IPA. *Jurnal Ilmiah Sekolah Dasar*, 1(1), 20-29.
- Kasneci, E., Sessler, K., Kuchemann, S., Bannert, M., Dementieva, D., Fischer, F., Gasser, U., Groh, G., Gunnemann, S., Hullermeier, E., Krusche, S., Kutyniok, G., Michaeli, T., Nerdel, C., Pfeiffer, J., Poquet, O., Sailer, M., Schmidt, A., Seidel, T., Stadler, M., Weller, J., Kuhn, J., & Kasneci, G. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and Individual Differences*, 103, 102274.

<https://doi.org/10.1016/j.lindif.2023.102274>

- Leithwood, K., Harris, A., & Hopkins, D. (2020). Seven strong claims about successful school leadership revisited. *School Leadership & Management*, 40(1), 5-22. <https://doi.org/10.1080/13632434.2019.1596077>
- Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Sage.
- Mailina, S., & Ali, H. (2024). Pengaruh kepemimpinan kepala sekolah, motivasi kerja dan budaya sekolah terhadap kinerja guru. *Jurnal Manajemen Pendidikan*, 5(4).
- Merriam, S. B., & Tisdell, E. J. (2016). *Qualitative research: A guide to design and implementation* (4th ed.). Jossey-Bass.
- Miles, M. B., Huberman, A. M., & Saldana, J. (2014). *Qualitative data analysis: A methods sourcebook* (3rd ed.). Sage.
- Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 1017-1054. <https://doi.org/10.1111/j.1467-9620.2006.00684.x>
- Mockler, N. (2010). Inquiry as stance: Practitioner research for the next generation. *Educational Action Research*, 18(4), 571-572. <https://doi.org/10.1080/09650792.2010.525018>
- Msambwa, M. M., Wen, Z., & Daniel, K. (2025). The impact of AI on the personal and collaborative learning environments in higher education. *European Journal of Education*, 60(1), e12909. <https://doi.org/10.1111/ejed.12909>
- National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press. <https://doi.org/10.17226/13165>
- Nellitawati, N., & Yunistisa, F. (2022). Analisis kontribusi kepemimpinan kepala sekolah terhadap kinerja guru sekolah menengah kejuruan. *Jurnal Konseling dan Pendidikan*, 10(2), 193-203. <https://doi.org/10.29210/181900>
- Nurhayati, N., Suliyem, M., Hanafi, I., & Susanto, T. T. D. (2024). Integrasi AI dalam collaborative learning untuk meningkatkan efektivitas pembelajaran. *Academy of Education Journal*, 15(1), 1063-1071. <https://doi.org/10.47200/aoej.v15i1.2372>
- Patton, M. Q. (2015). *Qualitative research & evaluation methods* (4th ed.). Sage.
- Pedaste, M., Maeoets, M., Siiman, L. A., De Jong, T., Van Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, 14, 47-61. <https://doi.org/10.1016/j.edurev.2015.02.003>
- Rahayu, R., Iskandar, S., & Abidin, Y. (2022). Inovasi pembelajaran abad 21 dan penerapannya di Indonesia. *Jurnal Basicedu*, 6(2), 2099-2104. <https://doi.org/10.31004/basicedu.v6i2.2082>
- Riana, L. W., Amalia, S., & Annisa, N. N. (2025). Persepsi guru PAUD terhadap penggunaan teknologi pembelajaran berbasis artificial intelligence (AI) untuk anak usia dini. *Jurnal Kridatama Sains dan Teknologi*, 7(1), 10-17. <https://doi.org/10.53863/kst.v7i01.1498>
- Sanusi, Y., Mukhsin, M., & Kambara, R. (2024). Mediation organization commitment role on the influence of organizational culture and the role of leadership on teacher performance at public center of excellence vocational schools in Serang Banten Regency. *Journal of Learning and Educational Policy*, 45, 1-12. <https://doi.org/10.55529/jlep.45.1.12>
- Stoll, L., Bolam, R., McMahon, A., Wallace, M., & Thomas, S. (2006). Professional learning communities: A review of the literature. *Journal of Educational Change*, 7, 221-258. <https://doi.org/10.1007/s10833-006-0001-8>
- Su, J., Ng, D. T. K., & Chu, S. K. W. (2023). Artificial intelligence (AI) literacy in early childhood education: The challenges and opportunities. *Computers and Education: Artificial*

- Intelligence, 4, 100124. <https://doi.org/10.1016/j.caeai.2023.100124>
- Timperley, H., & Alton-Lee, A. (2008). Reframing teacher professional learning: An alternative policy approach to strengthening valued outcomes for diverse learners. *Review of Research in Education*, 32(1), 328-369. <https://doi.org/10.3102/0091732X07308968>
- Trundle, K. C., & Sackes, M. (Eds.). (2015). *Research in early childhood science education*. Springer. <https://doi.org/10.1007/978-94-017-9505-0>
- UNESCO. (2023). *Guidance for generative AI in education and research*. UNESCO.
- UNESCO. (2024). *AI competency framework for teachers*. UNESCO.
- Voogt, J., Fisser, P., Roblin, N. P., Tondeur, J., & Van Braak, J. (2013). Technological pedagogical content knowledge: A review of the literature. *Journal of Computer Assisted Learning*, 29(2), 109-121. <https://doi.org/10.1111/j.1365-2729.2012.00487.x>
- Wildanah, F., Febrianti, S., Ginanjar, S., Ningrum, T. A., & Setiawati, M. (2025). Optimalisasi AI untuk mendukung peningkatan kompetensi pedagogik guru dalam mewujudkan aktivitas pembelajaran abad 21. *Jurnal Pengabdian Kepada Masyarakat*.
- Xie, X. (2023). Influence of AI-driven inquiry teaching on learning outcomes. *International Journal of Emerging Technologies in Learning*, 18(23), 59-70. <https://doi.org/10.3991/ijet.v18i23.45473>
- Yang, W. (2022). Artificial intelligence education for young children: Why, what, and how in curriculum design and implementation. *Computers and Education: Artificial Intelligence*, 3, 100061. <https://doi.org/10.1016/j.caeai.2022.100061>
- Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Sage.
- Yu, S., Jantharajit, N., & Srikhao, S. (2024). Collaborative inquiry-based instructional model to enhance mathematical analytical thinking and reasoning skills for fourth-grade students. *Asian Journal of Education and Training*, 10(1), 10-17. <https://doi.org/10.20448/edu.v10i1.5323>
- Zawacki-Richter, O., Marin, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education: Where are the educators? *International Journal of Educational Technology in Higher Education*, 16, Article 39. <https://doi.org/10.1186/s41239-019-0171-0>
- Zeng, M., Cheah, K. S. L., & Abdullah, Z. (2025). The influence of school principals' digital leadership on teachers' competency in integrating artificial intelligence: A systematic thematic review. *Frontiers in Education*, 10, 1655967. <https://doi.org/10.3389/feduc.2025.1655967>