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Systematic Review

Educational Approaches with AI in Primary School Settings: A Systematic Review of the Literature Available in Scopus

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Abstract: As artificial intelligence (AI) becomes increasingly prevalent, it has become a topic of interest in education. The use of AI in education poses complex issues, not only in terms of its impact on teaching and learning outcomes but also in terms of the ethical considerations regarding personal data and the individual needs of each student. Our study systematically analyzed empirical research on the use of AI in primary education, specifically for children aged 4–12 years old. We reviewed 35 articles indexed in SCOPUS, filtered them according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, analyzed them, and categorized the findings. The research focused on the studies' objectives, learning content, learning outcomes, learning activities, and the pedagogy of activities or the AI tools. Our categorization resulted in three main categories of research objectives regarding the creation, implementation, and evaluation of AI tools and five categories for learning content: AI and ML (machine learning) concepts in STEM and STEAM, language learning, mathematics, arts, and various other subjects. The learning activities were split into four categories: apply, engage, interact, use; project-based learning with multiple activities; experience and practice; and students as tutors. The learning outcomes were split into three levels: cognitive, affective, and psychomotor. The pedagogy of AI tools falls into four categories: constructivism, experiential learning, AI-assisted learning, and project-based learning. The implications for teacher professional development are discussed.

Keywords: artificial intelligence; AI education; AI applications; primary school; preschool; kindergarten; systematic review

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Citation: Aravantinos, S.; Lavidas, K.; Voulgari, I.; Papadakis, S.; Karalis, T.; Komis, V. Educational Approaches with AI in Primary School Settings: A Systematic Review of the Literature Available in Scopus. *Educ. Sci.* **2024**, *14*, 744. https://doi.org/10.3390/educsci14070744

Academic Editors: Irina Engeness and Siv M. Gamlem

Received: 5 June 2024
Revised: 24 June 2024
Accepted: 4 July 2024
Published: 6 July 2024

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1. Introduction

The term "artificial intelligence" (AI) can be defined in sufficient detail by encompassing its various aspects, which include the ability to achieve complex goals in complex environments, the explanation and simulation of intelligent behavior with computational processing in the context of rationality and logical reasoning, and the demonstration of behavior and intelligence that simulates human behavior and intelligence to achieve specific goals [1,2]. From the outset of AI, there has been a connection with the field of education that was driven by the desire of its pioneers to link AI to the learning process, to understand both how AI and learning work, as they emphasized the importance of cognitive science for the development of AI for educational purposes [3]. Nowadays, as the impact of AI increases and permeates more areas of our daily lives, the scientific field of education can not remain unaffected. Therefore, a rise in artificial intelligence in education (AIEd) research has been observed [4,5].

Additionally, over the last five years, some systematic reviews have tried to figure out the trends of AI and its educational implications. Specifically, Younis et al. [6] examined the applications of robots and natural language processing in education by studying 82 scientific articles from 2014 to 2023 with students of all ages. Even though their systematic review suggests that these technologies can provide feedback and personalized instruction, facilitate collaborative learning or critical thinking, and promote inclusivity, student engagement, and teacher support, they have not focused on learning content and activities or pedagogy of the AI applications. İpek et al. [7], in their systematic literature review of educational applications of ChatGPT with 40 studies from December 2022 to February 2023 and unspecified student ages, categorized ChatGPT's use into positive and negative themes and focused on the implications, challenges, or potential effects of integrating ChatGPT into education and not on its pedagogical use or learning approaches. Positive use, relative to the education field, includes abstracting, literature review, generating literature, translation, and paraphrasing, generating complex and deep answers for exams, identifying students' needs earlier, personalized learning experiences, grading and assessment, data analysis, prevention of cybercrime and cyberbullying, helping people to study, etc. On the other hand, potential problems with the use of ChatGPT can be cheating, creating bias, generating incorrect answers, and legal and ethical issues.

More related to our research aim are the following reviews. The systematic literature review on teaching and learning machine learning (ML) by Sanusi et al. [8] was not limited to a specific year range of research for its 43 articles, and even though about half included our target age of participants, it focused partly on pedagogy and not at all on learning activities or outcomes. The research explored ML teaching and learning in K-12 education from four development perspectives: curriculum, technology, pedagogical approaches, and professional development. The findings revealed that there needs to be more research on curriculum development, teacher professional development, and training in the context of ML. Additionally, there is a need for more ML resources for preschool and middle school levels and further evidence of the societal and ethical implications of ML.

Furthermore, Yim and Su [9], in their scoping review of AI learning tools in K-12 education with 46 studies from 1995 to 2023, more than half of which related to the preschool and primary school ages, focused on learning tools, learning outcomes, and the significance of innovative pedagogical strategies involved, but were mainly engaged to the context of AI literacy, exploring the way AI should be taught and not the way of teaching with AI. The review by Su et al. [10], which aimed to examine the thematic and content analysis of 16 empirical papers from 2016 to 2022, also identified challenges and opportunities emerging in digital literacy in early childhood education (ECE). However, although it addressed the learning content, pedagogies, and learning outcomes, it did not analyze the learning activities or consider students aged 6 to 12. The results point out challenges like teachers' need for more AI knowledge, skills, and confidence and the lack of teaching guidelines or an appropriate curriculum design; on the other hand, they point out opportunities for students to enhance digital literacy skills and attitudes. Su and Yang [11] also conducted a scoping review. They analyzed 17 studies from 1995 to 2021 about AI in ECE regarding research methods, AI tools and knowledge, activities, and impacts on teaching and learning. The researchers demonstrated improvements in teaching and learning, but more research is needed on AI tutoring systems for younger students. Although the review focused on ECE, AI literacy, and learning activities, there was no reference for the learning content or learning outcomes. The literature review of 39 papers from 2018 to 2022 by Crescenzi-Lanna [12] about human–machine cooperation in education and its ethical implications was also concentrated solely on ECE; it noted that AI challenges are present in ECE in terms of data privacy, and it also examined other aspects of AI in educational settings such as data collecting and processing and predicting events related to students' success and assessment, but it did not mention any pedagogical or learning aspect.

This work aims to present a systematic review providing valuable insights about the research trends for the educational applications of AI in preschool and primary school (age range 4 to 12). With this systematic review, we will cover the scarce presentations about the pedagogical approaches of AI in education in previous systematic literature reviews and the lack of empirical evidence for the students of our target age. Previous systematic literature reviews to date are limited and have either focused scarcely on different aspects of AI, involved a broader or narrower age range of students, or partially addressed the learning dimension, so we focused on filling this gap. A pedagogical approach to the integration of AI into educational environments can be the catalyst for redesigning the curriculum and transforming teacher education, as educators not only have positive attitudes about implementing AI in the classroom and its positive outcomes, but they are also willing to enhance their knowledge and skills with professional training [13]. Through adopting innovative pedagogical approaches with AI technology, it will be possible to establish new practices that optimize teaching processes and meet students' individualized needs to assist them in acquiring essential skills like critical thinking and problem-solving [14]. With all this ongoing development of existing and the design of new tools, the educational system is on the verge of a significant shift that will affect future approaches [15]. Educational policymakers, educators, counselors, and other stakeholders such as parents, local communities, and students are affected by all these rapid changes, so the scientific community should be ready to provide the needed answers.

