

Review

Preservice Teachers' Perceptions of AI and Robotics-Based Practices in Contemporary STEM Teaching: A Scoping Review

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Abstract

The application of artificial intelligence (AI) resources and robotics tools in education is considered vital for interdisciplinary fields to enhance the quality of the teaching and learning process. It also helps transform assessment techniques and revolutionize the whole pedagogical setting of science teacher education, in particular, AI and robotics integration in the teaching of Science, Technology, Engineering and Mathematics (STEM) subjects' courses at the primary level. In this study, a scoping review was conducted involving seventeen peer-reviewed research papers published from 2021 to 2025. Efforts are being made to find the current perceptions and practices of preservice teachers (PSTs) at the primary level (Years 1–6; ages 6–12 in the Australian context) regarding the use of AI and robotics resources, for example, generative artificial intelligence (GenAI), foundational robotics and AI-driven robotics in teaching STEM subjects. Findings indicate that there was a significant gap in primary PSTs' perspectives regarding their pedagogical practices to integrate STEM. As such, this influences future teachers' knowledge, understanding, AI acceptance, and attitude toward the integration of smart AI and robotics resources in STEM classrooms. Policymakers and teachers' education providers should align advanced technological AI resources and robotics applications with STEM curriculum guidelines and preservice teachers' professional training programs within primary school education.

Keywords: integrated STEM; artificial intelligence; integration; progressive technology; primary science education; robotics tools; preservice teacher

1. Introduction

Teaching Science, Technology, Engineering and Mathematics (STEM) concepts in primary education plays a crucial role in building creativity and developing core skills. It is imperative that primary school students acquire the skills needed to excel in a technologically advanced society by connecting classroom learning with everyday STEM experiences (Dardanou et al., 2023). Vasquez et al. (2020) defines STEM as an interdisciplinary dynamic, adaptive and synergistic approach. Research shows that STEM teaching methods make students' digital learning experiences rigorous, relevant, productive, and applicable to solving real-world problems (Schweingruber et al., 2014; Jaipal-Jamani, 2023). Australian curriculum frameworks have suggested that teachers prepare students for future careers by removing the conventional barriers separating four disciplines: science, technology, engineering, and mathematics, and instead integrate them meaningfully and

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locate purposeful ways to integrate GenAI and robotics in primary education (Australian Government Department of Education, [AGDE], (Department of Education, 2025)). The Australian Curriculum, Assessment and Reporting Authority (ACARA, 2025) states that the science discipline is considered a thinking style, whereas technology is a way of doing things; engineering follows a problem-solving procedure, and mathematics is a process of applying. AGDE (Department of Education, 2021) has also reported that the advantages of integrated STEM teaching are abundant, for instance, individualized learning opportunities, developing depth of knowledge, improving academic motivation, and team spirit among students, in addition to emphasizing cognitive development, enhancing the sense of community and discussion, coherent conceptual knowledge, and overall academic achievement. Hence, this scoping review aims to fill the gap in understanding primary preservice teachers' (PSTs') perceptions and current AI and robotics-based practices in integrated STEM teaching. In the Australian context, primary school typically includes Years 1–6, covering students aged 6–12 (ACARA, 2025). The next section further elaborates on the nexus between the use of AI and robotics tools for STEM integration-related practices.

Renowned and influential scholars from developed countries describe the STEM integration approach as project-based and problem-based learning. However, Vasquez et al. (2020) explain various levels of integration in Science, Technology, Engineering and Mathematics and consider learning these subjects' knowledge as a gradual continuum of progression. Their progression models start with disciplinary, then increasing levels of integration, multidisciplinary, interdisciplinary, and finally transdisciplinary for an organized STEM curriculum. In the first stage, learners understand concepts and develop skills distinctly in each discipline, called disciplinary. Multidisciplinary, also known as the thematically integrated approach, is where students learn concepts and skills in each STEM subject separately, yet these are linked together through a common theme. Interdisciplinary concepts are organized in curriculum units in a manner that they become tightly interconnected and interdependent to refine learners' knowledge and skills. Lastly, transdisciplinary is also referred to as a problem- or project-based learning approach, in which students navigate real-world challenges and shape their learning experiences by applying information and skills from two or more disciplines. The study by Ng et al. (2022) suggested that all four types of integrations (Figure 1) give a better understanding of how different categories of integrations are incorporated with STEM subjects to instruct students effectively. In line with the framework in Figure 1, this review defines STEM integration as preservice teachers teaching two or more of these discipline content subjects simultaneously in primary classrooms, the premise being to enhance students' intellectual abilities and cross-curricular task handling skills, and encourage use of AI resources and robotics tools that augments students' science, math or engineering learning.

Preservice teachers, as future STEM teachers play a pivotal and evolving role in implementing integrated STEM curricula in schools. This is particularly evident during their professional placements, when they have opportunity to apply their university learning to real classroom practice for integrated STEM teaching. However, lack of collaborative relationships within STEM teachers' professional networks, along with a shortage of qualified in-service teachers to act as STEM mentors, impedes development of PSTs' integrated STEM teaching capacity (Stevenson & Thompson, 2025). This review identified a gap in PSTs' perceptions of AI and robotics-based practices within primary education's integrated STEM teaching. Evolving and fast-paced technologies such as AI and robotics tools play a key role in preparing PSTs' digital competence as well as strengthening teachers' understandings of the know-how of STEM integration. Therefore, the review is guided by the following research question.

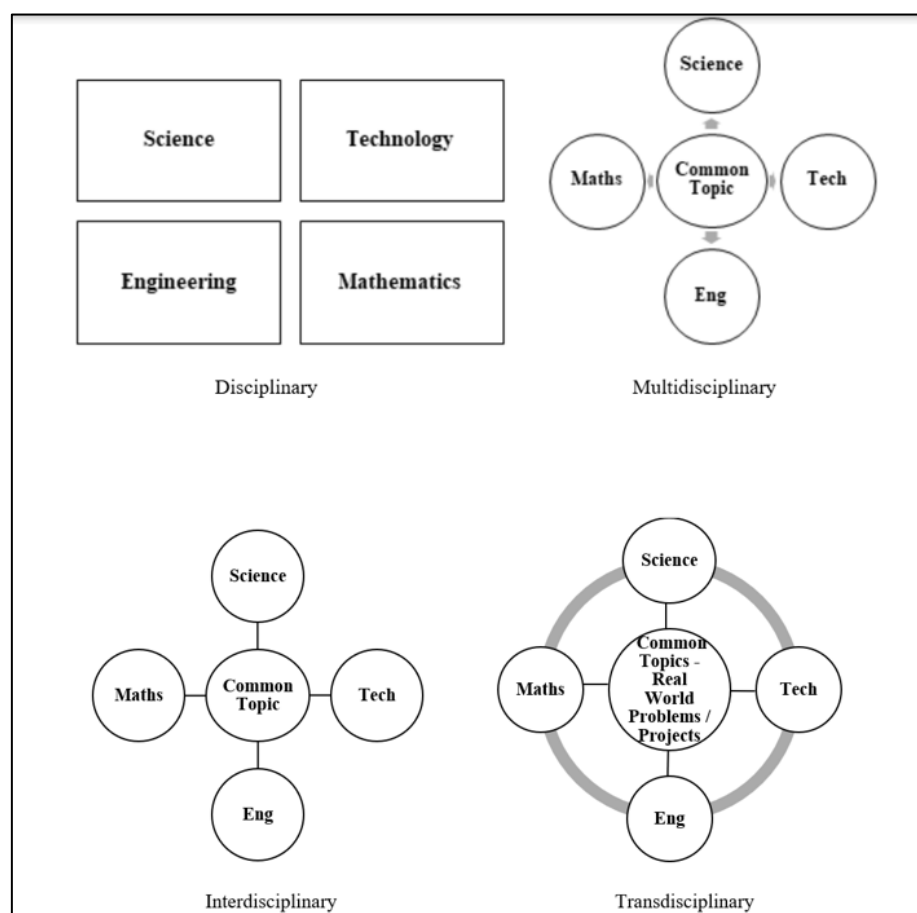


Figure 1. Disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary integration approach frameworks. Note: Disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary integration approach frameworks adopted with permission from (Ng et al., 2022).

What are the primary preservice teachers' perceptions of AI and robotics-based practices in integrated STEM teaching? In the next section, we elaborate upon why this scoping review is required in relation to investigating PSTs' digital competence in the midst of the globally fast-moving and progressively technologically driven landscape for STEM integration.

1.1. Progressive Technologies

At the outset, Veletsianos (2010) describes progressive technologies as equipment, inventions, and transformative advancements used in diverse educational environments and instructional delivery modes to serve varied academic-related purposes. Progressive technologies can be characterized by several key features, including rapid evolution, transformative impact, disruption potential, continuous innovation, and interdisciplinary reach. Innovative applications represent new developments and may build upon or transform conventional practices. Developing technologies and ideas experience critical hype cycles, usually beginning with a sharp rise and then diminishing; some achieve stability while others fade under prevailing circumstances. Progressive technologies, namely AI and robotics, have not reached the stage of complete understanding or research culmination, owing to their potential transformative and disruptive attributes (Veletsianos, 2010). AI and robotics are evolving continuously, existing in the state of coming into being by refinement and development, and they are rapidly reshaping educational practices (OECD, 2024). In this review paper, we define progressive technologies as five main categories, including Artificial Intelligence, Generative Artificial Intelligence, Metaverse,

foundational robotics, and AI-powered robotics. These categories emerged from a review of seventeen studies that used or referenced different technologies as intervention tools to explore PSTs' perceptions and practices. Although specific tools varied across studies, they continued to align with broader classifications outlined earlier. The forthcoming section explains the five types of progressive technologies that have been closely reviewed as part of the current study and PSTs' perceptions of how these technologies can support STEM integration practices.

