PATT43: The 43rd International Pupils' Attitudes Towards Technology Research Conference
Hosted by the Swedish National Centre for School Technology Education (Cetis) and Technology and Science Education Research (TekNaD), Linköping University, Norrköping, Sweden, June 15th to June 18th, 2026

Artificial Intelligence in Primary Science and Technology Education with a Focus on Implementation of AI in a Learning Context: Results of a Scoping Review

Malin Osnabrügge, Claudia Tenberge and Sabine Fechner
Paderborn University
malin.osnabruegge@upb.de

Abstract

Artificial intelligence has become an integral component of 21st-century life, necessitating ongoing adaptation to the profound social and technological transformations it precipitates (Yim & Su, 2025). AI impacts not only the everyday world, where it encompasses a wide range of technologies and applications, but also future primary education.

Primary education faces the challenge of raising awareness among learners and teachers for an AI-driven living environment and leveraging the technology's potential responsibly (Irion & Kuzu, 2025). In everyday school life, AI can be used particularly in science and technology lessons in primary schools, as this is where a basic understanding of the technological environment is acquired, as well as the ability to cope in an increasingly complex world. It is important to investigate how AI can be integrated into both instructional preparation and classroom learning activities, contributing to the ongoing development of primary education (Irion & Kuzu, 2025). Building on these perspectives, there is a need for structured frameworks that specify which AI-related -should be fostered in primary education in order to systematically support learners' understanding and use of AI in their everyday lives. A theoretical framework for AI-competences in primary education is adopted and divided into *fundamental knowledge*, *use & control*, *reflection (in everyday life)*.

This article presents a scoping review of the literature on the use of Artificial Intelligence in a teaching and learning context in primary science and technology education. The scoping review identifies central aspects of AI use in primary science and technology education and outlines the current state of research in this field.

Key Words: Artificial Intelligence, Primary School, Technology Education, Science Education

1 INTRODUCTION

The term artificial intelligence (AI) was first introduced in 1955 by John McCarthy, Marvin Minsky, Nathaniel Rochester, and Claude Shannon in a research funding proposal (De Florio-Hansen, 2020). Since the release of ChatGPT in 2022 at the latest, however, AI has assumed a central role in society. "The advent of artificial intelligence in many areas of life marks the beginning of one of the most significant transformations in human history" (Autenrieth et al., 2024, p. 26).

Increasingly powerful AI systems are taking over tasks traditionally performed by humans, gradually blurring the boundaries between human and machine intelligence (Autenrieth et al., 2024).Given this strong relevance to learners' everyday lives, the role of AI in school education has come into focus. The Standing Conference of the Ministers of Education and Cultural Affairs of Germany has developed policy recommendations that explicitly emphasise AI-based learning materials and underline that foundational and future-oriented competences are not contradictory but mutually supportive (KMK, 2025). Overall, AI is gaining increasing importance in school education.

Despite these rapid developments in society and education, the development of AI-related competences among young learners remains at an early stage, with a lack of clear conceptualisations and effective implementation approaches what needs to be expected (Yim & Su, 2025). To understand AI applications, both students and teachers require basic knowledge about how algorithms work (De Florio-Hansen, 2020). In this context, there is a growing demand to introduce AI-competence education already at the primary level and integrate it into early childhood and primary education.

In view of these technological transformations, the present article examines the use of AI in primary science and technology education and provides an overview of existing applications through a scoping review. It focuses primarily on the use of AI and its implementation. These findings are then discussed in terms of AI skills in primary schools, and implications for further research are drawn.