2. Research Objectives and Questions

We aimed to systematically review empirical articles related to the educational implementation of AI in preschool and primary education and to examine the latest trends in the research field. More specifically, we explored the SCOPUS-indexed literature on integrating AI into education settings for our age group with a pedagogical focus. The age range includes students from early childhood education (4 years old) to the upper grade of primary school (12 years old). This paper will focus on (a) the research objectives of the articles reviewed, (b) the learning content, (c) the learning activities, (d) the learning outcomes, and (e) the pedagogy of the activities or the AI tools used. The research objectives refer to what the authors of each study state about their aim for conducting the specific research, and the learning content refers to the specific lesson, course, or subject being taught with the aid of AI [11]. The learning activities refer to the activities that students engage in during the learning process, and the learning outcomes refer to what the students are learning regarding cognitive or non-cognitive skills [16]. The cognitive learning outcomes refer to specific skills and knowledge, whereas the non-cognitive learning outcomes include skills like cooperation, communication, critical thinking, problem-solving abilities, and motor skills [10]. The pedagogy of the activity or the AI tool is the one described in the studies for the design of the learning activities or the AI tools that are used in each case and can refer to various pedagogical approaches like direct instruction, inquiry-based learning, design-oriented learning, collaborative learning, interactive learning, project-based learning, hands-on activities, and participatory learning. To design an effective pedagogical model, elements like objectives, content, strategy, group organization, time and space allocation, selection of resources, evaluation, and feedback should be considered [17].

Our research questions were as follows:

RQ1: What are the objectives of the studies regarding the implementation of AI?

RQ2: What is the learning content of the teaching process with AI?

RQ3: What learning activities do students engage in each study with AI?

RQ4: What are the learning outcomes regarding cognitive and non-cognitive skills?

RQ5: What are the pedagogies of the activities or AI tools used?

3. Methods

For our research, we used SCOPUS as a single database with unrestricted access because of its content coverage, its convenience and practicality, and its more trustworthy impact indicators, which cannot be manipulated as easily as those provided by WOS [18]. The choice of SCOPUS has also been decided since it may offer better specialized coverage in this field of human–computer interaction, which is highly relevant to our review [19]. The string query for the search that occurred in January 2024 was the following:

TITLE-ABS ((preschool OR pre-school OR “primary school” OR “elementary school” OR “early years”) AND “artificial intelligence” AND (us* OR utiliz* OR implement* OR intervent*)) AND (EXCLUDE (SUBJAREA, “MEDI”) OR EXCLUDE (SUBJAREA, “HEAL”) OR EXCLUDE (SUBJAREA, “BUSI”) OR EXCLUDE (SUBJAREA, “BIOC”)) AND (LIMIT-TO (DOCTYPE, “cp”) OR LIMIT-TO (DOCTYPE, “ar”) OR LIMIT-TO (DOCTYPE, “cr”)) AND (LIMIT-TO (LANGUAGE, “English”)).

Figure 1 presents the process of the method we have chosen for identifying and screening the articles, which follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for systematic literature reviews [20]. For the screening process, we used only empirical studies and focused on educational applications of AI in school settings from early childhood to the highest grade of primary school. The index search yielded 194 entries, of which 3 were duplicates, 18 were excluded by title, 32 by abstract, 58 were unavailable, and 1 was unreachable. After removing the above, we ended up with 82 articles, of which 3 were previous systematic literature reviews, 3 were retracted, 2 were not full papers, 16 were theoretical, and 23 referred to technical terms about the computer systems used in AI for education, so they were not directly related. An overview of the final 35 empirical studies that met the inclusion criteria for the review can be found in Table A1.

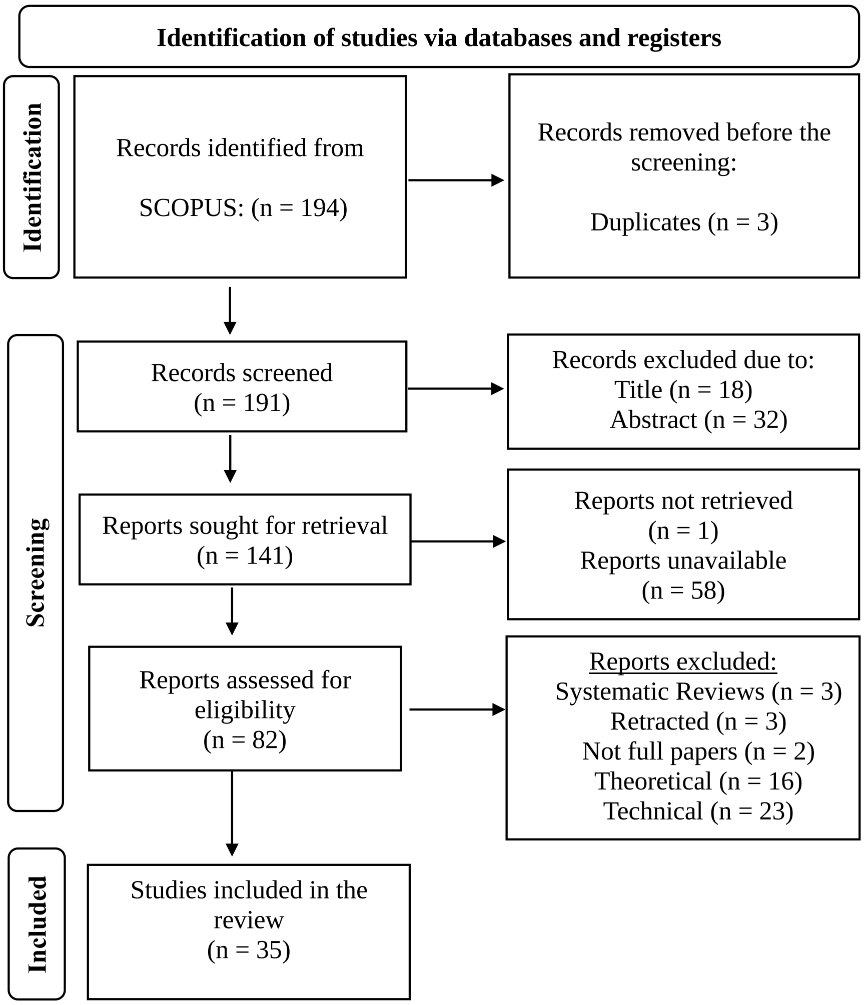

Figure 1. Process of selection of empirical studies.

Journal articles and conference papers of unspecified date were included, although most of the studies were published in the last three years, more specifically, 11 in 2023, 8 in 2022, and 7 in 2021. Papers in languages other than English or unrelated scientific fields such as biochemistry, genetics and molecular biology, business, management and accounting, health professions, and medicine were excluded. The reason we included articles from conferences as well as journals was to allow us to identify the most recent developments being addressed by the research community. The chosen studies had students of our target age as participants. However, we excluded studies with only educators or parents, including those with mixed groups, such as teachers and students (Table 1). Most research took place in China (N = 9), Taiwan (China) (N = 5), South Korea (N = 3), the USA (N = 2), Ecuador (N = 2), Indonesia (N = 2), and Japan (N = 2). Other studies were conducted in Germany, Israel, Singapore, India, the Russian Federation, Bangladesh, Finland, Slovenia, the Netherlands, and Sweden. Asia was the continent with the most research (N = 25), followed by Europe (N = 6), North America (N = 2), and South America (N = 2). Regarding the age of the participants, 27 of the empirical studies had primary school students with ages 6 to 12 as their target, 4 focused on preschool with ages 4 to 6, and another 4 had mixed ages of participant students.