The High-Level Expert Group on Artificial Intelligence (2019) defines AI as a system that functions with a certain degree of autonomy to accomplish specific aims. In doing so, through the display of intelligent behavior and the analysis of the environment based on human inputs, the AI system subsequently takes action. Other researchers, Sheikh et al. (2023), described AI simply as the use of algorithms for problem solving and performing calculations. This technology is capable of operating autonomously by drawing on environmental foresight. Additionally, these computer-based systems are capable of imitating many inherent human intellectual abilities. As a result, digital systems can solve intricate tasks by imitating complex human skills in technically demanding settings. AI operates in a sophisticated and diverse field, with its level of computational skill commonly referred to as deep learning, enabling it to perceive, pursue goals, and initiate actions through a feedback loop. Artificial intelligence has gained substantial momentum in recent years and continues to change over time. One of the major drivers of this has been advancement in a specific area of the field, including Generative Artificial Intelligence (GenAI), Metaverse and AI-powered robotics, along with innovation (Sheikh et al., 2023). However, to date, research is yet to understand primary preservice teachers' perceptions of AI in the context of STEM integration practices, successes and perceived challenges for curriculum planning and teaching, such that it augments students' cognitive learning, behavior, and achievement, rather than being seen as AI replacing teachers in real-world classrooms.

Ronge et al. (2025) define GenAI in terms of four central aspects understood as describing a spectrum: integrated modality, productivity, interaction, and flexibility. These dimensions constitute a first step in functionally defining GenAI beyond its technical foundation from other forms of AI. Modality means receiving multimodal prompts and producing related images. It enables productivity gains through easily accessible, intuitive interactions between user and system. It can be flexibly applied to a wide variety of challenges in various complex settings. These four aspects can be depicted as a form of coordinative creativity between humans and intelligent systems. GenAI is a multifunctional range of applications that expands existing boundaries of artificial systems, owing to its multifaceted and novel mode of user-oriented operation, generating useful and innovative outputs. It is non-deterministic but randomly open to individual samples generated by the model employed across diverse contexts, advancing towards a state of Artificial General Intelligence. Additionally, it is a change in basic assumptions due to its generative capabilities that shapes a new intersection between the real and digital worlds (Ronge et al., 2025). The use of the Metaverse powered by AI can serve as a 3D digital space, functioning as a virtual extension of classrooms and immersive digital collaborative environments. Particularly, digital field trips and virtual STEM lab experiences into educational practices can make learning interactive and interdisciplinary (Lin et al., 2022).

As identified by Siciliano et al. (2025), foundational robotics is an interdisciplinary field of science that primarily involves mechanical engineering, electrical engineering, and computer science. In this review, LEGO robotics is identified as foundational robotics and is used as an intervention tool in the five studies discussed later. Similarly, AI-powered robotics are related to integrated artificial intelligence, machine learning, electronics, computer vision, nanotechnology, intelligent autonomous deliberating task domains, and

numerous others. The example of AI-based robotics in this review is LEGO Mindstorms EV3, which is used during primary PSTs' professional training programs. Robot-centric artificial capabilities require both scientific embodiment properties and machine engineering discipline design concerned with the composition, structure, creation, and evaluation that can mimic human movement and behavior. AI and robotics are adapting to changing conditions, gradually improving functionality by learning from data, performing tasks with minimal human intervention, and managing complex unstructured environments (Siciliano et al., 2025). Therefore, it is crucial to understand the role and current condition of AI and robotics tools in the STEM teaching and learning process and how we can better prepare PSTs as the future STEM teaching workforce.

1.2. Role of AI and Robotics Tools for Integrated STEM Teaching

Recent academic trends have gradually shifted from STEM education, seeking to integrate STEM teaching and learning with real-world impact in classrooms (Schweingruber et al., 2014). This leads to PSTs teaching learners how to prepare for the anticipated future, yet-to-be-addressed global challenges and contemporary workforce demands. Today, the majority of the global technological complexities require cross-disciplinary critical thinking and problem-solving skills supported by situated learning theories and STEM literature rather than expertise in isolated STEM subjects (Livstrom et al., 2019). This study also mentioned exemplary models of primary purposeful community-based learning environments that naturally integrated STEM in schools. The outcome of this framework execution is an increase in students' interest and motivation to explore integrated STEM careers. There is rapidly growing momentum to form a STEM-literate society. However, in primary education settings, whether this approach seems realistically achievable creates a major question for stakeholders, particularly due to curricular and pedagogical challenges, lack of subject-specific expertise, overloaded curriculum within teacher education programs, and absence of tailored professional development for PSTs (Hourigan et al., 2022), thus leaving none to minimal room for PSTs to plan, teach and reflect upon using AI and robotics technologies for STEM integration practices.

On the other hand, the term AI and robotics continues to rapidly proliferate in all global industry fields as a prevalent developing technology. Those capable of performing tasks require human intelligence in daily life, such as acting and thinking. Its applications include manufacturing and controlling robotics toys, idea generation, programming, coding, interface to create interactive projects, smart assistance, smooth Google search, and automation (Dardanou et al., 2023). AI and robotics in STEM education is considered an emerging interdisciplinary field that applies progressive technological tools to strengthen instruction, learning design, the methodological process, and to revolutionize and cultivate science education assessment. There are sub-branches of AI and robotics in education, one of which pertains to AI and robotics in STEM education, where AI and robotics tools are applied in STEM education to enhance and support the design and quality of the teaching and learning process, for instance, intelligence tutoring systems, personalized learning, programmed assessment, automated grading, data refining and learning analytics (Chen et al., 2020).

Currently, another sub-category has been introduced: AI and robotics in integrated STEM. There have been a few studies conducted in this area in countries other than Australia that broadly reported positive outcomes in teaching and learning practices in higher education environments (Berisha & Vula, 2024; Li et al., 2024; Maršálek et al., 2025). Therefore, testing integrated STEM teaching with AI resources and robotics technology applications during the instructional process is deemed to be crucial, in order to be aware of its practicality, advantages, disadvantages and design future progressive technological integrated STEM pedagogy and curriculum development policies in Australia for PSTs at the

primary level. There is an urgent need to identify PSTs' perceptions and current practices with AI and robotics tools in integrated STEM teaching practice.

2. Methodology

This paper deploys a scoping review methodology to articulate themes concerning primary PSTs' perceptions of AI and robotics integrated instructional practices within STEM education. According to Pollock et al. (2024) a scoping review is a type of descriptive evidence synthesis approach that has the central goal to steadily identify, map and report the breadth of data. The records are meant to include a variety of research sources such as primary, non-empirical and other reviews within or across targeted contexts accessible on a particular topic, field, concept, and issue. This inductive review approach, characterized by questioning objectives, is to explore the in-depth knowledge of different topics or concepts. Scoping reviews are a specific and appropriate type of evidence synthesis ecosystem that conducts qualitative content analysis to clarify key definitions in the literature and determine theoretical frameworks (Munn et al., 2018). Furthermore, this review aids in identifying key characteristics or factors related to a concept, including those related to methodological research and other variables. It can be used to answer broad questions from researchers and decision-makers by using transparent methods. Additionally, it often involves extensive and detailed extractions accompanied by tables, other visuals, and narrative summaries, which contribute to reducing research waste by excluding duplication of research effort, inform future research priorities and policy, and on occasion influence practice (Munn et al., 2022).

As reported by Peters et al. (2020) the following steps are in the conduct of scoping reviews, beginning with structuring the review protocol by developing, defining, and aligning the research questions with the inclusion criteria. The subsequent stage entails writing down the precise strategy for searching relevant papers through title screening; the standardized approach is replicable. Afterwards, select articles based on screening abstracts and full texts. Thereafter, extract, analyze, and present the data as evidence to answer the research questions. At the end, summarize, conclude, and note down the implications of the findings to fulfill the review purpose (Peters et al., 2020).

This scoping review consisted of multiple stages and followed a step-by-step process (Peters et al., 2020):

1. Beginning with the problem identification phase, research questions developed: What are primary preservice teachers' perceptions of AI and robotics-based practices in integrated STEM teaching?
2. We applied a search strategy to collect evidence from relevant literature. That strategy was developed in consultation with the institution's librarian to ensure an extensive search. Terms and their alterations were generated for use in ERIC, EBSCOhost, ProQuest, Web of Science, and other education database searches. The search terms are shown in Figure 2.
3. After conducting a search of the relevant papers and screening peer-reviewed scholarly articles in collaboration with supervisors, filters were applied with a five-year limit, English language, full-text, peer-reviewed, and a specific focus on primary education.
4. Covidence is an online screening tool used to screen titles and abstracts of articles based on predetermined exclusion criteria.
5. Included papers were assessed, and afterwards the articles were compared, reviewed, and synthesized, and later relevant information was retrieved and organized through a thematic approach (Bryman, 2016).