2 LITERATURE REVIEW

2.1 Artificial intelligence

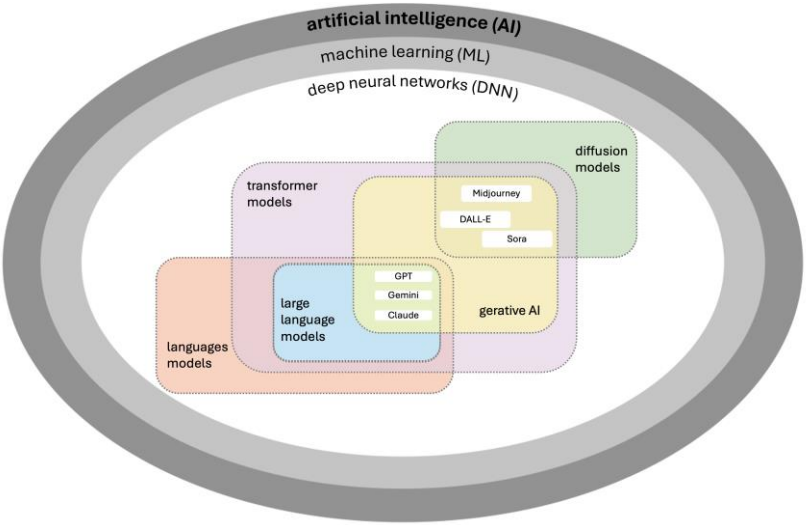
A review of the term 'artificial intelligence' (AI) reveals the challenge in achieving a uniform definition (Scheiter et al., 2025). In general terms, *intelligence* can be described as the ability to solve different kinds of problems. In technological contexts, AI refers to the simulation of this capability by computer systems (Stiperberger & Renner, 2023).
Accordingly, Scheiter et al. (2025, p. 6), define AI as "a field of computer science concerned with the creation of intelligent machines through algorithms". A wide range of technologies and fields of application are encompassed by the use of AI (Scheiter et al., 2025). The European Commission's guidelines for teachers on the use of AI (2022) provide a practice-oriented perspective by defining AI as software designed to perform tasks that would normally require human intelligence, including learning and reasoning. In addition, AI systems can be trained on

data to independently generate predictions, recommendations, and decisions, sometimes without direct human involvement.

Technically, AI can be divided into several major areas (Scheiter et al., 2025), including machine learning (supervised, unsupervised and reinforcement learning, as well as deep learning), logic- and knowledge-based approaches (e.g. knowledge representation, inductive programming, expert systems), and statistical methods such as Bayesian estimation, search and optimisation techniques. This classification highlights the diversity of methods that fall under the umbrella of AI. Based on Buchholtz et al. (2024), AI can be structured into several interconnected components, as shown in Figure 1. Machine learning encompasses algorithms that identify patterns in data and make decisions based on them. Deep neural networks process complex structures within large datasets. Language and transformer models enable the comprehension and generation of text; large language models (LLMs) are based on this architecture and produce human-like language. Diffusion models generate visual or audiovisual content. The overarching concept of generative AI refers to approaches that combine multiple methods to autonomously create new content (Buchholtz et al., 2024).

Figure 1

Areas of AI (adapted from Buchholtz et al., 2024)



2.2 Artificial intelligence in primary science and technology education

Artificial intelligence has become part of everyday life and is increasingly embedded in the experiences of primary school children, even when it is not always directly visible in the digital

tools they use (Irion & Kuzu, 2025). In this context, AI is expected to play a key role in nearly all areas of children's future lives and should therefore be systematically included in digital basic education (Autenrieth et al., 2024). Similar to findings from research on traditional literacy, which highlight the importance of starting early with reading and writing development (Kandlhofer et al., 2016), it can be assumed that basic AI-competences should also be addressed from the primary level onwards. Primary education places particular emphasis on understanding fundamental AI concepts and relating them to concrete applications (Chung et al., 2025). Introducing AI at this stage can support the development of early interest, foster responsible attitudes, and enhance students' motivation and engagement (Su & Yang, 2024).

At the same time, it is emphasised that, from a didactic perspective, AI should connect to children's everyday realities and therefore has a place in contemporary teaching, as existing prior knowledge needs to be taken up, related, and further developed (Scheiter et al., 2025). AI can be a useful tool for differentiated tasks, interactive learning activities, and playful learning designs; however, it should remain a supplementary resource and cannot replace social, creative, and hands-on learning (Scheiter et al., 2025).

The use of AI can be linked to science and technology education due to its connection and emergence in the everyday lives of students. Within science education, primary school has a dual function: children learn to interpret natural phenomena and, at the same time, develop basic scientific concepts and methods (Möller et al., 2011). Technology education at the primary level aims to equip students with fundamental technological practices, as well as with knowledge and skills that are relevant for lifeworld (Möller, 2002).

Consequently, elementary schools are tasked with the responsibility of "responsibly harnessing both the fascination and the potential of AI for learners and teachers and preparing children for a world shaped by AI" (Irion & Kuzu, 2025, p. 4). In particular, learning with, about and despite AI can take place in science and technology education.