Table 1. Inclusion and Exclusion criteria for SCOPUS-indexed articles.

Inclusion Criteria	Exclusion Criteria
Empirical studies (peer-reviewed)	Systematic reviews and meta-analyses
Studies focusing on implementations of artificial intelligence (AI) in preschool and primary school (students aged 4 to 12)	Studies about AI literacy—teaching AI (except if teaching about AI occurred with the use of AI)
Sample: children in the age range of 4 to 12	Sample: only teachers and/or parents
Scientific fields: computer science, social sciences, engineering, mathematics, psychology, physics and astronomy, decision sciences, arts and humanities, neuroscience, multidisciplinary, materials science, energy, Earth and planetary sciences, chemical engineering, environmental science, economics, econometrics and finance	Irrelevant scientific fields: biochemistry, genetics and molecular biology, business, management and accounting, health professions, medicine
Written in English	All other languages

All the essential data from the 35 eligible articles were extracted using an EXCEL spreadsheet with different themes, where the crucial information was recorded in the appropriate cells, as described by Crescenzi-Lanna [12]. When everything was coded into the spreadsheet, our next step was to look for similar patterns in relevant fields of the studies and perform a thematic analysis to highlight some significant themes by analyzing the data. More specifically, we used the ideas and themes we were investigating to make a coding scheme, which we applied to the data and identified relevant categories within our study fields. We then conducted the analysis where the themes we identified were examined, and we interpreted any connections or distinct patterns among them [21]. Regarding our research questions, the studied categories included (a) the research objectives, (b) the learning content, (c) the learning activity, (d) the learning outcomes, and (e) the pedagogy of the activity or the AI tool.

4. Results

The results of the previous process are presented below for each of the five themes of the studies we focused on for this review.

4.1. Research Objectives

Figure 2 presents the research objectives of the studies, which can be divided into three distinct categories. First and most often, researchers wanted to discover how integrating

AI into education can enhance teaching and improve student learning outcomes. For this reason, new tools to support students were designed, developed, and tested, and existing ones were evaluated. The focus was on different cognitive areas, such as using music programs to enhance creativity [22], the improvement of handwriting with educational Robot Kiddo [23], and the promotion of computational thinking [24] by constructing a design-based STEM + AI teaching model. In addition to these, the development and evaluation of AI-based teaching and learning models like the CP3 in the context of converging multiple subjects were reported [25], and the design of an alternative teaching system for preschool education specialty courses to assist and guide educators to accurately and efficiently retrieve curriculum resources was tested [26]. There was also the development of robotic quiz games to promote self-regulated learning and increased learning engagement [27], in conjunction with AI and its role in promoting cognitive development and physical health of students through interactive learning with "Internet +" and "Big data ML" [28]. In this category, teaching material that integrates AI and ML concepts was constructed in the context of social and science education [29], as well as an ability-oriented STEAM-graded teaching system [30]. AI-based solutions to help identify dyslexia in primary school pupils [31] and AI applications as immersive learning environments that can assist children with Down syndrome [32] were developed. In the form of Natasha Bot, virtual learning partners were created for children with visual impairments [33], to improve their learning outcomes. Research also focused on the innovation of teaching methods and learning systems, with examples of voice assistants being used to assist children in using the toilet independently [34], and the development of intelligent educational and English teaching resources [35]. Completing the first category, we found a program (CAI) designed to assist students' learning of open-sentence mathematical problems [36] and a recognition learning system for mathematical concepts such as natural numbers [37].

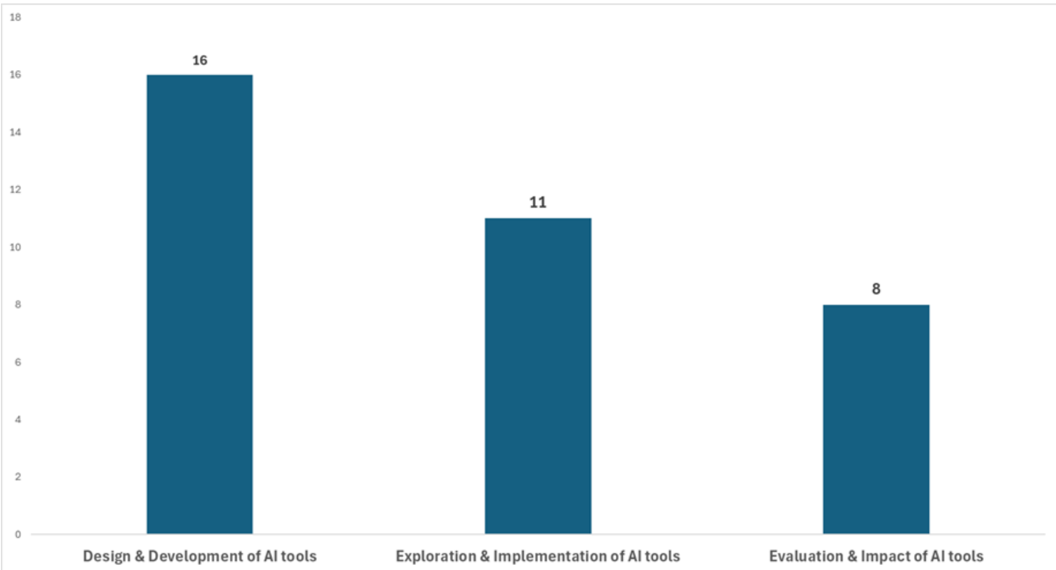

Figure 2. Research objectives.

Moving to the second research category, we included studies that aimed to investigate the implementation of a tool as a teaching aid in terms of learning outcomes, effectiveness, or AI–student interaction. Podpečan [38] examined students' engagement by investigating their emotional responses, and Williams et al. [39] explored their interactions with social robots to learn about AI. Wu and Yang [40] studied AI science activities in informal curricula on students' AI achievement, and Chen et al. [41] used an AI-based children's digital art ability training system to improve their imagination and drawing skills. The motivation to understand and learn ML through programming and computational concepts was accomplished in a constructivist learning environment and with the use of appropriate scaffolds, students managed to construct a neural network in the study of Shamir and Levin [42] which investigated course scaffolds and course outcomes.

Furthermore, personalized and adaptive learning experiences for English language learning and interactions were examined [43] by implementing an AI coach as a humanized agent following the CoI framework [44]. Educational games were also explored to further enhance the learning experiences offered and the engagement in mathematics [45], and Wu et al. [46] analyzed attitude, motivation, and cognitive load on continuous learning intention in STEAM education and learning outcomes associated with AI-assisted educational activities. The impact and the role of AI and robotics regarding teaching and learning practices were also addressed concerning physical development, social–emotional skills, and intellectual growth among students [47] and by identifying the pedagogical and technical considerations when designing teaching interventions with Google Teachable Machine (GTM) [48].