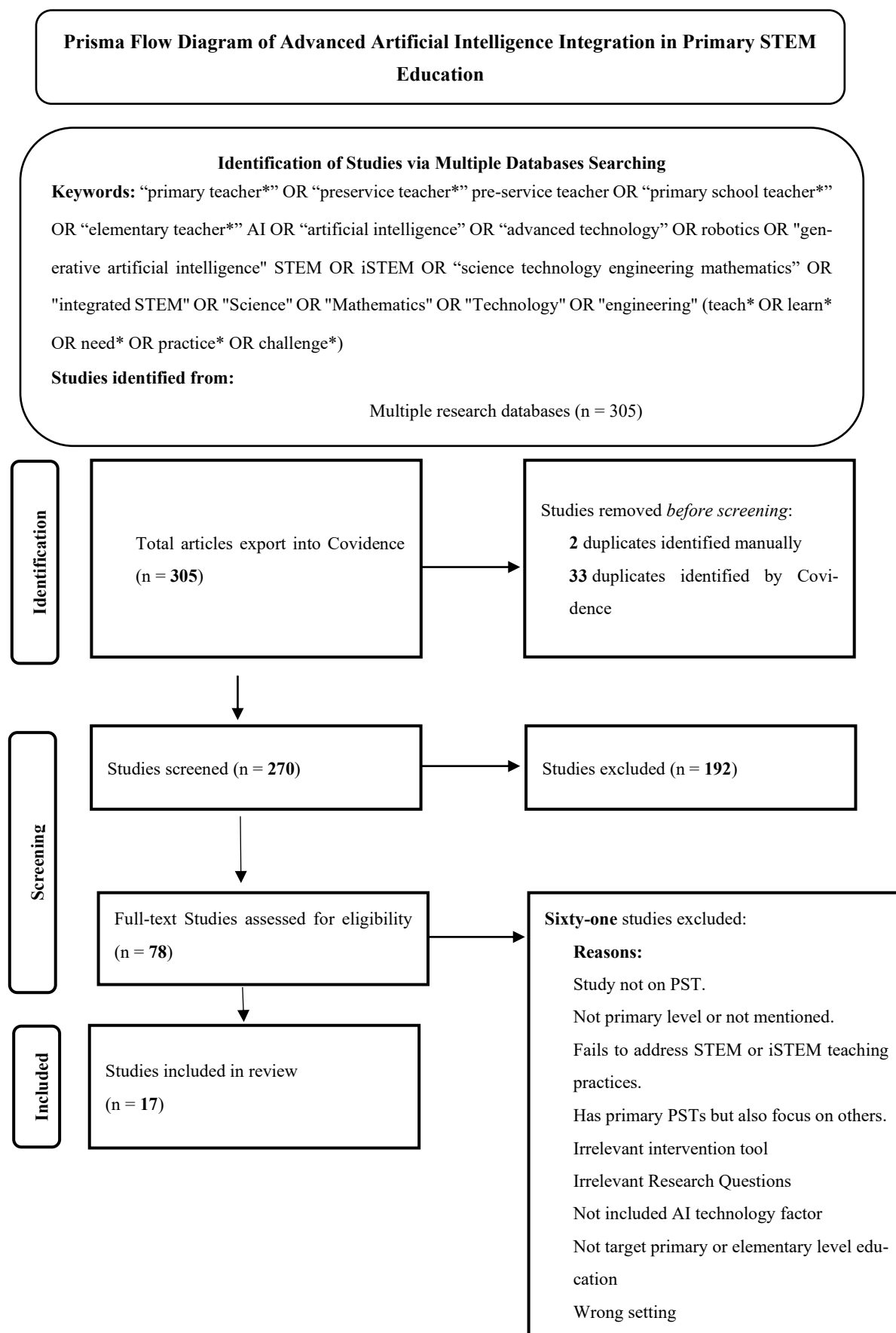


Figure 2. PRISMA flow diagram for literature search and selection process.

The literature search was conducted in November 2025. A total of 305 AI and robotics technology in STEM teaching-related articles were screened against the inclusion and exclusion criteria in Covidence. The inclusion criteria for the articles published within the last five years (2021–2025) were STEM, integrated STEM, science, technology, engineering and mathematics, primary education, elementary education, advanced technology integration, artificial intelligence (AI), robotics, preservice teachers (PSTs), teaching practices, challenges, and needs. The exclusion criteria were articles reporting early childhood education school, secondary school, high school, tertiary education, in-service teacher education, non-teaching activities, non-AI tools, English language education, social and art studies, non-STEM disciplines, and teacher studies. Seventy-eight articles were further analyzed after screening for titles and abstracts. At the end of this stage, seventeen articles were included in this scoping review. The reading of each article was based on two phases: firstly, literature review, in which research questions and objectives of each article were reviewed to confirm its pertinence to the integration of progressive AI and robotics technology in STEM teaching and teacher-associated instructional practices. Thereafter, the results, discussion and conclusion of each article were studied. Figure 2 illustrates the process of including and excluding papers in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews (PRISMA-ScR) guidelines by Tricco et al. (2018). No protocol was registered for this review.

3. Data Analysis

In order to synthesize the content of the seventeen selected articles (see Table 1) of this qualitative review study, we adapted the reflexive thematic analysis approach proposed by (Braun & Clarke, 2021). This approach is conceptual, pragmatic, comfortable and familiar to novice researchers. The reflexive thematic analysis technique is theoretically flexible, centered on the analysis of patterns of meaning across the data items or cases that comprise a qualitative data set. This method reflects a general principle of research design coherence and fits with this review’s purpose, theoretical assumptions, and is aligned with the research question. Our reflexive approach involves six recursive phases, including familiarization with review data, and at the next stage a coding scheme was outlined, consistent with teachers’ AI and robotics-related perceptions and practices in STEM teaching. The articles (presented in Table 1) were read and coded by generating initial themes. Afterward, we reviewed, refined, defined and named themes across the articles’ content based on their context, and at the end we wrote up this paper (Braun & Clarke, 2013, 2021).

Table 1. PSTs’ perceptions of AI and robotics-based practices in STEM studies.

Author(s)	Participants	Study Context	Country	Tool Use in Research Activities
Casler-Failing (2021)	Five undergraduate pre-service middle-years teachers.	Exploring Lego robotics for middle-years mathematics (Years 4–8)	United States	Lego robotics (LEGO Education, Billund, Denmark)
Amador-Terrón et al. (2022)	59 third-year student teachers enrolled in primary education degree	Teacher education setting focused on robotics in mathematics.	Spain	WeDo 2.0 robot
Casler-Failing and Collins (2022)	Seven preservice teachers enrolled in an undergraduate middle-years mathematics methods course.	Experiencing how to operate and program Lego robotics for middle-years mathematics students (Years 4–8)	United States	Lego robotics (LEGO Education, Billund, Denmark)
Saleh et al. (2023)	91 fourth year preservice primary science teachers (PSTs).	PSTs’ attitudes toward adaptive expertise in	Bahrain	Integrated STEM (iSTEM) teaching activities (adaptive expertise)

		science and integrated STEM teaching.		
Jaipal-Jamani (2023)	Elementary preservice science teachers certified to teach primary junior years (K–6)	PSTs practicing year 4 science teaching concepts such as gear types and functions through robotics-based activities.	Canada	Scaffolded robotics kits (LEGO® Education WeDo v.1.2, Billund, Denmark)
Lee and Zhai (2024)	29 preservice elementary science teachers	Evaluate PSTs' ChatGPT integrated science lesson plans and activities.	United States	ChatGPT (GPT-3.5)
Filiz and Gür (2025)	Participants were preservice Year 4 mathematics teachers, with 42 in quantitative phase and 4 in qualitative phase.	Preservice teacher education setting within elementary mathematics teaching program.	Turkey	ChatGPT
Ceylan and Karakuş (2024)	24 prospective science teachers enrolled in second, third, and fourth years of mathematics and science education department.	Designing outdoor science education activities.	Turkey	ChatGPT (API or Browser) and Artificial Intelligence-based mobile application (custom-built)
Avinc and Dogan (2025)	49 preservice science teachers from 1st to 4th year in faculty of education	Experiencing Metaverse environment with 3D glasses by primary preservice science teachers	Turkey	Smart metaverse
Fegely et al. (2024)	19 preservice computer science teachers	Impact of robotics programming on science PSTs' motivation and retention.	United States	Lego Mindstorms EV3 robots
Lee et al. (2025)	15 preservice elementary science teachers.	PSTs' collaborative learning with Artificial Intelligence Speakers as both peer and user.	Korea	Custom prototype with AI speakers (smart voice assistants' devices)
Getenet (2024)	58 primary preservice teachers (PSTs) enrolled in mathematics education course.	Teachers' mathematics problem-solving skills compared with ChatGPT version 3.5	Australia	ChatGPT (GPT-3.5 model)
Yorulmaz et al. (2025)	46 third-year preservice primary teachers	Exploring preservice teachers' experiences with ChatGPT as assistance during lesson planning.	Turkey	ChatGPT (OpenAI)
Abualrob (2025)	Twenty preservice teachers working with Year 4 students.	Reflecting on PSTs' use of Copilot prompts when planning lessons	Palestine	Microsoft Copilot (standard web-based user interface)
Yanar and Ergene (2025)	21 preservice mathematics teachers enrolled in university elementary mathematics teacher education program.	Examining how preservice mathematics teachers use ChatGPT during lesson planning.	Turkey	ChatGPT (free web-based interface)
Akosah (2025)	Nine preservice primary mathematics teachers	Exploring engagement of mathematics PSTs in AI-	Ghana	AI-tools (generic AI-assisted learning tools)

		assisted collaborative learning environment.		
Fitzpatrick and Leavy (2026)	30 preservice teachers'	PSTs' evolving understandings of integrated STEM education across 12-week intervention.	Ireland	Pedagogical robotics toolkit

4. Results and Discussion

Of the seventeen articles, a significant majority of papers either concisely or extensively discussed the following research question that pertains to PSTs' technological perceptions and practices (Artificial Intelligence, GenAI, Foundational Robotics and AI-powered Robotics) in integrated STEM teaching. Based on the findings, we divide the analysis into two core sections: PSTs' current perception on AI and robotics in relation to integrated STEM teaching and PSTs' AI and robotics practices in STEM education. Subsequently, further sub-themes emerged in each category to elaborate on primary PSTs' current perceptions and practices in this review of the literature. Thereafter, in the second part of the review paper we analyze and discuss what type of challenges primary PSTs experience due to the use of artificial intelligence and robotics tools. Additionally, we highlight the broader needs required to enhance the integration of AI and robotics technology within integrated STEM teaching and teacher education curricula.

4.1. Preservice Teachers' Current Perceptions on AI and Robotics Use in Relation to STEM Teaching

This theme comprises two sub-themes that have been discussed in conjunction with the scoping review of the literature (see Table 2).

Table 2. Coding process of PSTs' perceptions of AI and robotics-based practices in STEM themes and sub-themes.