2.3 AI-competences in primary education

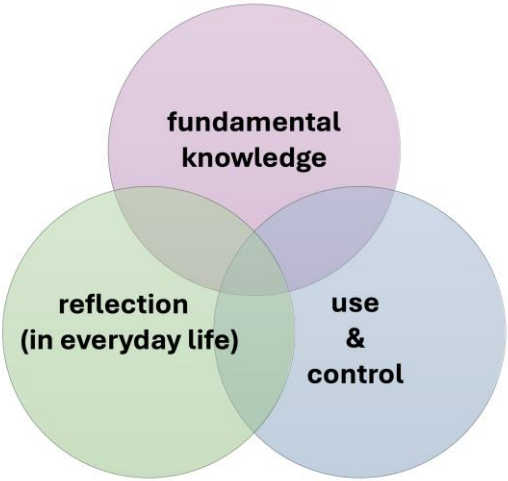
Teaching AI-competences in primary education is a relatively recent development (Yim & Su, 2025). The concept of AI-competences was introduced by Kandlhofer et al. (2016), highlighting that technical skills for understanding core AI concepts are a fundamental prerequisite (Yim & Su, 2025). The development of AI competences follows a stepwise process, beginning with basic conceptual understanding (UNESCO, 2022).

AI-competences frameworks and national guidelines aim to address existing gaps in research and practice by providing guidance for the development of age-appropriate AI learning resources (Yim & Su, 2025). As Autenrieth et al. (2024) argue, making use of AI's potential and dealing with its challenges requires a reflective understanding of AI systems from multiple perspectives. In recent years, a number of models for AI-competence development have been proposed, including those targeted at school students. Notably, UNESCO (2024) published the AI Competency Framework for Students as a global reference for integrating AI into national curricula. Likewise, the OECD (2025) introduced the AILit Framework, with a particular focus

on primary and secondary education. However, most of these frameworks address the full educational continuum or only partly consider primary school learners. To better capture AI-competences at the primary level, three key domains were derived from Alles et al. (2025), Chiu et al. (2024), Irion & Kuzu (2025), OECD (2025) & UNESCO (2024). As shown in Figure 2, these domains include *fundamental knowledge*, the *use & control* of AI, and *reflection (in everyday life)*.

Figure 2

Framework of AI-competences in primary education (Osnabrügge based on: Alles et al. (2025), Chiu et al. (2024), Irion & Kuzu (2025), OECD (2025) & UNESCO (2024))



In the area of *fundamental knowledge*, primary school science and technology students should develop basic understanding of artificial intelligence, including data, algorithms, and how AI systems work (e.g. Alles et al., 2025). A key goal is that learners understand that AI systems process data and use algorithms to generate likely outcomes or predictions (UNESCO, 2024). The domain of *use & control* focuses on enabling children to develop basic operational skills in working with AI systems through selected AI tools (e.g. Irion & Kuzu, 2025). This includes using AI as a support for completing tasks and learning simple strategies for effective input formulation, often referred to as prompting (e.g. OECD, 2025). In the domain of *reflection (in everyday life)*, attention is given to the opportunities and limitations of AI. Students should be able to identify and critically reflect on the effects of AI use on individuals, social relationships, and society more broadly (Irion & Kuzu, 2025). Examples for each category are shown in Table 1. Overall, the primary-level AI-competence framework draws on established framework but adapts them to the age-specific needs and capabilities of young learners.

Table 1

Example competencies for primary science and technology education (based on Alles et al., 2025 & OECD, 2025)

Category	Technology education	Science education
fundamental knowledge	if-then or rule structures that underlie automated decision-making processes	understanding scientific phenomena through AI
use & control	formulation of prompts	use of AI, e.g. in experiments
reflection & everyday life	recognising and evaluating misinformation	use of AI to reflect CO_2 emissions on the environment

3 PROBLEM STATEMENT

Artificial intelligence is becoming increasingly influential across social, economic, and educational domains. This trend is also evident in children's everyday lives, as AI-based applications such as Siri and Alexa are already widely used (Su & Yang, 2022). At the same time, there is a lack of clarity regarding the assumptions and competences underlying the use of AI (Yim & Su, 2025).

Research has increasingly taken up this topic, exploring both the opportunities and the challenges of AI in school settings. As a result, the question arises of how AI can be meaningfully integrated into primary science and technology education. However, it is still unclear to what extent and in what ways AI is currently used in primary-level science and technology classrooms.

To address this gap, the present scoping review investigates the following research questions:

1. What types of AI applications are used in primary science and technology education?
2. What goals are associated with the implementation of AI in primary science and technology education?

4 METHODOLOGY

The research questions were developed using a scoping review approach (Von Elm et al., 2019). Scoping reviews aim to systematically map the available literature, consolidate existing evidence, and identify gaps in knowledge, while deliberately refraining from a formal appraisal of study quality. In addition, they support decisions about the scope and value of conducting a subsequent systematic review and provide a basis for formulating recommendations for future research. As such, scoping reviews constitute an efficient and transparent method for synthesising research and identifying priority areas for further study.