The last category of research was concerned with the evaluation, assessment, and analysis of the impact of AI on children's learning and interactions. The influence of social and emotional intelligence on student character development in educational settings was assessed with the PKES instrument [49], and Neurofeedback technology with the aid of AI was used to analyze the level of attention and temperament of children [50]. Students' perceptions and the process of accepting intelligent machines such as robots were tracked [51], and the influence of AIEd on adolescents' social adaptability and emotional intelligence was studied [52]. Ethical implications were also brought into this category by testing the effectiveness of an AR-based contextualized dilemma discussion approach and by studying concepts such as trust, privacy, and the responsible use of technology [53], as well as an AI-automated analysis of digital storytelling for interdisciplinary learning, with integrated CT skills, for real-time adaptive feedback in STEM education [54]. Finally, Kajiwara et al. [55] examined the educational impact and changes in impressions of AI before and after role-playing the ML process by practicing problem-solving skills and computational thinking, and Bingi et al. [56] facilitated and evaluated learning with AI-based education tools and a humanoid.

4.2. Learning Content

The theme of learning content can be split into four main categories, which contain most of the studies, and a fifth one, which includes many studies with distinct learning contents, as shown in Figure 3.

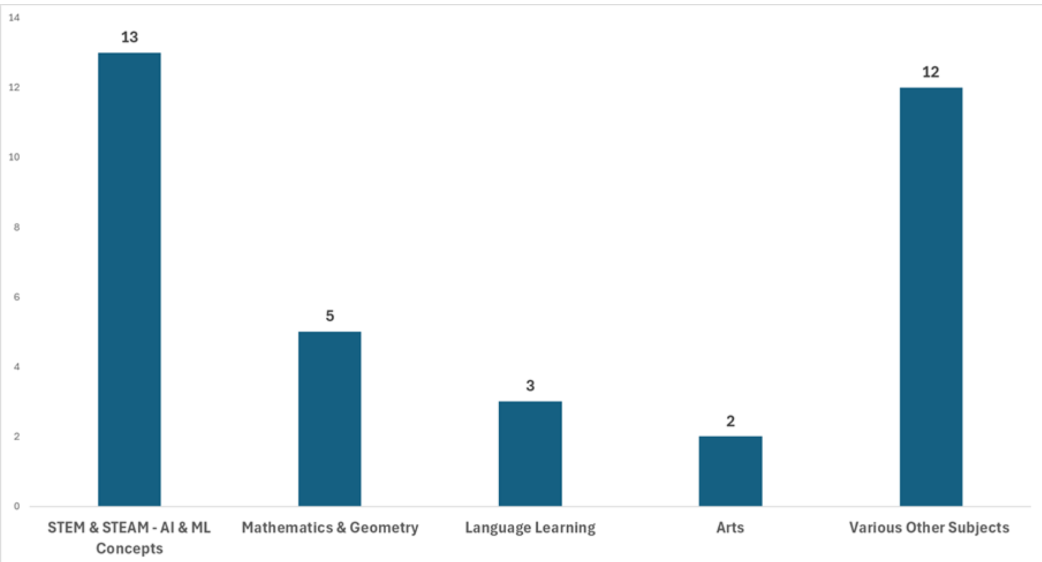

Figure 3. Learning content.

The first category consists of STEM [24] and STEAM concepts [30,46] and AI and ML elements like mechanical expression, perception, reasoning, and consciousness, as well as their integration into educational environments [42,48,55]. Connecting such objects to real-life stories or problems and digital storytelling with incorporated physical science concepts [54], combined with scientific adventures mixing biology and AI concepts [29], can engage students in STEM education. The use of robotics and its applications in education, where robots like NAO bot or Natasha Bot were used as intelligent learning partners for students [38], can also be included here along with engineering, robotics courses, and other STEAM concepts. Learning AI concepts like knowledge-based systems, supervised machine learning, and generative AI [39], as well as sorting network algorithms and data [25], AI knowledge, coding, AI visual applications, and problem-solving through programming [40] or robotics [47], is a final branch of this category.

The second category refers to mathematics and geometry, where children learn basic arithmetic concepts and reasoning by doing and by acting as tutors for teachable agents [45] or are taught to recognize and write natural numbers from 0 to 10 [37]. In this category, students also formulated mathematical questions and added or subtracted numbers with a computer-assisted instruction (CAI) program [36]. Children with Down syndrome were assisted in recognizing or classifying geometric drawings [32]. The development of quiz games with fifth-grade math questions by Weng et al. [27], along with problem-solving abilities and a robot companion, was also found in this category.

The third category includes language learning with an AI coach for speaking and listening [43,44], where researchers were concerned with teaching vocabulary and all its aspects (word, sentence, meaning) in the context of English teaching as a second language. Huang [35] designed and developed educational robot teaching resources using AI to enhance English language teaching.

The fourth category is related to art education, where students can improve their painting performance [41] and enhance their understanding of music theory and harmony [22].

The rest of the studies were scattered among many learning contents, and one instance of each category was found. There is a study that explored ethical dilemmas and the role of educators in implementing AI technology [53] and other studies focusing on environmental issues [56], physical health education [28], or the promotion of children's autonomy with independent toilet training [34]. Omokawa and Matsuura [51] focused on the theme "What is life for me", exploring the moral notions of students about life by interacting with a humanoid, while Khilmiyah and Wiyono [49] explored the emotional and social responses of students with an instrument (PKES) that measured the learning outcomes. Andinia and Isnainiyah [33] accommodated a virtual learning partner to assist students with vision impairment disabilities answer questions from several subjects. Additionally, Mispa and Sojib [23] practiced handwriting and drawing skills with the aid of the robot Kiddo, and Shalileh et al. [31] proposed a robust AI-based solution to identify dyslexia in primary school pupils. Another category that we found is connected to curriculum development and teacher guidance and included topics related to information technology and programming in conjunction with AI specialty courses [26]. Finally, Lee et al. [50] proposed a system to predict and analyze children's temperament and attention levels to investigate possibly hidden cognitive disorders, and Lai et al. [52] aimed to study the influence of AIEd on adolescents' social adaptability through multiple courses from AI curriculum reform experimental schools.

4.3. Learning Activity

The learning activities students engaged in were categorized into four main groups, although they were often interconnected due to overlaps (see Figure 4).