Themes	Sub-Themes	Coding Process Description
PSTs' current perceptions on AI and robotics use in relation to STEM teaching	1–PSTs' AI and robotics readiness and disposition in STEM	We follow the six steps of thematic analysis to code the review data. We initially familiarized ourselves with the review data's general ideas. Subsequently, we generated codes for the entire data set, later searching for potential themes within the data and reviewing them, such as perceptions and practices. Thereafter, we defined and labelled themes based on ongoing analysis and finally produced the report by validating (cross-checking) with the research question and literature outcomes to ensure alignment and consistency (Braun & Clarke, 2013).
	2–Pedagogical perception of AI and robotics integrated STEM teaching	
PSTs' current practices on AI and robotics in relation to STEM teaching	1–PSTs' implementation of AI and robotics integrated STEM teaching	
	2–Pedagogical practices of AI and robotics integrated STEM teaching	

4.2. Preservice Teachers' AI and Robotics Readiness and Disposition in STEM

This sub-theme summarizes the findings from six article studies regarding PSTs who demonstrated a positive attitude and readiness to integrate AI and robotics tools into their primary STEM instructional practices. However, most had limited prior experience using such AI and robotics tools in STEM classrooms and possessed a moderate level of technological competency. A receptive attitude serves as a critical mediator, reconciling the gap between primary PSTs' technical inexperience with advanced technology and their pedagogical openness to trying AI and robotics tools. Disposition serves as a more substantial predictor of success than prior experience with AI and robotics tools. A moderate level of

competency acts as a baseline that prevents a positive attitude from devolving into frustration for the educators.

Beginning with teachers who had no prior AI and robotics tools exposure, this review synthesized the findings of previous papers. For instance, three studies out of seventeen, Casler-Failing and Collins (2022), Lee and Zhai (2024), and Yanar and Ergene (2025), all incorporated from the conceptual standpoint that primary PSTs have no prior experience with artificial intelligence, including ChatGPT usage in STEM instructional application. Separately, Casler-Failing and Collins (2022) elaborated that primary PSTs benefit from experiencing productive struggle firsthand with robotics by following a deliberate error strategy during the preparation of future lesson plans. This sub-theme argues that the preparation process itself becomes a diagnostic tool for PSTs' success in the USA. Correspondingly, Lee and Zhai (2024) stated that the first exposure of primary PSTs in the USA to technology often began with ChatGPT as Large Language Models. Therefore, many teachers have not yet fully exploited ChatGPT's functions to their full potential. This results in an inability to select across multiple AI knowledge domains platforms, particularly when the educational content encompasses complex cross-cutting concepts. Reflecting on the results mentioned above, regarding an inadequate technological background, the primary factor that motivates teachers toward AI and robotics usage is their mindset, which is discussed comprehensively thereafter to explain how internal motivation can overcome technical gaps.

Building on this discussion, the following 5 out of 17 studies, Avinc and Dogan (2025), Lee and Zhai (2024), Saleh et al. (2023), and Yanar and Ergene (2025), all indicated that primary PSTs demonstrated a positive attitude toward integrating AI technology into their STEM teaching, while the study by Getenet (2024) revealed that Australian teachers held negative attitudes toward AI use, largely due to ChatGPT's limited diversity and flexibility in practical applications. In mathematics subjects, they also noted that AI relied heavily on algebraic equations and formulas often produced incorrect outputs, which further contributed to their concerns. In contrast Saleh et al. (2023), Avinc and Dogan (2025), and Yanar and Ergene (2025) reported in their studies that 28% of teachers expressed positive intentions to use adaptive AI expertise. This means that PSTs demonstrate high self-efficacy, which builds competency in analyzing AI content, and are able to overcome their anxiety to apply AI knowledge flexibly, creatively, and innovatively in new or complex science teaching settings. In particular, integrating the metaverse, for instance, through virtual classrooms, immersive digital environments, and virtual lab experiences into general STEM educational practices can make learning interactive and interdisciplinary. All three studies suggest a growing recognition of the role of ChatGPT and other digital technologies, as discussed above, in enhancing science instructional strategies and lesson planning. Another study, by Lee and Zhai (2024), stated that primary PSTs demonstrated balanced views on the value of integrating ChatGPT into teaching and learning. The findings show that many teachers prefer to use ChatGPT to support students' research and deepen their understanding of the disruption of ecological balance beyond what is available in textbooks. This approach not only broadens content knowledge but also strengthens both individual inquiry and collaborative learning activities. Therefore, a positive attitude combined with even moderate technological knowledge among PSTs tends to enhance the integration of AI and robotics in primary STEM classroom practice. In light of these observations, the following paragraph turns to findings on PSTs' digital competency, which is outlined below.

Drawing from the preceding discussion, the study by Lee and Zhai (2024) indicated that only a small proportion of PSTs in the United States demonstrate moderate competency in integrating ChatGPT into science teaching and learning. Most educators tend to align their practice with the modified Technological Pedagogical Content Knowledge

(TPACK) framework-based rubric as an evaluation tool, particularly in the area of instructional strategies and language-based task support. However, only a few preservice teachers possess sufficient prior knowledge or emerging awareness of ChatGPT to effectively support high-quality questioning, self-directed teaching, individualized learning, and formative assessment. In the context of our future study, this review helps anticipate Australian PSTs current AI and robotics perceptions across disposition, competency, and exposure in STEM teaching. Moreover, this supports the development of appropriate standards for AI-based robotics workshop activities. Educators' digital competency is associated with their awareness of how advanced technological tools function and the advantages they offer when integrated into the instructional process. In addition, this review examines the selected articles in depth, with the resulting insights presented under the forthcoming theme on pedagogical perception of AI and robotics integrated STEM teaching.

4.3. Pedagogical Perception of AI and Robotics Integrated STEM Teaching

Having established the broader review, teachers and researchers generally hold high expectations and positive perceptions of AI and robotics tools, viewing them as capable of enhancing STEM teaching and learning practices. However, the technology is used primarily by instructors for basic digital worksheet tasks, creating a mismatch between the intended goals and the actual classroom practices. The pedagogical gap highlights a clear discrepancy between the anticipated benefits of advanced technology and its limited implementation. For instance, teachers who possess awareness of robotics tend to foster higher levels of student engagement, yet their classroom use of ChatGPT often remains limited to functions such as text summarization and idea generation. The three studies that document this are discussed in later sections of this review.

Having noted the scope of three of the seventeen studies, Abualrob (2025), Yanar and Ergene (2025), and Lee and Zhai (2024) highlighted the most common pedagogical perceptions of some teachers related to AI practices. As documented in a recent study by Abualrob (2025), it is demonstrated that PSTs primarily employed the Copilot application for lesson preparation. Accordingly, this supports the integration of instructional media, development of teaching aids, construction of authentic assessment tools, and creation of tables, images, and drawings. Correspondingly, Lee and Zhai (2024) reported a small cohort of PSTs who discussed the use of AI to support a wide spectrum of cognitive and instructional functions. These functions included cooperative learning, observation, explanation, learning cycle, analogy generation, experimentation, and conceptual mapping. Moreover, the GenAI-Based TPACK Framework assisted with role-playing activity design, scriptwriting generation, formulation of follow-up questions, facilitation of discussion, implementation of discovery-based learning, provision of feedback and promotion of reflective practice. These outcomes were made possible through extensive application of ChatGPT as a large language model. A limited number of primary preservice mathematics teachers in Turkey employed ChatGPT during the 5E (Engage, Explore, Explain, Elaborate, and Evaluate) lesson planning process to support both instructional and pedagogical content development. This tool enabled them to refine their teaching ideas in linear algebra, probability, geometry by generating targeted suggestions, recommending relevant resources, obtaining examples of engaging activities, and synthesizing complex information into more manageable forms (Yanar & Ergene, 2025).

On the other hand, two studies indicated that instructors anticipated substantial benefits arising from the use of technology within the primary science, technology, engineering and mathematics subject areas. As an illustration, the study by Lee and Zhai (2024) revealed that primary PSTs in the USA envisioned a broad applicability of ChatGPT in both science teaching and learning processes. They perceived its potential to simplify

complex concepts by using analogies, examples, interactive visuals and concept mapping. ChatGPT can also generate engaging lesson materials, support differentiated instruction, enhance the quality of questioning and foster enquiry-based thinking among students. Another study in Palestine determined that teachers anticipated instructional strategies and academic benefits of AI tools that engage all students in science lessons, when Copilot is employed as a pedagogy technique (Abualrob, 2025). These findings concerning the anticipated substantial benefits of AI and robotics tools in STEM teaching will support the planning of future project workshop components. The next section elaborates on how advanced technology such as AI and robotics integrated implementations influence primary PSTs' digital technology practices in STEM teaching.

4.4. Preservice Teachers' Current Practices on AI and Robotics in Relation to STEM Teaching

This theme comprises two sub-themes that have been discussed in conjunction with the scoping review literature (see Table 2).

4.5. Preservice Teachers' Implementation of AI and Robotics Integrated STEM Teaching

In the context of using educational robotics and AI tools for STEM integration, Amador-Terrón et al. (2022) conducted a study in Spain, and findings indicate that, for the majority of PSTs, use of robotics generates clear benefits and enhances their mathematics subject-specific instructional skills. The WeDo 2.0 robot provides pupils with a wide range of learning possibilities and appears to elicit diverse emotional responses. Additionally, science PSTs largely recognize the usefulness of metaverse AI. Evidence shows that PSTs who initially held negative views tended to revise these perceptions after taking part in the designed activities and started to accept use of the smart metaverse in Turkey (Avinc & Dogan, 2025). Furthermore, math teachers in Turkey regard ChatGPT as useful for creating learning materials of linear algebra, probability, and geometry topics. Teachers can easily access relevant knowledge and shape teaching approaches that have a stronger impact on learners (Yanar & Ergene, 2025). In view of the seven studies discussed here in this sub-theme, we observed that AI functions not only as a practical instructional resource that strengthens PSTs' developing professional capabilities but also as a key influence on their cognitive and affective competence for using AI and robotics tools. It supports a more structured, practice-oriented form of participation that PSTs regard as genuinely effective, a point further elaborated in the following paragraph.