Table 2

Identification information

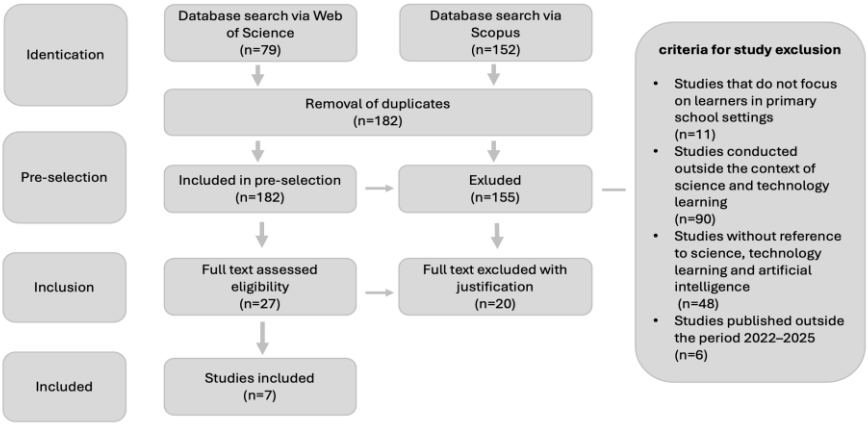
Database	web of science & Scopus
Search date	22.12.2025
Search strings	TS=(schoolchild* OR school-age child* OR "elementary school child" OR "elementary student*" OR "primary student*" OR "primary school" OR "elementary school" OR "primary education" OR "elementary education" OR "primary level" OR "elementary level" OR "primary grade*" OR "elementary grade*" OR "lower grade*" OR "early school year*" OR "early childhood education" OR "grade 1" OR "grade one" OR "grade 2" OR "grade two" OR "grade 3" OR "grade three" OR "grade 4" OR "grade four" OR "year 1" OR "year one" OR "year 2" OR "year two" OR "year 3" OR "year three" OR "year 4" OR "year four" OR "first grade" OR "second grade" OR "third grade" OR "fourth grade" OR K4 OR "K-4" OR "K 4" OR K5 OR "K-5" OR "K 5") NOT (TS= ("higher Education" OR "pre-service teachers" OR "middle school" OR "highschool" OR "pre-service teachers" OR "kindergarden" OR "adult" OR "metastases" OR "veterinary" OR "secundary education" OR "higher education" OR "tertiary education" OR "postsecondary education" OR "post-secondary education" OR "university*" OR "college*" OR "third level education" OR "out of school")) AND TS=("science learning" OR "scientific learning" OR "science education" OR "science teaching" OR "science instruction" OR "science classroom" OR "science lesson*" OR "science activity" OR "science activities" OR "scientific inquiry" OR "inquiry-based learning" OR "inquiry learning" OR "guided inquiry" OR "scientific literacy" OR "science literacy" OR "scientific understanding" OR "scientific knowledge" OR "science understanding" OR "technology learning" OR "technical learning" OR "technology education" OR "technical education" OR "technology instruction" OR "technology teaching" OR "technology-

	based learning" OR "technology-rich learning environment*" OR robot* OR STEM) NOT (TS= (medic* OR linguistics* OR "surgery" OR medicine* OR "health insurance" OR "foreign language learning" OR "vocabulary" OR "language learning" O R "cancer" OR "review")) AND TS=("artificial intelligence" OR "AI" OR "intelligent system*" OR "AI-based system*" OR "educational AI" OR "AI in education" OR AIEd OR "ChatGPT" OR "Mistral" OR "DeepSeek" OR "Gemini" OR "Bard" OR "LaMDA" OR "Claude" OR "Grok" OR "Bing AI" OR "LLaMA" OR "Sage" OR "Fobizz" OR "machine learning" OR "ML" OR "machine intelligence" OR "neural network*" OR "convolutional neural network*" OR "large language model*" OR LLM OR "generative AI" OR "GenAI" OR "foundation model*" OR chatbot* OR "AI tutor*" OR "virtual tutor*" OR "intelligent tutoring system*"OR "text generation" OR "speech recognition" OR "image recognition" OR "automated feedback" OR "AI-supported assessment") NOT (WC = (Hematology OR Surgery OR Oncology OR Medicine OR Immunology O R Cell Tissue Engineering OR Transplantation OR Surgery OR Orthopedics OR Urology OR Dermatology OR geriatrics OR Gerontology))
Search filter	Publication years: 2022 - 2025; Document Types: Article; Languages: English
Number of results	N = 231

Table 2 provides an overview of the search strategy, including the databases searched, the search date, the query, the search filters, and the number of records retrieved. The study selection process followed the PRISMA guidelines and is illustrated in Figure 3.