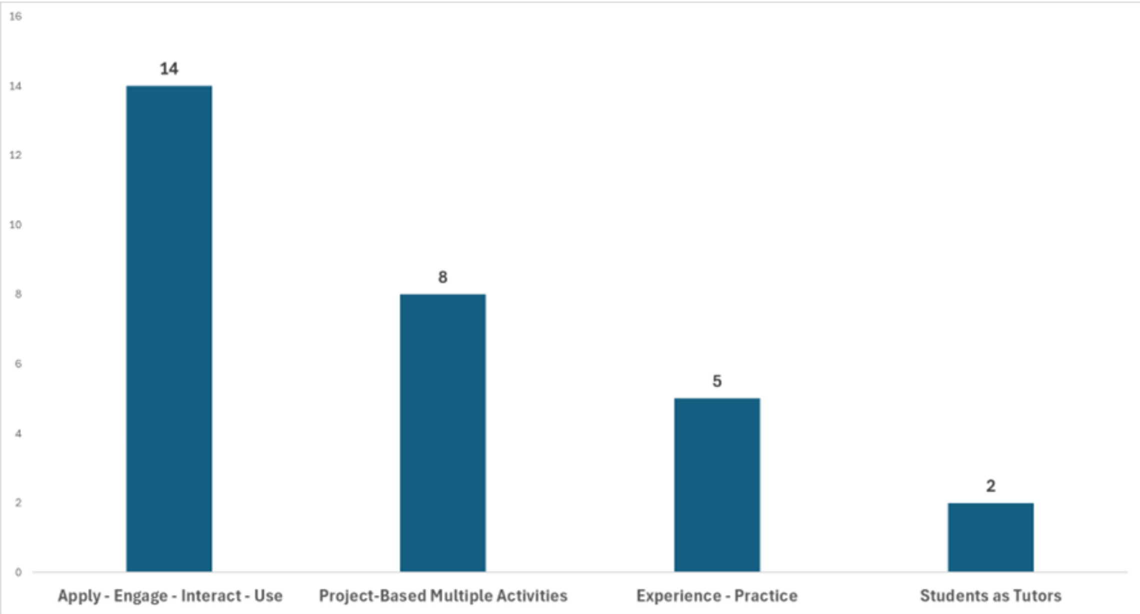

Figure 4. Learning activity.

The first category focuses on interactions with various platforms, tools, or agents, application engagement, participation, and implementation. Thus, Choi [22] examined the music program Doodle Bach to assist students in creating music compositions, Shamir and Levin [42] had students construct an ML-based artifact using a programmable environment, and Barnard et al. [36] used a computer-assisted program (CAI) for students to diagnose problem-solving strategies and their misconceptions. In the study of Gupta et al. [54], students used a learning environment to engage in problem-solving activities and the creation of interactive science narratives, and in the study of Napierala et al. [29], students played with a memory game to identify leaf types in biology, testing decision trees in AI and ML concepts at the same time. There was also an interaction with a virtual environment for children with Down syndrome, using the Leap Motion Controller for kinesthetic engagement [32], and an interaction with a voice agent to guide and support the toilet training process of young children [34]. Bingi et al. [56] referred to interactive learning activities like listening, answering, and receiving feedback from the humanoid NAO, and Wang et al. [43] described an AI coach for EFL learning that aids students in practicing speaking and listening, as well as pronunciation [44]. Additionally, students engaged with the PopBots platform to answer multiple-choice questions [39] and used applications for question-and-answer sessions with Natasha Bot [33]. Participation in math quizzes with the AI robot Zenbo by Weng et al. [27] and writing on a shared whiteboard with the robot Kiddo [23] were also included in this category.

Moving to the second category, we find studies incorporating multiple activities in the form of project-based learning, to provide students with holistic approaches suited to various needs and to enhance their learning outcomes. Here, there were real problem situations that promoted active participation in solving them with peers, and programming and model-building activities for improving computational thinking [30]. In the study of Li et al. [24], students focused on creating scenarios that contained practical problem-solving by designing and implementing solutions to promote scientific literacy and interdisciplinary exploration. In the study of Huang [35], students engaged in role-playing scenario creation, questioning and answering sessions, classroom interactions, group discussions, cooperative gaming, and knowledge carding. In the study of Wu and Yang [40], students were involved in a 6 h AI education program based on the STEM learning conceptual framework and project-based learning, which included teaching sessions, hands-on exercises, group problem-solving activities, and designing and solving problems in real-life scenarios.

Podpečan [38] demonstrated multiple applications: motor development activities and games, children's games, theatrical performances, artificial intelligence applications, and data harvesting applications, based on the main topic and programming techniques for the NAO robot. Joo and Park [25] engaged students with unplugged hands-on activities and natural interaction exercises, for tool exploration and understanding the social impact of AI, as well as with games for the collection and analysis of data, targeting the enhancement of problem-solving and reasoning skills. Students also used web-based tools for an introduction to ML fundamentals, participated in group discussions to exercise critical thinking and creativity, and were assigned a project to work on with Google Teachable Machine (GTM) in the work of Toivonen et al. [48], with the aim of training models and developing applications to conclusively reflect and obtain feedback for their actions. Finally, Wu et al. [46] integrated STEAM with AI into their activities to provide children with hands-on opportunities to create intelligent systems, understand vision recognition, code a program, assemble a game, make graphs, and evaluate and tune correct parameters.

The third category consists of more experiential and practicing activities that can enhance expression and creativity, like observing simulations and role-playing for an inquiry, based on AI issues and ethics in real life [53]. There was also the experience of a machine learning role-playing game (ML-RPG) where students engaged in tasks related to the ML process [55]. In the work of Salas-Pilco [47], students brainstormed, designed advanced robotic models to solve community problems, and presented their solutions, demonstrating social responsibility. Moreover, students collaborated with the NAO robot and its programmer, pretended to be humanoid, watched a movie about care robots, or wrote reflectively in the study of Omokawa and Matsuura [51]. The practice of art painting finally included a series of activities like the creation of the work, the recognition of its technical details, and the experience of an augmented reality (AR)-enriched exhibition of paintings [41].

Lastly, we have two cases where students acted as the tutors for the teachable agent game or the system, interacting with it by playing and answering situation-specific questions [45] or practicing mathematics [37].

4.4. Learning Outcomes

Regarding the learning outcomes, we categorized them into three levels: cognitive skills, affective skills, and psychomotor skills [57], with the focus of the literature being on the affective level. Adopting new desirable behaviors and critical thinking, knowledge acquisition, an overall increase in learning, and presenting a higher quality of work from students are direct observations from the data synthesis. Figure 5 shows the frequency of reports about learning outcomes per level, and Figure 6 presents a word cloud of all learning outcomes.

The first category of affective skills includes reports of social and emotional development of the participants [56], as there was an acknowledgment, appreciation, and management of their emotions [49], as well as an increase in social responsibility and commitment [47], and cooperation with and respect for others in social interactions [30]. Emotional engagement with robotic assistants, empathy for them, and higher levels of learning satisfaction and interest were also recorded [51]. In general, self-efficacy and self-confidence increased as well [47,49], and a shift in students' attitudes to more favorable levels with less anxiety and less fear of accepting AI was observed [55]. In this category, we included autonomous learning [30,35], responsibility, communication [29], collaboration, and increased reports of student engagement [25,37,39,45,46], in line with students' overall improvement in a variety of areas. Students' interest and enjoyment in learning increased, as did their reflective ability and intrinsic and extrinsic motivation [37,41,43,44,46], enhanced attitude [46], and the acquisition of new behaviors with behavioral shaping techniques [34].