Extending the observation of the use of AI and robotics tools as evidenced by five of seventeen studies, Amador-Terrón et al. (2022), Avinc and Dogan (2025), Lee et al. (2025), Yanar and Ergene (2025), and Akosah (2025) indicated that PSTs agree that AI supports active participation of both students and teachers within the STEM educational process. Additionally, Amador-Terrón et al. (2022) investigated how educational robotics enables active participation of Spanish teachers within the math instructional process. In the experimental process, Avinc and Dogan (2025) found that metaverse AI (virtual classrooms and labs) provides prospective primary teachers with opportunities for interactive engagement, immersive experiences, and personalized learning exposure. Similarly, in Korea, future teachers indicated that smart speakers contribute to smoother interaction among students, who often take on expert-like roles when explaining concepts during practical science activities. Furthermore, PSTs' own AI engagement and the quality of their interactive experience are shaped by their prior exposure to technology, ease of using those tools, and dynamics within their teaching groups (Lee et al., 2025; Akosah, 2025). Another study in Turkey identified that preservice mathematics teachers used ChatGPT during the exploration and elaboration stages to access examples of engaging and enjoyable learning activities for learners (Yanar & Ergene, 2025). Analysis of the results of this study indicates that integrating ChatGPT assists PSTs in making a pedagogical shift

toward iSTEM teaching practices by reframing mathematics as a dynamic, interdisciplinary field. With the support of AI and robotics, this shift can amplify personalization, creativity and engagement within integrated STEM teaching. AI and robotics not only stimulate PSTs' involvement but also foster collaboration with their colleagues, a point that is discussed in the next paragraph.

This section clarifies seven studies: Akosah (2025); Amador-Terrón et al. (2022); Avinc and Dogan (2025); Casler-Failing (2021); Casler-Failing and Collins (2022); Lee et al. (2025); and Yorulmaz et al. (2025). These studies highlighted how AI and robotics can boost collective social competences in primary PSTs. Likewise, in studies conducted by Amador-Terrón et al. (2022), Casler-Failing (2021) and Casler-Failing and Collins (2022), PSTs indicated that educational robotics tasks meaningfully strengthened the collaborative dimension of math instructions, particularly through shared game-based activities and structured team discussions. Group work grounded in PSTs socially constructing knowledge and skills together has been seen as a critical factor in these studies. When student teachers engaged with peers, they were able to articulate strategies, offer mutual support, troubleshoot challenges collectively, and deepen their conceptual understanding through dialogue. Correspondingly, the findings of Avinc and Dogan (2025) from a field experiment conducted in Turkey showed that metaverse AI improves collaboration and overcomes social anxieties in science primary PSTs. Evidence from Turkey illustrated this pattern clearly: during experimental research, PSTs collaborated effectively with ChatGPT when generating ideas, formulating questions, requesting storytelling, and proposing STEM instructional techniques (Yorulmaz et al., 2025).

Another two studies conducted in Korea and Gana confirmed that both AI and humans tended to view peers as part of the cooperative learning strategy. Participation in collaborative science learning sessions incorporating smart voice assistant device activities was associated with measurable gains in student teachers' digital pedagogical knowledge scores. Participants recognized the potential of AI to enhance collaborative teaching and learning, noting in particular its role in supporting peer interaction and facilitating more sustained group discussion. The AI-assisted collaborative learning platforms' and intelligent tutoring systems' ability to adjust dynamically based on input appeared to make the instructional process more responsive. Additionally, PSTs experience higher levels of engagement and cultivate a positive learning atmosphere, as AI reshapes interaction patterns by providing adaptive support, enabling collaboration, and creating a safe space for exploration (Lee et al., 2025; Akosah, 2025). Sustained collaborative engagement among educators contributes significantly to professional growth and refinement of problem-solving abilities in PSTs, particularly within digital technology-enhanced teaching environments.

Next, the findings show that AI and robotics support strengthening problem-solving abilities in primary PSTs. Considering the case of five of seventeen studies, Amador-Terrón et al. (2022), Casler-Failing and Collins (2022), Filiz and Gür (2025), Fitzpatrick and Leavy (2026), and Getenet (2024) explored primary preservice teachers' experience with AI technology to enhance their problem-solving abilities. Notably, Filiz and Gür (2025) and Getenet (2024) indicated that ChatGPT practices substantially enhance PSTs repertoire of problem-solving abilities. These capabilities include uploading pictures of mathematical problems, formulating an initial solution, verifying answers, correcting errors, producing graphical representations, constructing tables and exploring alternative solution methods. Similarly, Amador-Terrón et al. (2022) and Casler-Failing and Collins (2022) noted that for future teachers, use of Lego robotics generates numerous benefits, for instance developing mathematical problem-solving abilities and critical thinking skills, which allow connection with abstract concepts, forming reasoning and building concentration. PSTs consistently demonstrated an enhanced growth mindset, evidenced by

sustained perseverance and an unwillingness to disengage when working with robotics. Preservice teachers adopting critical analysis skills towards integrated STEM tasks in Ireland (Fitzpatrick & Leavy, 2026). This research evidence indicates that AI and robotics technology is a critical catalyst for PSTs professional growth. Beyond problem-solving dimensions explained above, further competencies are explored in the following section.

Building on this foundation as an illustration, six out of seventeen empirical studies, Abualrob (2025), Amador-Terrón et al. (2022), Fegely, Gleasman, and Kolski (2024), Fitzpatrick and Leavy (2026), Yanar and Ergene (2025), and Yorulmaz et al. (2025), discussed the development of primary PSTs' intellectual skills due to AI and robotics. Likewise, two studies, Amador-Terrón et al. (2022) and Fegely et al. (2024), integrated educational robotics, namely Lego Mindstorms EV3 robots, into primary PSTs' training in the USA and Spain, promoting specialized skill acquisition. For example, there was a documented emphasis on advanced mathematical reasoning and elevated programming comprehension. In parallel, Yanar and Ergene (2025), and Yorulmaz et al. (2025) reported that ChatGPT supports math primary teachers' development of creative competencies and helps them connect STEM lessons to real-life situations. As exemplified by Copilot, this contributes to the development of PSTs' cognition by exposing them to new ideas, directing their attention toward instructional aspects that may previously have remained outside their perspective. This approach in Palestine not only supports the formation of new educational strategies but also encourages the reconsideration of established concepts (Abualrob, 2025). In addition, teachers began to cultivate a more practical pedagogical toolkit that could support and enrich their understanding of STEM classroom teaching in Ireland (Fitzpatrick & Leavy, 2026). As PSTs experience professional growth, their enhanced instructional capabilities foster significant benefits, exclusively by refining their problem-solving abilities. This advancement further stimulates the adoption of digital technologies and promotes deeper professional engagement. The transition from basic skills acquisition to practical application of AI and robotics in STEM instruction serves to elevate diverse teaching strategies in student teachers.

4.6. Pedagogical Practices of AI and Robotics Integrated STEM Teaching

Grounded in this sub-theme, the findings are presented as follows: six of the seventeen studies, Ceylan and Karakuş (2024), Filiz and Gür (2025), Fitzpatrick and Leavy (2026), Jaipal-Jamani (2023), Yanar and Ergene (2025), and Yorulmaz et al. (2025), discussed that with the integration of AI technology, preservice teachers cultivate heightened awareness, which facilitates improved STEM teaching productivity. Six studies demonstrate that ChatGPT significantly enhanced prospective mathematics teachers' metacognitive awareness. PSTs' productivity is shown to improve particularly during the design phase; moreover, evidence across abundant studies indicates that workshops cultivate PSTs' AI awareness. It enables educators to work more efficiently and save time, thereby significantly improving their professional productivity. Moreover, the experimental study performed by Ceylan and Karakuş (2024) in Turkey revealed that use of AI-powered apps like AImPLANT (Artificial Intelligence-based Mobile Plant Learning Application) supports a significant improvement in plant species identification skills and knowledge for both teacher and student. This shift is primarily attributed to interactive outdoor plant learning activities, which strengthen science education by making abstract or overlooked topics more engaging.

Likewise, in a Canadian study Jaipal-Jamani (2023) pointed out that a scaffolded robotics kits used to include LEGO® Education WeDo v.1.2 leads to significant gains in elementary science pedagogical knowledge for PSTs. Subsequent study findings indicated that preservice teachers developed deeper, richer, and more critical understandings of integrated STEM education, largely attributed to the influence of structured workshops.

Analytically, these participants recognized the inherent versatility of ChatGPT in generating conceptual ideas and curating digital resources. The use of AI serves as a source for acquiring examples of high-quality math lesson plans through iterative practices of verification, reflection and the refinement of initial strategies (Fitzpatrick & Leavy, 2026; Yanar & Ergene, 2025). Furthermore, educators demonstrated an increased reliance on ChatGPT for guidance in the complex task of integrating multiple STEM disciplines (Filiz & Gür, 2025; Yorulmaz et al., 2025). PSTs' operational efficiency is fundamentally linked to the time saved through the integration of AI during instructions. Three out of seventeen studies, Abualrob (2025), Filiz and Gür (2025), and Yanar and Ergene (2025), expressed that the broad experience of primary preservice math teachers confirms that ChatGPT practices facilitate both time efficiency and conservation of instructional effort. ChatGPT enhances pedagogical practices by automating the design of routine mathematics tasks for children, providing instantaneous feedback, and offering clear step-by-step demonstrations of complex activities. To illustrate, the ways in which AI awareness and holistic efficiency cultivate interest and enhance motivation among PSTs are discussed below.

Four studies, Akosah (2025), Amador-Terrón et al. (2022), Avinc and Dogan (2025), and Fegely et al. (2024), discussed AI and robotics-driven motivation in primary PSTs after technology-enabled academic facilitation. Two studies, Akosah (2025) and Amador-Terrón et al. (2022), expressed that the use of educational robotics by future math teachers reinforces their motivational levels during academic activities. Educational robotics activities sustain a notable increase in PSTs' motivation to integrate programming into instruction. Another study in the USA reported that participants in mathematics recognize the potential of AI and robotics to boost intrinsic factors such as personal interest, motivation and general enthusiasm (Fegely et al., 2024). Furthermore, it is observed that metaverse AI increases motivation and interest among both science teachers and students (Avinc & Dogan, 2025). Findings demonstrate that PSTs' motivation to employ AI and robotics during STEM teaching significantly facilitates its usage as a multifunctional STEM integration pedagogy.