Figure 3

Diagram for identifying studies



The text was written as a German version and translated with generative AI tools (Perplexity, Deepl, and Deepl Write) to English.

5 FINDINGS

The studies included in the scoping review (n=7) are summarized in Table 3. Among them are six quantitative studies examining the use of AI in science education, as well as one qualitative study in which teachers were interviewed about their experiences with implementing AI in a learning context.

Table 3

List of identified studies

Code*	Study title/ source	Authors	Country/ context	Methodology / design	Sample	Main findings
FNS	*Facilitating the Acquisition of Natural Science*	Niyoxon et al., 2025	Uzbekistan	Pedagogical pilot study in primary schools	221 primary students (Grades 1–4)	Significantly higher learning performance, understanding and engagement;

	Knowledge by Primary School Students through Artificial Intelligence: Case Study – 3D Modelling of Lessons and Virtual Classrooms					support of abstract thinking; more ecologically sustainable teaching
EAM	*Experimenting with AI-based mobile applications to improve student engagement in ornamental plant learning in rural Indonesian schools*	Setyawan & Purbohadi, 2025	Indonesia (rural)	Quasi-experimental (pre–post-test)	93 students (Grades 5–6)	35% increase in understanding; higher enthusiasm and engagement; improvement linked to high activity level in app use
ALB	*Affirmative Large Language Model-Based Dialogue Robot for Broadening or Deepening the Perspective of Children*	Uchida et al., 2025	Japan	Experimental comparison of two conditions (affirmative vs. refutational/control)	53 students (Grade 6)	Affirmative strategy led to significantly greater expansion/deepening of perspectives (objective and subjective) and more positive impressions (anthropomorphism, likeability, perceived intelligence)
GAC	*Generative AI + AR: a novel embodied*	Cai et al., 2025	China	Quasi-experimental pretest–post-test design	62 students	Significant gains in learning motivation and curiosity

	conversational agent in an interactive learning environment			with control group and interviews	(Grade 6)	(dimension of critical thinking); better learning performance; high technology acceptance
EEM	*Exploring the Effects of the CER Model-Based GenAI Learning System to Cultivate Elementary School Students' Computational Thinking Core Skills in Science Courses*	Zhao et al., 2025	China	Quasi-experimental study (three groups: CER-GenAI, CER without GenAI, causal-explanation GenAI without reflection)	118 students (Grade 5)	CER-GenAI system significantly improved science achievement and CT skills (especially pattern recognition and algorithms); no pre-test differences, significant post-test group effect
EIV	*Effects of immersive virtual reality on primary student's science performance in classroom settings: a generative AI pedagogical agents-enhanced 5E approach, Interactive Learning Environments*	Wei et al., 2025	China	Mixed-methods design (experiment + qualitative data)	80 students (Grade 6)	IVR with GPA-5E significantly improved academic performance, self-efficacy and collective efficacy; qualitative data indicated vivid, enjoyable learning and simplification of abstract concepts
TPE	*Transforming Primary Science Education: Unlocking the Power of*	Al-Karasneh et al., 2025	Saudi Arabia	Qualitative study with semi-structured interviews	43 primary school teachers	Reported support for personalised and motivating learning, interactive simulations,

	Generative AI to Enhance Pupils' Grasp of Scientific Concepts	scientific curiosity, creativity and problem-solving, simplification of complex concepts; supports constructivist and inquiry-based learning

* Each study was assigned a code to facilitate the understanding of the subsequent tables.

5.1 What types of AI applications are used in primary science and technology education?

To answer the first research question, the analysis focuses both on the technological foundations of artificial intelligence and on its thematic application in science classrooms. Table 4 presents the thematic integration of artificial intelligence within science education. The table highlights how AI was incorporated into different teaching contexts. With the exception of the interview study (TPE), AI was consistently connected to one or more science-related topic.

Table 4

Applications from AI in science and technology education in the studies

Code	Applications in Science and Technology Education
FNS	Use of virtual reality (VR) through a 3D modelling of a virtual classroom addressing topics such as the solar system, plant development, and animal body structures → use of AI systems to control students' attention, provide real-time answers to questions, and employ gamification elements and interactive simulations
EAM	Application of an AI-based mobile app for recognizing ornamental plants, provide and compare real-time information
ALB	Deployment of the social communication robot CommU, powered by the LLM GOT-4 (OpenAI) and speech recognition from WebSpeechAPI, to explore topics such as living organisms, the environment, and maintaining a clean school → sing AI to conduct critical dialogues and discussions on scientific or sustainability topics.
GAC	Integration of augmented reality (AR) and an embodied conversational agent (ECA) “Virtual Scientist” to study plant growth under sunlight setting → using AI for personalised and context-sensitive dialogues in real time