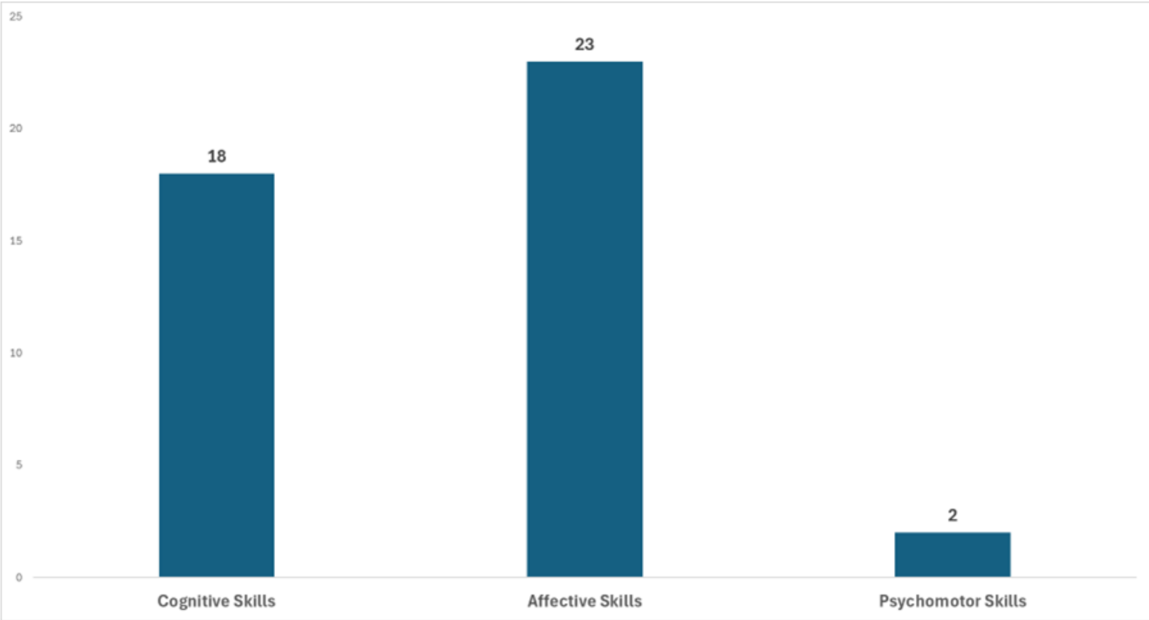

Figure 5. Learning outcomes.

Figure 6. Word cloud of learning outcomes.

Regarding the cognitive level, there were learning outcomes about understanding AI [42], understanding core machine learning concepts and how students use this practical knowledge to train ML models or build applications [48], and understanding computational thinking [25]. Understanding the ethical issues that arise from the use of AI in an educational context [53] was one of the learning outcomes, as were the discussions within the specific bounded context of the possibilities and limitations of technology, especially regarding the perception of robots [39]. The recognition of numbers and geometric figures and the comprehension of the quantities represented by numbers was another learning outcome [32,37], along with proficiency in science concepts and story structuring [54]. With the development of student's ability to solve a problem [34] came the acceptance of AI [55] and insight into processes [36] requiring improved competence and the development of technical skills [46]. Improvement was also observed in many areas, like work quality [40], pronunciation, listening comprehension and vocabulary [44], artistic expression, originality, performance, and creativity [41], music cognitive abilities [22], learning new expressing abilities [24], and technology application ability [27].

At the psychomotor level, there was an improvement reported in the fine motor skills of students, with visual recognition and categorization of geometric figures in mathematics [32], and motor mimicry involving handwriting and drawing skills [23].

4.5. Pedagogy of Activity or AI Tool

Figure 7 shows the pedagogies used in the studies, which we split into four main categories. The pedagogies used were usually mixed, so most studies belong to more than one category.

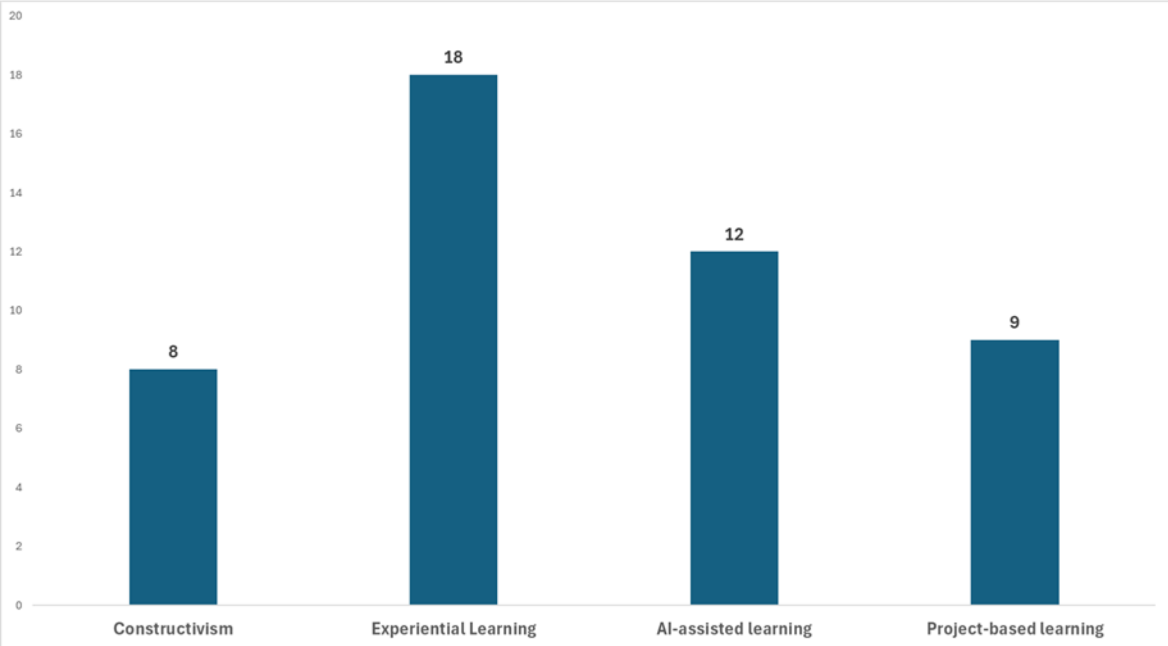

Figure 7. Pedagogy of activity or AI tool.

Among the pedagogical methods used, the most common was experiential learning, with activities adapted to the student's interests, abilities, and experiences and with the employment of immersive environments [32]. Additionally, here, we included problem-solving activities [30,33,43,47], with the exercise of computational thinking skills [25,54], hands-on learning through interactive objects [29,40,47], and interactive narratives [54], as well as role-playing games or scenarios [35,53,55]. In this category, the transfer of knowledge and learning [45,53] and promotion of ethical reasoning skills [53] were also found as means of learning, along with the interaction between students, teachers, and AI [56].

In the second category, technology was used to enhance pedagogical methods. Here, we found social robots as learning assistants [38], adapted to support self-efficacy and self-regulation of learning [27,49], or even taking the role of the learner, positioning the student as the tutor [37,45]. Gamification elements strongly contributed to learning engagement and increased motivation, providing tutoring guidance and feedback [37], and auxiliary teaching systems were used to overcome deficiencies of traditional teaching and enhance shortcomings of existing courses [26]. Collaborative hands-on learning by teaching was also found [23], along with interactive dialogues with AI agents [34]. The involvement of AI in the learning process enhanced interest and upgraded the quality of the material provided [22], emphasized motivation, guided observation and thinking, and encouraged creation [41], personalizing the feedback that was given by the virtual intelligent teacher to each individual learner [44].