PSTs' pedagogical experience suggests that AI and robotics-driven learning ecosystems serve as critical catalysts for professional transformation. As an illustration, five studies, Akosah (2025), Amador-Terrón et al. (2022), Ceylan and Karakuş (2024), Filiz and Gür (2025), and Lee et al. (2025), mutually highlight the evolving practices of primary PSTs regarding the role of AI and robotics within educational contexts. The findings of Filiz and Gür (2025) indicate that primary mathematics PSTs with more extensive ChatGPT experiences perceive it as fundamental supportive tool. Mainly, Amador-Terrón et al. (2022) reported that primary teachers experienced robotics as a multidisciplinary tool that functions as a mediator of students' learning within mathematics. Relatedly, Ceylan and Karakuş (2024) and Lee et al. (2025) emphasized that student teachers reported the Collaborative Learning with AI Speakers (CLAIS) system as a smart voice assistant devices that can interact with learners. It functioned as a model to facilitate explanations during PSTs' training science practical exercises in Korea, particularly assisting in teaching biology at the primary and elementary level. The PSTs' role transitioned toward targeted intervention during occurrences of errors, such as correcting conceptual, procedural, interpretive, and communication mistakes in AI generated content. In addition, teachers engaged with the CLAIS system through navigation, while AI assumed the role of a primary mediator for science knowledge delivery. Moreover, AI tools functioned as a facilitator among PSTs providing essential support, scaffolding hints and guided solutions for complex mathematical equations (Akosah, 2025).

Supporting the prior arguments, two scholarly investigations further demonstrate the efficacy of smart tech-assisted learning approaches. In this regard, one study highlighted that educational robotics facilitates more practical and manipulative mathematics

learning within peer-to-peer and teacher–student interactions (Amador-Terrón et al., 2022). Similarly, the application of theoretical knowledge through metaverse AI offers diverse opportunities for virtual laboratories, digital meetings, interactive lessons, and theatrical simulations (Avinc & Dogan, 2025). On a similar note, to reinforce both previous claims, two inquiries explored an AI-facilitated aspect that enhanced the quality of learning. In connection with this, Lee et al. (2025) found that collaborative sessions involving smart speakers significantly increased digital pedagogical knowledge scores among student teachers, fostering a positive and engaging learning environment. Furthermore, in separate research, primary preservice mathematics teachers utilized ChatGPT specifically during exploration and elaboration stages of the instructional process to identify high-engagement activities (Yanar & Ergene, 2025). Prospective teachers observe that AI and robotics tools encourage more active participation within instructional processes. Once trainee teachers gain a comprehensive understanding of a multi-dimensional pedagogical technology infrastructure, they are better positioned to facilitate students' academic growth and support personalized learning experiences.

Of the seventeen studies reviewed, five, Amador-Terrón et al. (2022), Avinc and Dogan (2025), Casler-Failing (2021), Jaipal-Jamani (2023), and Saleh et al. (2023), indicated that AI and robotics facilitated educators in aiding learner development. Two studies, Amador-Terrón et al. (2022) and Avinc and Dogan (2025), clearly stated that robotics enhances engagement of the learning process, effectively reducing student apprehension toward complex subjects. Educational robotics assists child development, promoting curiosity and creative imagination. Likewise, the metaverse is transforming science instructions into an immersive format that actively arouses student inquiry. Another study conducted in the USA mentioned that PSTs gained professional confidence and reflected their TPACK development by designing and delivering AI-integrated lessons that support learner academic growth (Casler-Failing, 2021).

In elaborating the pedagogical repertoire of AI and robotics integrated STEM teaching practices, adaptive expertise in science teaching (AEST) boosts self-efficacy for both students and teachers. Moreover, scaffolded robotics involvement results in statistically significant gains in PSTs' self-efficacy compared to self-guided interventions (Jaipal-Jamani, 2023; Saleh et al., 2023). Students' academic success is contingent upon the satisfaction of specific learning demands; therefore, the subsequent claim regarding artificial intelligence emphasizes its role in aligning instruction with learners' needs. To demonstrate, Avinc and Dogan (2025) argued that primary PSTs observe how the metaverse is used as a mechanism to facilitate virtual lab attendance, generate virtual cues during experiments, and enable interaction with 3D models of the ecosystem without barriers. For example, PSTs can ensure both operational ease and greater inclusiveness for students with diverse needs/disabilities by bridging accessibility gaps and providing adaptive simulations within science classrooms. Simultaneously, In Palestine Abualrob (2025) reported that teachers experience Copilot compatibility as aligning with students' needs. When PSTs actively contribute to fulfilling learning requirements through AI and robotics, they markedly influence academic outcomes. To exemplify, Ceylan and Karakuş (2024) stated that teachers in Turkey found that utilization of an AI-based mobile app during outdoor activities and acquiring plant knowledge led to a significant enhancement in student academic performance and satisfaction.

In connection with the above outcomes, the analysis presented implies that PSTs' practices with AI and robotics tools strengthen communication channels between teachers and learners. Technology functions as an alternative pathway to academic success by enabling rapid, meaningful evaluation that enhances the efficiency of knowledge acquisition. As an illustration, Amador-Terrón et al. (2022) discussed that the WeDo 2.0 robot improves communication channels both among peers and between teachers and students

by fostering a collaborative teamwork, encouraging dialogue and reflective practices through hands-on robotics tasks. Similarly, participants experienced improved communication through metaverse AI, explicitly within the domain of education and healthcare (Avinc & Dogan, 2025). On the other hand, in the USA Casler-Failing (2021) highlighted that primary PSTs observe the immediate feedback provided by the LEGO robotics. This is facilitated by AI features of coding integration and sensors that promote learning through active reflection and collaborative discussion. All the benefits found in the studies explained under this theme in relation to AI and robotics integrated pedagogical practices are instructional efficiency, effective pedagogical ecosystem, PSTs' motivation for collaborative engagement, and learners' academic growth, which are reinforced by effective communication and synchronous feedback. Artificial intelligence and robotics tools holistically accelerate both teaching and learning improvements. In Table 3 below, the key findings and research focus of each article are presented in detail.

Table 3. Key findings: PSTs' perceptions of AI and robotics integrated practices in STEM.

Author(s)	Study Focus/Purpose	Summary of Findings
Casler-Failing (2021)	Learning to teach mathematics with robots: developing the "T" in TPACK.	• Lego robotics enabled collaboration, instant feedback, and reflective dialogue. • PSTs gained confidence and demonstrated their TPACK development by designing and teaching math lessons.
Amador-Terrón et al. (2022)	Teaching mathematics with support of robotics.	• WeDo 2.0 robot as a highly useful and supportive tool. • Both cognitive and emotional benefits were seen for students. • Robotics as a multifaceted aid for participation, motivation, communication, skill development, and collaborative learning.
Casler-Failing and Collins (2022)	Learning with robots: teaching and supporting productive struggle in a math methods course.	• Initially PSTs had no firsthand experience using robotics in maths lessons. • Through collaborative workshop tasks, PSTs developed a growth mindset, critical thinking and key problem-solving skills.
Saleh et al. (2023)	Attitudes toward integrated STEM teaching and adaptive expertise among preservice primary science teachers	• PSTs generally expressed positive attitude toward integrated STEM teaching. • Adaptive expertise fosters high self-efficiency, enhances perceived relevance and lowers anxiety.
Jaipal-Jamani (2023)	PSTs' science learning and self-efficacy for teaching with robotics-based activities.	• Scaffolded robotics such as LEGO education strengthen PSTs' self-efficiency and expand their science knowledge.
Filiz and Gür (2025)	Students' perceptions and applications of metacognitive awareness during problem solving with ChatGPT	• Mathematics PSTs valued ChatGPT as an effective, supportive, time-saving, and strategy-enhancing tool in STEM education. • Use ChatGPT for verification, error correction, and strategy refinement. • Varying depths of metacognitive engagement among PSTs.
Ceylan and Karakuş (2024)	Assessing science PSTs' virtual plant collection projects using an AI app for plant blindness and knowledge.	• AI app as a facilitator of satisfaction, learning, and deeper awareness in science education. • AI app plus outdoor learning is seen as effective and transformative in biology education.
Avinc and Dogan (2025)	Metaverse experiences shaping pre-service science teachers' perspectives.	• Metaverse fosters personalized, curiosity-driven learning, supporting social development, and greater accessibility and inclusion. • Design-based activities increased PSTs' motivation, collaboration, confidence, and acceptance of metaverse technology.

Fegely et al. (2024)	Educational robotics as a maker-learning tool for PST computer science instruction.	• LEGO-robot activities boosted PSTs' motivation and supported development of programming skills. • PSTs hold a positive perception of integrating educational robotics into their teaching.
Lee et al. (2025)	Preservice science teachers' responses to an AI speaker collaborative learning prototype	• Smart devices act as mediators, promoting interactive collaboration between AI and humans. • Positive experience led PSTs to enhance their AI-integrated technology competencies.
Getenet (2024)	PSTs and ChatGPT in multi-strategy problem solving: implications for primary mathematics teaching	• PSTs expressed an adverse perception toward AI because ChatGPT lacks flexibility and diversity. • Teachers often rely heavily on algebraic equations when practicing mathematics tasks.
Yorulmaz et al. (2025)	Enhancing STEM lesson plans: primary PSTs' collaboration with ChatGPT.	• ChatGPT supported collaboration and enabled PSTs to produce higher-quality STEM lesson plans with greater productivity. • ChatGPT promotes PSTs' creative thinking skills and helps connect lessons to real-life situations.
Yanar and Ergene (2025)	Integrating AI in education: how mathematics PSTs use ChatGPT for 5E lesson-plan design.	• Math PSTs have no prior experience with ChatGPT or only minimal interaction. • Teachers expressed positive intention to use AI in future lesson planning. • ChatGPT is viewed as time-efficient, creativity-enhancing for math PSTs, and overall highly beneficial.
Akosah (2025)	AI-assisted collaborative learning in mathematics education.	• AI acts as facilitator in PSTs' group discussions, offering guidance and boosting motivation. • Math teachers recognize potential of AI tools for collaborative learning, and peer interaction helps foster positive teaching learning environment.
Lee and Zhai (2024)	PSTs using ChatGPT for science lesson planning.	• PSTs showed moderate competency and emerging awareness in using ChatGPT for science education. • Teachers used AI to support cooperative learning, but fully leveraging its instructional value will require deeper training and familiarity. • PSTs recognised ChatGPT's potential for individualized support, questioning, and formative assessment.
Abualrob (2025)	How PSTs use AI to teach science to Year 4 students.	• Copilot was mostly applied in lesson planning, instructional strategies and authentic assessment design. • Teachers used AI to recall prior concepts, saving time, and foster cognitive growth tailored to student needs.
Fitzpatrick and Leavy (2026)	PSTs' evolving understandings of integrated STEM education.	• Working with pedagogical robotics deepened PSTs' understanding of how to teach integrated STEM. • Robotics toolkits support teachers in building critical perspectives and strengthening their STEM task skills.