EEM	Implementation of a GenAI-based learning system addressing the principle of levers → using Ai for enabling the generation and explanation of answers to students' questions
EIV	Use of a virtual robot within an immersive virtual environment (IVR) to introduce tools and instruments → Using AI to better understand complex scientific concepts through 3D visualisation and dynamic interaction, feedback & use of scaffolds
TPE	Overview of applications includes:
	Personalized learning support to account for individual differences
	Development of comprehensive and interactive learning experiences through visual representations and simulations of natural phenomena (e.g., the water cycle)
	Use of tools such as ChatGPT to provide real-time feedback and individualized instruction
	Chat-based feedback sessions to clarify abstract and complex scientific concepts
	Analysis of student interactions to support teachers in improving science instruction

Table 5 illustrates the different types of AI applications identified in the reviewed studies. Three studies used AI in virtual environments (VR, AR, IVR). Additionally, one study made use of a robot, another employed an AI-based learning system, and one implemented an app.

Table 5

Technical applications of artificial intelligence in the studies

Type of AI Application	Related Studies
use of VR / AR / IVR / 3D (integrating LLMs)	FNS, GAC, EIV
use of robots (integrating LLM)	ALB
AI-based learning system (integrating GenAI)	EEM
LLM-based mobile application (mobile app plant recognition)	EAM

5.2 What goals are associated with the implementation of AI in primary science and technology education?

To answer the second research question, which explores the implications of artificial intelligence use in educational settings, Table 6 offers a structured overview. The identified implications are

grouped into the categories shown in the table. Each category lists the studies that explicitly discuss the respective implication by their abbreviations, making it clear which aspects of AI use were addressed in each study.

Table 6

Implications of use of AI in science and technology education in the studies

Category	Related Studies
emotional and affective dimensions	FNS, EAM, GAC, EIV
cognitive learning objectives	FNS, EAM, GAC, ALB, EEM, EIV, TPE
individual learning needs	EEM, EIV
methodological approaches	TPE
reflection	ALB, EEM, TPE
theory–practice transfer	EAM, GAC, EEM
value-oriented and future competencies	ALB, TPE

6 DISCUSSION

The present scoping review provides a systematic overview of the current state of empirical research on the use of AI in primary science and technology education. Seven studies were included in the analysis, offering insight into how AI is currently integrated into classroom practice and which forms of implementation are being used.

Across the reviewed studies, artificial intelligence was predominantly implemented in technologically advanced learning environments, including AR and VR, immersive virtual scenarios, social robots, and generative AI systems. These applications require not only teachers but also students to possess basic operational skills in interacting with AI. In this context, AI primarily functioned as a didactic tool for supporting subject-related learning rather than as an explicit object of instruction. The results further indicate that the reviewed studies focus mainly on cognitive and affective learning outcomes in science education. All studies reported positive effects on learning performance, conceptual understanding, motivation, or student engagement. In particular, technology-rich environments such as virtual or agent-based scenarios were associated with increased curiosity, enjoyment, and self-efficacy, highlighting the potential of AI to make complex and abstract scientific content more accessible for primary school learners.

When these findings are interpreted in relation to the AI framework for primary education outlined in the literature review, a more differentiated picture emerges. The model distinguishes three domains: f*undamental knowledge*, *use & control*, and *reflection (in everyday life)*. The analysis shows that these domains are not addressed equally. The domain of *use & control* is

strongly represented, as students in all studies actively interacted with AI systems such as chatbots, learning platforms, apps, or virtual agents to solve tasks, ask questions, and receive feedback. In contrast, the domain of *fundamental knowledge* is weakly developed. Although advanced AI technologies such as large language models, generative AI, and intelligent agents were used, their underlying principles were rarely made explicit. Concepts such as data, algorithms, or the probabilistic nature of AI outputs were largely neglected, leaving AI as a "black box" for many learners. An even more pronounced gap can be observed in the domain of *reflection (in everyday life)*. Only a small number of studies addressed reflective or value-oriented aspects of AI, such as students' perceptions of AI systems, trust in AI-generated information, or broader societal implications. Yet this domain is crucial for fostering responsible and critically informed engagement with AI, particularly in primary education, where foundational attitudes towards technology are formed.

7 CONCLUSION

This scoping review aimed to map how AI is currently implemented in primary science and technology education and which educational goals are associated with its use. The results demonstrate that AI-based applications are already embedded in diverse and innovative learning environments and positively affect students' achievement, motivation, and engagement.