In the third category, we found project-based learning, defined by the objectives pursued and implemented by the project method for acquiring STEAM skills [30]. The activities were child-centered, and the research was carried out through project work [47] to resolve the problem and find innovative solutions. Participatory and active learning [39], as well as situational assessment [56], placed the students in truth-seeking scenarios of inquiry [46,53], with the guidance of the AI tools in question. There was also a combination of activities, including lectures, exercises, and group discussions, to come up with a solution [40], or to promote logical reasoning skills on the ethical issues of AI [53], as well as action-oriented learning and design-based research [29].

Lastly, constructivism was another emerging category that stood out as a theory that supports the active involvement of students in the construction of knowledge [24,42,51]. Group collaboration, in conjunction with critical thinking activities, contributed to the acquisition of new knowledge [39], which was adapted to the needs and capabilities of the students [36]. Children became the designers and constructors of their own learning [48], and by reflecting on AI [39], and prompting for self-explanation [45], students managed to refute any misconceptions they may have had.

5. Discussion and Implications

5.1. Relevance with Previous Systematic Reviews

This paper provided insights regarding the research objectives of the relevant studies, which we divided into three main categories according to the researcher's approach to the AI tools. Most of the studies proposed and designed new tools, others implemented and explored their applications, and the least of the studies evaluated their impact on teaching and learning outcomes and students' responses. Some similarities occurred with the systematic review of Sanusi et al. [8] in learning aims, e.g., AI concepts, social robots, games, understanding of ML, and decision trees, and with Su and Yang [11] in assessing the effectiveness of platforms and robots, exploring multiple applications, and investigating their use, children' s perceptions, and learning outcomes.

The learning content of our studies was mainly focused on AI and ML concepts like the learning content reported in [10], e.g., experience machine learning, knowledge-based systems, AI robots, and ethics. Our findings were also focused on language and math learning; however, some of our studies were spread throughout many different subjects, e.g., AI ethics [53], physical health promotion [28], environmental awareness [54,56], children's autonomy [34], moral notions about humanoids [51], emotional and social responses [49], handwriting and drawing [23], learning partner for vision impairment disabilities [33], dyslexia identification [31], specialty courses [26], temperament and attention levels of children [50], curriculum reform [23], and social adaptability [52].

Regarding the theme of learning activities and more specifically the category where students practice and experience simulations, our findings had similarities with those stated in [8] about discussions, role-play, robot and simulation games, scientific inquiry, the use of Google Teachable Machine (GTM), and unplugged activities. GTM was also found in the reviews of Yim and Su [9], Su et al. [10], and Su and Yang [11], along with hands-on activities in [10], for assisting preschool students in their learning of concepts about knowledge-based systems and supervised machine learning. Su and Yang [11] also mentioned the effectiveness of intelligent tutoring systems, problem-solving, peer-to-peer interactions, and creative inquiry literacy, as we also did.

Cognitive learning outcomes like understanding of AI, machine learning, or knowledge-based systems were also reported by Yim and Su [9] and Su et al. [10], along with affective and behavioral outcomes, e.g., motivation, self-efficacy, high student engagement, collaboration, and communication skills. Affective skills were reported more than any other category in our study, in contrast to the review of Su et al. [10] in which only two researchers had designed activities to enhance students' higher-order thinking skills. On the contrary, creative, emotional, and collaborative inquiry were reported as improved skills, although there was no mention of attitudes, motivation, and confidence [10].

Our findings on the theme of pedagogy showed that project-based learning, ML-based solutions, active-based and participatory learning, collaborative methods, and lectures were utilized, as was found in [8]. The most popular pedagogy used in our studies was experiential learning, which in combination with project-based and constructivist methods as interrelated theories, comes in agreement with the findings of the review of Yim and Su [9]. Human–computer interaction and child-centered play-based active learning follow, while the findings in [10] are similar to ours regarding activity-based and experiential learning. Project-based approaches are used less in preschool than in primary schools, while creative inquiry literacy is more suitable for younger students.

5.2. Teachers' Role and Skills

The use of AI and its implementations in preschool and primary education (ages 4 to 12) is an area of growing interest and has experienced significant growth in recent years. Integrating AI in school environments should promote empowering experiences for students and support teachers to further enhance the quality of education. Technology and AI tools aid the teaching process by enriching the learning content and can enhance educators' work, improving students' knowledge and skills. Teachers play a crucial role in facilitating student interactions with AI, guiding and evaluating their use of technology in creative ways. For this reason, educators need to prepare themselves to effectively utilize new AI tools and integrate them into classroom settings to improve learning outcomes [58]. The role, required skills, and perceptions of educators, as well as teacher training for improving knowledge, are expected to be of significant concern for the educational community in the immediate future [59].

Moreover, the development of an AI literacy-implemented curriculum should be organized based on teachers' perspectives and students' needs and provide the appropriate tools to promote learning [60]. On the other hand, the issues raised by the implementation of AI in educational settings are complex, both in terms of its impact on teaching processes and learning outcomes and the ethical dilemmas involved [61]. All stakeholders must be aware of these rapid advancements, and educational policymakers must focus on organizing teacher professional development opportunities and on incorporating AI approaches into curriculum design.

5.3. Suggestions

Considering the importance of teachers for education generally and more specifically for facilitating the interactions of students with AI, educators' AI readiness [62] is vital for the implementation of AI in school settings. Therefore, we suggest the following:

- Focus on teacher training programs and professional development of educators, according to their specific needs. Some topics of interest could be as follows:
    - AI-assisted applications for various everyday class activities and routines;
    - Artificial intelligence, computational thinking, and machine learning basics;
    - Artificial intelligence implications and challenges like AI ethics and inclusivity;
    - AI implementations of platforms and tools, teaching methods and assessment, and curriculum design;
    - Teachers' training should be remunerated, take place during working hours or on educational leave, to surpass any resistance or difficulties and enhance their positive view of technology, ensuring the ethical implementation of AI in preschool and primary school education.
- Further research is needed on implementing AI in preschool (ages 4 to 6) mostly, and primary school (ages 6 to 12), for teaching multiple subjects and addressing students' individual needs.
- Research on implementing AI on various courses and student ages, e.g., adult education, musical instrument courses, AI literacy, history, differentiated learning approaches, and personalized feedback for the tutor and the learner.
- Examine the effectiveness of AI implementation in terms of pedagogical strategies and learning outcomes according to the student's age.
- A theoretical framework and/or policy guidelines for successful AI implementation in educational settings could be developed so that teachers can rely on it to increase the adoption of such technologies in their classrooms.

5.4. Limitations and Future Recommendations

The first limitation of this paper is that the articles that were not accessible at the time of retrieval might contain critical empirical evidence needed for this review. Another shortcoming of this systematic review is that it did not consider other databases and indexes, such as WOS, and it used only literature from SCOPUS. Also, a noted consideration for our research is that the themes we studied are inextricably linked, making it difficult at times to differentiate our findings, due to the size of overlapping information.

Future research could focus on preschool education to provide a more detailed overview of AI approaches and their learning outcomes, or other implications with students of this age. Even though the studies included in this review were disproportionally more about primary school than those focusing on preschool, further research is recommended for all school ages, as we think that the AI curriculum development should be unified for all levels of education. Research should also occur in more countries, and within different educational contexts, as most of the empirical studies that we found were located in Asia, whereas continents like North and South America or Europe had the fewest.