5. Discussion and Conclusions

The initial part of this review paper investigated primary PSTs' perceptions and practices regarding AI and robotics technology-driven STEM instructions. The synthesis of the literature revealed that, while PSTs possess a moderate level of AI and robotics knowledge and limited prior experience, they maintain a highly receptive attitude toward future technological integration. Simultaneously, PSTs acknowledged the efficacy of AI and robotics practices in STEM education as a primary driver for building pedagogical awareness, fostering collaboration, and stimulating active participation. These practices serve as a motivational framework that improves communication channels and provides structured

guidance within diverse learning approaches. All 17 studies were conducted outside of Australia (for example, Turkey, Spain, USA, Canada, Palestine, Gana, Korea, Bahrain, and Ireland) and primarily focused on the use of general Artificial Intelligence, and educational robotics in STEM or mathematics teaching practices, while engineering-related concepts were missing. These studies either overlooked or only minimally addressed primary PSTs' perspectives on AI and robotics use in science teaching and on integrated STEM pedagogical practices within academic settings.

To situate these findings within a broader international context, this section presents a global comparison of PSTs' perceptions of AI and robotics-based STEM practices. Most of the studies included in this review come from the Middle East region, particularly Turkey, Palestine, and Bahrain. Results from five studies conducted in Turkey show that PSTs significantly improved their mathematics teaching by integrating ChatGPT as an assistive tool (Filiz & Gür, 2025; Yorulmaz et al., 2025; Yanar & Ergene, 2025). Two additional studies from Turkey highlighted the importance of AI mobile applications and Metaverse tools in supporting PSTs to design science activities (Ceylan & Karakuş, 2024; Avinc & Doğan, 2025). The study by Abualrob (2025) indicates that PSTs in Palestine used Copilot for lesson planning during their teacher training program. Similarly, Saleh et al. (2023) conducted a study in Bahrain that investigated PSTs' attitude and perceptions toward use of adaptive expertise in teaching science concepts. All these studies collectively show that PSTs in the Middle East region hold an optimistic attitude toward using AI in lesson planning and instructional design. However, studies reported above indicate no evidence of robotics tools being used in primary classrooms to enhance STEM teaching in this region.

The second highest number of studies documented in this review comes from the North American region, particularly from the USA and Canada. Three studies from the United States demonstrated benefits of LEGO robotics for PSTs, notably in improving mathematics teaching, additionally fostering science motivation in students through programming activities (Fegely et al., 2024; Casler-Failing & Collins, 2022). In a similar way, one study from Canada examined the use of scaffolded robotics kits for teaching science concepts and revealed positive outcomes (Jaipal-Jamani, 2023). On the other hand, research conducted by Lee and Zhai (2024) in the USA emphasized the significance of ChatGPT for designing assessments in primary STEM classes. Overall research evidence from this region synthesized in this review shows that developed countries like the USA and Canada are adopting robotics tools as teaching aids, rather than being a replacement tool for teachers' planning, curriculum innovation practices. Therefore, providing PSTs with training during their teacher education studies is imperative to build their confidence in using AI and robotics tools for primary STEM teaching. The third most dominant continent represented in this review is Europe, including Spain and Ireland. Both countries apply pedagogical robotics as foundational technology toolkits, for instance the WeDo 2.0 robot in integrated STEM training and particularly in mathematics teaching. The results show that robotics tools improve and strengthen cognitive, critical and effective skills in both students and PSTs during collaborative tasks (Fitzpatrick & Leavy, 2026; Amador-Terrón et al., 2022). Evidence from European countries also supports the use of robotics in primary STEM education, based on findings from articles included in this review. This scoping review poses international implications for policy and curriculum designers to consider the study findings while innovating their STEM courses. For example, they could strategically embed AI and robotics tools as a supportive tool for STEM integration, strengthening educators' practices in an effort to build PSTs' digital competence and confidence, as they begin to prepare PSTs' journeys of becoming digital-savvy and employable STEM teachers.

Continuing the comparison across a global context, only one study reported in this review comes from the African region, notably Ghana. In this study, PSTs used AI as an

assisted collaborative tool during mathematics teaching and recorded positive findings (Akosah, 2025). Likewise, only one study presented in this review comes from the Asian region, namely South Korea, which highlighted the importance of AI speakers. PSTs use AI speaker devices as collaborative tools to promote the STEM teaching–learning process (Lee et al., 2025). Generally, the above evidence indicates that both continents targeted AI-based resources more than robotics tools in efforts to improve STEM teaching. This global comparison situates the findings within an international context and indicates that the Middle East, African and Asian regions are more inclined toward the use of AI-based resources. Conversely, North America and Europe are gradually moving toward the application of robotics tools in primary classrooms. However, this claim is not generalizable because it is based on evidence from only seventeen studies included in this review, which limits the strength and scope of the findings. Moreover, the review includes only one study from the Oceania region, which was carried out in Australia and focused on the use of ChatGPT in mathematics teaching. Since AI-interfaced robotics tools have not yet been applied in STEM teaching in this region, the model (Figure 3) conceptualized from this review can therefore be used as a potential framework for further research. Globally, there are implications for future research on how AI and robotics-based technologies can enhance PSTs' digital competency. The model details are discussed in the upcoming paragraphs.

This review enables supportive perspectives on the implications and adoption of integrated AI and robotics into primary STEM education. The analysis provides guidelines as a conceptual framework (see Figure 3) for primary, elementary, and initial phase academic learning centers of AI and robotics-integrated STEM programs. The goal is to support preservice teachers in STEM lessons to deliver rich, contextually and developmentally appropriate AI and robotics tech-integrated learning experiences to primary students. The scoping review results can guide future studies in AI and robotics integration for STEM-related research focusing on workshop arrangement for PSTs' professional development. The implications of our study findings provide a pedagogical practice lens to use our conceptual framework to guide, analyze and interpret future study data about AI and robotics integration, which will allow sustained, highly relatable, authentic STEM education pedagogies. Our conceptual framework can be seen and used as a baseline example to test, refine and develop adaptive frameworks suited to the curriculum and policy levels for best AI and robotics integration in primary STEM education.

The conceptual model derived from the literature contributes to STEM education development both theoretically and practically. The model exemplifies the relationship between STEM, pedagogy, AI and robotics. Systematic integration of AI and robotics tools into pedagogical design supports PSTs' professional development and enhances students' academic outcomes. As depicted in the framework in Figure 3, PSTs' readiness, pedagogical openness and growth mindset are closely linked to how effectively they integrate AI and robotics tools into their STEM teaching. To illustrate, PSTs' productive use of AI and robotics in STEM lesson planning, instructional design and teaching aid depends on their readiness. Equally, teachers' STEM pedagogical openness relies on their adoption of innovative approaches, including use of AI and robotics for authentic assessment and discovery learning. Alongside this, when PSTs use AI-generated feedback on student work and performance, they simultaneously demonstrate and strengthen their professional growth mindset.

Similarly, findings from the literature indicate that the use of AI and robotics tools as pedagogical support, particularly in STEM instructional planning, enhances and strengthens students' foundational skills. Holistically, the AI resources and robotics tools enriched students' skill development, collaborative engagement, problem solving abilities and metacognitive awareness. For example, collaborative engagement among students is elevated

through AI-supported discovery learning, which encourages participation by providing interactive and group-focused STEM tasks. Likewise, AI-generated assessment STEM tasks that require reasoning help develop learners' problem-solving abilities. In the same way, students' metacognitive awareness and thinking processes are accelerated through personalized immediate feedback that AI tools provide.