However, when examined through the lens of the primary-level AI relevant competences a clear imbalance becomes apparent. While the domain of *use and control* are covered in all studies, the domains of *fundamental knowledge* and especially *reflection (in everyday life)* remain largely underrepresented. Taken together, the findings suggest that although AI offers substantial educational potential in primary science and technology education, it is currently used mainly as an instrumental means to support subject learning or to be immersed in scenarios. The systematic development of AI-competences, particularly in terms of reflective and informed engagement with AI, is given comparatively little attention, indicating an important area for future research and instructional development.

8 REFERENCES

Al-Karasneh, S. M., Kanaan, E. M., Al-Barakat, A. A., AlAli, R. M., Zaher, A. M., & Ibrahim, N. A. (2025). Transforming Primary Science Education: Unlocking the Power of Generative AI to Enhance Pupils' Grasp of Scientific Concepts. *International Journal of Learning, Teaching and Educational Research*, *24*(5), 304–322. https://doi.org/10.26803/ijlter.24.5.16

Alles, S., Falck, J., Flick, M., & Schulz, R. (2025, March 13). *KI-Kompetenzen für Lehrende und Lernende. Aus der Praxis für die Praxis – eine adaptierbare Basis. [AI skills for teachers and learners. From practice for practice - an adaptable basis]* https://www.uni-paderborn.de/fileadmin/lehre/Digitale_Lehre_2023/KI-Talks/KI-Kompetenzmodell_VK_KIWA_Falck_Alles_Flick_Schulz_v1_1.pdf

Autenrieth, D., Autenrieth, N., & Irion, T. (2024). Digitale Grundbildung und KI. [Digital literacy and AI] *On. Lernen in Der Digitalen Welt, Hybrides* Lernen, *18*, 26–27.

Buchholtz, N., Schorcht, S., Baumanns, L., Huget, J., Noster, N., Rott, B., Siller, H.-S., & Sommerhoff, D. (2024). Sechs Leitgedanken zu Implikationen und Forschungsbedarfen zu KI-Technologien im Mathematikunterricht [Six guiding principles oft he implications ans research needs of AI technologies in mathematics education]. *Mitteilungen der Gesellschaft für Didaktik der Mathematik*, *117*.

Cai, S., Huang, H., Jiao, X., & Zhang, Y. (2025). Generative AI + AR: A novel embodied conversational agent in an interactive learning environment. *Interactive Learning Environments*, 1–15. https://doi.org/10.1080/10494820.2025.2589942

Chiu, T. K. F., Ahmad, Z., Ismailov, M., & Sanusi, I. T. (2024). What are artificial intelligence literacy and competency? A comprehensive framework to support them. *Computers and Education Open*, *6*, 100171. https://doi.org/10.1016/j.caeo.2024.100171

Chung, K., Kim, S., Jang, Y., Choi, S., & Kim, H. (2025). Developing an AI literacy diagnostic tool for elementary school students. *Education and Information Technologies*, *30*(1), 1013–1044. https://doi.org/10.1007/s10639-024-13097-w

De Florio-Hansen, I. (2020). *Digitalisierung, Künstliche Intelligenz und Robotik: Eine Einführung für Schule und Unterricht [Digitalisation, artifical intelligence and robotics: an introducation for schools and teaching]*. Waxmann. https://doi.org/10.36198/9783838554297

European Commission. Directorate General for Education, Youth, Sport and Culture. (2022). *Ethische Leitlinien für Lehrkräfte über die Nutzung von KI und Daten für Lehr- und Lernzwecke [Ethical quidelines for teachers on the use of AI and data for teaching and learning purposes]*. Publications Office. https://doi.org/10.2766/494

Irion, T., & Kuzu, T. E. (2025). Künstliche Intelligenz in der Primarstufe. Chancen, Herausforderungen, Perspektiven [Artificial intelligence in primary education. Opportunities, chalannges, perspetives]. *Grundschule aktuell : Zeitschrift des Grundschulverbandes*, *170*, 3–6. https://doi.org/10.25656/01:33137

Kandlhofer, M., Steinbauer, G., Hirschmugl-Gaisch, S., & Huber, P. (2016). Artificial intelligence and computer science in education: From kindergarten to university. *2016 IEEE Frontiers in Education Conference (FIE)*, 1–9. https://doi.org/10.1109/FIE.2016.7757570

Kultusministerkonferenz (KMK) [Confernece of Ministers of Education and Cultural Affairs]. (2024). *Handlungsempfehlung für die Bildungsverwaltung zum Umgang mit Künstlicher Intelligenz in schulischen Bildungsprozessen. Themenspezifische Handlungsempfehlung [Recommendations for action for education authorities on dealing with artificial intelligence in school education processes. Recommendations for action on specific topics]*. Sekretariat der Kultusministerkonferenz.