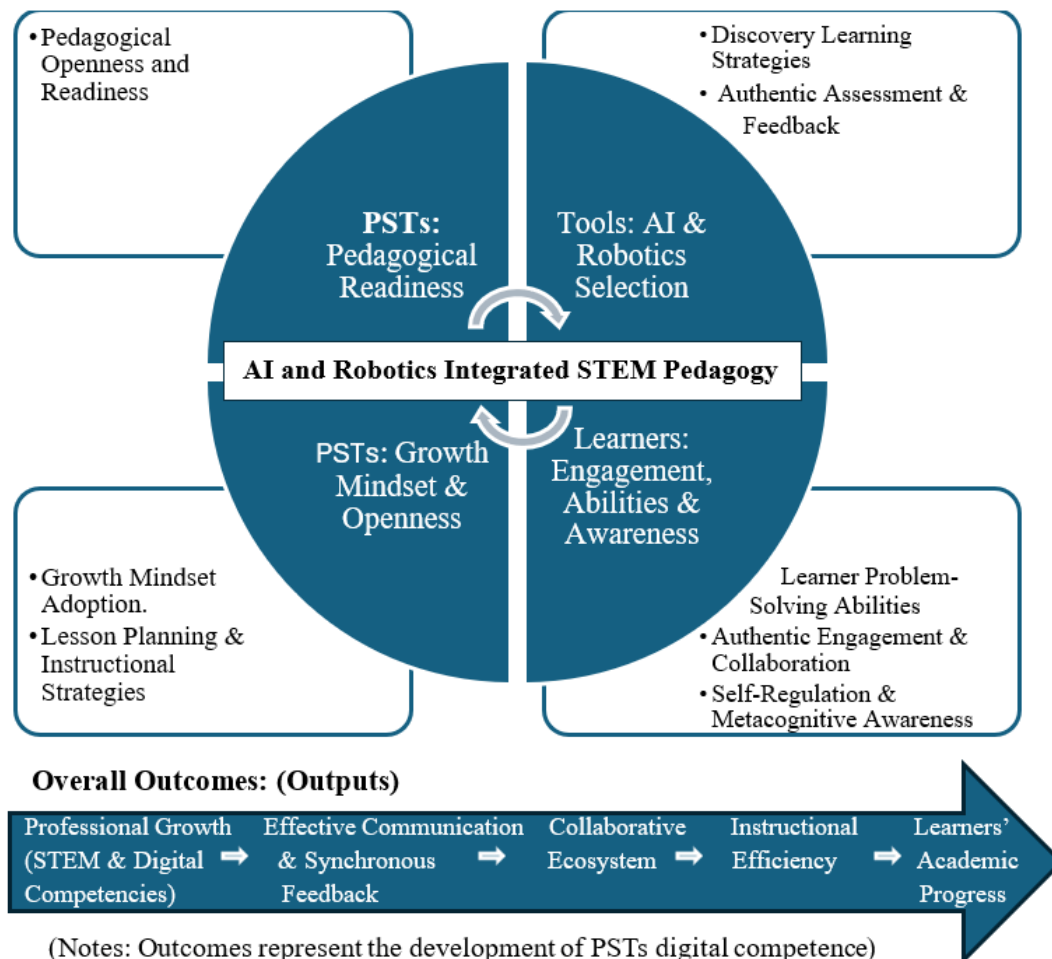


Figure 3. Inputs and outputs of AI and robotics integrated STEM pedagogical model: conceptual framework.

To explain further, AI works not only as tool but as a solution that transforms STEM disciplinary directions and reshapes the pedagogical landscape through its meaningful integration (Espinoza, 2026). A reciprocal and transformative relationship exists between STEM, pedagogical practices, AI and robotics tools. For instance, AI and robotics reshapes STEM learning by acting as a mediating layer that challenges traditional pedagogical approaches and as such, opens doors to teachers' critical thinking while planning for STEM integration practice. STEM disciplines focus on problem solving, exploration, and experimentation, which directs the ways in which AI and robotics are used. As a result, both PSTs and students act as central agents in adopting this AI and robotics integrated STEM pedagogical model, ensuring that it augments rather than replaces their critical thinking and reasoning.

AI and robotics integrated STEM pedagogy, positioned at the center with learners', PSTs', AI and robotics tools linked as its three interconnected nodes, operates through dynamic interaction. The model shows how PSTs select and use AI and robotics-supported tools during instructional planning, shaping students' STEM learning. Initially, with the support of AI and robotics tools, PSTs create adaptive, inquiry-driven, and data-

rich STEM learning environments that develop students' core skills. Simultaneously, teachers' STEM pedagogical skills improve through feedback generated from students' AI-based performance insights. Hence, teachers' guided use of AI and robotics collectively improves the teaching and learning process, refining ongoing pedagogy and supporting a more coherent STEM educational ecosystem.

The collaborative work of model-internal components leads to the achievement of overall outcomes represented at the outer edge of this model. AI and robotics contribute to improving PSTs' instructional efficiency by streamlining planning to assessment processes. Accordingly, teachers' continuous professional growth in STEM and digital AI competencies is closely linked to adaptive pedagogical disposition. Moreover, to strengthen communication and feedback systems for both PSTs and learners, an AI and robotics-enabled collaborative ecosystem is essential. As a result, students' academic progress naturally accelerates when all these elements operate together.

Collectively, the achievement of students' learning outcomes and teachers' professional growth depends on how effectively progressive technologies (AI and robotics) are implemented. Therefore, successful AI and robotics integration is ultimately determined by how PSTs and students work together in synergy to make STEM teaching and learning productive within this model. This demonstrates that AI and robotics tools alone do not improve learning; rather, their implementation does. Hence, overall outcomes depend on how it is used.

6. Study Limitations and Future Directions

This study has a few limitations, including the relatively small number of papers, albeit they are bespoke studies in the field of AI and robotics in STEM integration practice that met the inclusion criteria. The review focused on scholarly work published between 2021 and 2025, a period often regarded as the early generative AI-driven robotics era. Additionally, we considered only articles published in English, which led to the exclusion of potentially relevant studies in other languages. As a result, findings may have limited generalizability to more diverse educational contexts. Furthermore, this paper may not fully capture global perspectives on AI and robotics in the teaching and learning process. However, we strategically targeted studies in initial teacher education that focused on preparing PSTs for STEM teaching. It can be argued that future research should adopt a broader timeframe of 10–15 years and include in-service teachers and school leaders, in order to better understand how progressive educational technologies work in STEM and also to incorporate publications released in other languages to understand studies done in the Global South as well.

This scoping review is intended to inform our future research in the Australian primary education context. For this reason, comparisons were made with Australian studies. However, this has been acknowledged as a study limitation, and it is recommended that future research incorporate comparative analyses across international curriculum contexts. Moreover, most of the studies included in this review focus on the use of AI and robotics in mathematics, particularly in areas such as problem solving and reasoning. Therefore, future studies should more deeply investigate how AI and robotics integration differs across STEM sub-domains, including applications in scientific experimentation, observational inquiry and engineering teaching practices at the primary level. This gap is also highlighted in the discussion and conclusion section of this review, as no detailed analysis or comparison was conducted within or across each of the STEM sub-domains. Hence, future research should investigate how AI and robotics integration functions across science and integrated STEM contexts internationally and within Australia. Future research should also consider applying and adapting this study's conceptual framework

(Figure 3) to demonstrate the relationship between STEM, pedagogy, AI and robotics across varied cultural and educational contexts.

7. Conclusions

To summarize, this scoping review consolidates current perceptions and practices related to AI and robotics integrated STEM teaching. The paper examines current gaps in the literature on integrating AI and robotics in primary STEM education. In addition, the review reveals how AI and robotics integration across STEM disciplines is interpreted and highlights current approaches to integration. Future research should address challenges of incorporating advanced technology into STEM teaching in primary schools and offer recommendations for more rigorous AI and robotics integration and measurement of PSTs' growth mindset, professional learning, STEM and digital competencies as well as outcomes for learners. Furthermore, the question of how to guarantee equal opportunity and accessibility for prospective STEM teachers is central to the discussion. Thus, there is an urgent need for STEM teacher education courses and teacher educators to build targeted environments where PSTs can practice AI and robotics integrated STEM teaching during placements.

The core AI and robotics contributions identified in the review are awareness building, efficient work performance, problem-solving abilities, and teachers' skill development. Furthermore, AI and robotics facilitate diverse teaching strategies, encourage teachers' active participation, and promote coordination with colleagues such as their placement mentors and peers. In addition, teacher educators' motivation to employ AI and robotics in STEM teaching supports a personalized learning experience for PSTs. As a result, AI and robotics should be used to facilitate PSTs' educational growth, satisfying learning demands and influencing academic outcomes, reinforced by persuasive communication and timely feedback.

Although challenges occur, they should not deter PSTs from prioritizing AI and robotics integrated STEM teaching. This causes consistent switching of teachers' pedagogy and aligning their lessons according to the contemporary needs of their learners. The review results pertaining to each dimension of the research question serve as a guidance framework for conducting meaningful AI and robotics integrated STEM training workshops for PSTs to optimize their teaching practices in our potential study. The AI versatility offers an opportunity to be integrated not only into every STEM discipline's class, but also to accommodate general subjects' curriculum standards within diverse educational settings. It also allows PSTs to collaborate with students during their placement experiences and pilot lesson sequences to build holistic inclusive classrooms and simultaneously develop not only their own digital competence, but also their students' AI literacy skills.

The review identified gaps in the literature across populations from countries at all levels of economic development. Notably, the absence of any empirical inquiry in Australia indicates an under-explored area. The emerging field requires further investigation and conceptualization of AI and robotics in STEM integration practices as part of a learning continuum at the primary school level in Australia. The review primarily centers on the use of AI and robotics in either math or STEM subject areas, without particular attention to science or other integrated STEM fields that remain outside the currently highlighted evidence. Moreover, only a limited number of studies employ AI-powered robotics as a pedagogical tool in the organization of PSTs' workshops. Therefore, additional research and further discussion on AI-powered robotics integration in primary STEM teaching are needed, particularly to inform the design and organization of classroom workshops on robotics implementation. Several studies are presented here that suggest continued investigation in this field.

For example, Casler-Failing and Collins (2022) and Amador-Terrón et al. (2022) suggested that comparative studies be undertaken in future research to examine outcomes before and after implementation of LEGO robotics intervention sessions in P-12 classroom settings by PSTs. Likewise, Avinc and Dogan (2025) and Yorulmaz et al. (2025) recommended future studies on the long-term effects of workshops, to explore transferability of skills and potential metaverse AI risks. As stated by two studies, Lee et al. (2025) and Akosah (2025), teacher educators, school-based teachers who act as mentors during PSTs' placements, are required to prioritize improved methods for fostering human–AI partnerships and to examine the role of specific AI features in enhancing teamwork and collective productivity. Similarly, prospective teachers may cultivate critical evaluation skills to identify biased AI information and thereby provide a clearer understanding of how such technologies can best support educational objectives in ethical and safe manners. In addition, there is a need for more in-depth research on the role of generative AI in science learning (Lee & Zhai, 2024; Abualrob, 2025).

This general review creates an understanding of the impact of AI and robotics integration in the STEM field. It provides a foundation for further inquiry within a specific region (namely, Australia) and in real-world settings with PSTs and teacher educators as curriculum designers, to be pursued in future research. Teaching approaches that align with AI and robotics integration across STEM disciplines should be the subject of future research studies.

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