Möller, K., Kleickmann, T., & Sodian, B. (2011). Naturwissenschaftlich-technischer Lernbereich [Science and technology learning area]. In W. Einsiedler, M. Götz, & F. Heinzel, *Handbuch Grundschulpädagogik und Grundschuldidaktik [Handbool of Primary School Education and Primary School Teaching Methods]*, 3., completely revised edition, pp. 509–517, Klinkhardt.

Möller, K. (2002). Anspruchsvolles Lernen in der Grundschule—Am Beispiel naturwissenschaftlich-technischer Inhalte [Challenging learning in primary school – using science and technology content as an example]. *Pädagogische Rundschau*, *56*, 411–435.

Niyoxon, T., Yulduz, N., Muattar, P., Mukhayyokhon, I., Khudaybergan, K., & Inomjon, M. (2025). Facilitung the acquisation of natural science knowledge by primary school students through artifical intelligence: Case study – 3D Modeling of lessons and virtual classrooms. *Procedia Environmental Science, Engineering and Management*, *12*, 393–402.

OECD. (2025). *Empowering learners for the age of AI: An AI literacy framework for primary and secondary education (Review draft).* OECD. https://ailiteracyframework.org

Scheiter, K., Bauer, E., Omarchevska, Y., Schumacher, C., & Sailer, M. (2025). *Künstliche Intelligenz in der Schule* [Artificial intelligence in schools]. Bonn. https://www.empirische-bildungsforschung-bmbfsfj.de/img/KI_Review.pdf

Setyawan, H., & Purbohadi, D. (2025). Experimenting with AI-based mobile applications to improve student engagement in ornamental plant learning in rural Indonesian schools. *Edelweiss Applied Science and Technology*, *9*(3), 2333–2343. https://doi.org/10.55214/25768484.v9i3.5787

Stiperberger, F., & Renner, T. (2023). Künstliche Intelligenz. Chancen, Herausforderungen und Tipps für den Einsatz für die Schule [Artificial intelligence. Opportunities, challenges and tips for use in schools]. *Schulmagazin*, *5/6*, 29–33.

Su, J., & Yang, W. (2022). Artificial intelligence in early childhood education: A scoping review. *Computers and Education: Artificial Intelligence*, *3*, 100049. https://doi.org/10.1016/j.caeai.2022.100049

Su, J., & Yang, W. (2024). AI literacy curriculum and its relation to children's perceptions of robots and attitudes towards engineering and science: An intervention study in early childhood education. *Journal of Computer Assisted Learning*, *40*(1), 241–253. https://doi.org/10.1111/jcal.12867

Uchida, T., Ban, M., Koshino, A., Maeda, M., Sakai, K., Matsuura, N., Ishiguro, H., & Yoshikawa, Y. (2025). Affirmative Large Language Model-Based Dialogue Robots for Broadening or Deepening the Perspective of Children. *International Journal of Social Robotics*, *17*(11), 2729–2741. https://doi.org/10.1007/s12369-025-01331-5

UNESCO. (2022). *K-12 AI curricula: A mapping of government-endorsed AI curricula*. UNESCO. https://doi.org/10.54675/ELYF6010

UNESCO. (2024). *AI competency framework for students*. UNESCO. https://doi.org/10.54675/JKJB9835

Von Elm, E., Schreiber, G., & Haupt, C. C. (2019). Methodische Anleitung für Scoping Reviews (JBI-Methodologie) [Methodological guidance for scoping reviwes (JBI methodology]. *Zeitschrift für Evidenz, Fortbildung und Qualität im Gesundheitswesen*, *143*, 1–7. https://doi.org/10.1016/j.zefq.2019.05.004

Wei, X., Chen, Y., Zhao, P., Wang, L., Lee, L.-K., & Liu, R. (2025). Effects of immersive virtual reality on primary students' science performance in classroom settings: A generative AI pedagogical agents-enhanced 5E approach. *Interactive Learning Environments*, 1–20. https://doi.org/10.1080/10494820.2025.2514101

Yim, I. H. Y., & Su, J. (2025). Artificial intelligence literacy education in primary schools: A review. *International Journal of Technology and Design Education*, *35*(5), 2175–2204. https://doi.org/10.1007/s10798-025-09979-w

Zhao, J., Shangguan, S., & Wang, Y. (2025). Exploring the Effects of the CER Model-Based GENAI Learning System to Cultivate Elementary School Students' Computational Thinking Core Skills in Science Courses. *Journal of Computer Assisted Learning*, *41*(5), e70110. https://doi.org/10.1111/jcal.70110