Author Contributions: Conceptualization, S.A., K.L. and I.V.; methodology S.A., K.L. and I.V.; software, S.A., I.V. and S.P.; validation, S.A., K.L. and I.V.; formal analysis, S.A., K.L. and S.P.; investigation, S.A.; resources, V.K.; data curation, T.K.; writing—original draft preparation, S.A, K.L. and S.P.; writing—review and editing, S.A., K.L. and S.P.; visualization, I.V.; supervision, T.K. and V.K.; project administration, T.K. and V.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on reasonable request.

Acknowledgments: This paper has been supported by the funding program "MEDICUS" of the University of Patras.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Summary table of all studies and areas of focus.

No.	Reference	Country/ Region	Research Aim	Learning Content	Learning Activity	Learning Outcomes	Pedagogy of Activity or AI Tool
1	Andinia and Isnainiyah (2020) [33]	Indonesia	Virtual learning partner Natasha Bot for people with vision impairment disabilities	Questions about subjects in schools, presented in the form of guessing or trivia	Use the application and engage in a question-and-answer processing session with Natasha Bot	Addressing psychological aspects of learning for individuals with disabilities	Design thinking approach, problem-solving, and user-centered design to create innovative solutions
2	Barnard et al. (1988) [36]	Netherlands	Development of a computer-assisted instruction (CAI) program for open sentence mathematical problems	Elementary mathematics, open sentences in + and -, the identity of the unknown, and the operation sign	Use the CAI Program to diagnose students' problem-solving strategies and misconceptions	Gain insight into problem-solving processes and improve competence in solving such problems	Adapt instruction to the level of individuals by diagnosing their existing knowledge and misconceptions
3	Bingi et al. (2021) [56]	India	Facilitate and evaluate learning among students by using AI-based education tools and humanoid	Stories from NCERT textbooks and environmental science topics from Wikipedia	Interactive learning activities with the humanoid NAO (listening, answering, receiving feedback)	Quality of social interaction; warmth, competence, discomfort, emotional response, feelings for robot	Active learning and assessment, interactive and engaging learning experiences
4	Chauca et al. (2023) [32]	Ecuador	Develop two applications as immersive environments for children with Down syndrome	Geometric figures recognition and classification and performing and recognizing numbers from 1 to 10	Interact with the virtual environment using the Leap Motion Controller to engage with the applications	Recognition and classification of geometric figures and numbers. Improvement of fine motor skills	Immersive environments, interactive learning experiences, supervised learning

Table A1. *Cont.*

No.	Reference	Country/Region	Research Aim	Learning Content	Learning Activity	Learning Outcomes	Pedagogy of Activity or AI Tool
5	Chen et al. (2022) [41]	Taiwan	Improve imagination and drawing ability using a children's digital art ability training system based on AI	Students' cognition of chromatics and enhancement of students' imagination and painting performance	Create work, recognize outline, match hue color, calculate color ratio, view actual AR paintings	Improvement in originality, flexibility, title abstractness, and total scores, imagination and painting performance	Emphasizing motivation, guide observation and thinking, encourage creation
6	Choi (2023) [22]	South Korea	Design, implementation, and effects of an elementary music creation class using AI-based music program	Tonality cognition, rhythm cognition, and melody cognition through the program	Use AI-based music program, Doodle Bach, to create music compositions	Improvements in music cognitive abilities, growth in ability to perceive rhythm, positive impact of sharing creative works and providing feedback	Incorporated AI as an active 'media' in the lesson to engage students and maintain interest in learning
7	Gupta et al. (2023) [54]	United States	Digital storytelling for interdisciplinary learning, science narratives that integrate CT skills	Physical science concepts and energy conversions, aligned with US science standards	Use learning environment, engage in problem-solving activities and create interactive science narratives	Proficiency in science concepts, CT, and story structure. Storytelling and problem-solving strategies	Problem-solving scenarios, interactive narratives, storytelling, physical science, and computational thinking
8	Huang (2021) [35]	China	Design and develop educational robot teaching resources using AI to enhance English teaching	Vocabulary teaching functions. Speech, meaning, example sentence, and unit of a word input by the user	Role-playing scenarios creation, vocabulary teaching, classroom interaction, Q and A, group discussions, cooperative games, word detection and consolidation, teaching review and knowledge carding	N/A	Innovative teaching, autonomous learning, interactive and dynamic learning experiences

Table A1. *Cont.*

No.	Reference	Country/Region	Research Aim	Learning Content	Learning Activity	Learning Outcomes	Pedagogy of Activity or AI Tool
9	Huh et al. (2022) [34]	South Korea	Develop a service design using AI voice agents to assist in independent toilet training	Using the toilet independently	Interact with an AI voice agent named Ddongddong to guide and support toilet training process	Developed problem-solving abilities and acquisition of new behaviors with behavioral shaping techniques	Interactive dialogues with the AI agent. The agent acts as a practical tool to provide reinforcement
10	Joo and Park (2022) [25]	South Korea	Development and application of an AI-based convergence education teaching–learning model, the CP3	Sorting network algorithm, procedural thinking, sequential structures, and procedural thinking	Implementing the CP3 model, which consists of problem recognition, planning, and play stages	Computational thinking ability, higher satisfaction, interest, and engagement in the AI-based classes	Problem-solving with step-by-step computational thinking skills. Recognition, planning, and play stages
11	Kajiwara et al. (2023) [55]	Japan	Educational impact and changes in impressions of AI before and after role-playing of the ML process	ML process, AI decision criteria, math of ML, decision tree models, and classification results	Experience a machine learning role-playing game (ML-RPG) where they engage in tasks related to the ML process.	Understand ML, skills in perceiving, expressing, reasoning and learning, self-efficacy and acceptance of AI	Hands-on experiential learning through role-playing and interactive tasks
12	Khilmiyah and Wiyono (2023) [49]	Indonesia	Effectiveness of an android-based emotional and social intelligence assessment instrument (PKES)	Emotional and social intelligence aspects, through cognitive, affective, and psychomotor domains	N/A	Recognize, appreciate, manage self-emotions. Social responsibility and cooperation, respect and tolerate others	Use of experimental methods tailored to student interests, abilities, and learning experiences

Table A1. *Cont.*

No.	Reference	Country/ Region	Research Aim	Learning Content	Learning Activity	Learning Outcomes	Pedagogy of Activity or AI Tool
13	Lai et al. (2023) [52]	China	Identify the influence of AIEd on adolescents' social adaptability via social support	IT, general technology and programming courses, flat panel teaching, intelligent reading, assembling robots, 3D printing, Lego plug-ins, teaching boxes	N/A	N/A	N/A
14	Lee et al. (2019) [50]	Taiwan	Predict and analyze the attention levels of children aged 4–7 years old	N/A	N/A	N/A	N/A
15	Li et al. (2023) [24]	China	Construction of a design-based STEM + AI teaching model to cultivate computational thinking	AI robot courses (voice, text, automatic translation, companion, police, shopping guide, and accounting robot)	Focus on the creation of scenarios that lead to the design of tasks related to the intelligent learning partners	Ability to express, ability to question and ability to connect in the context of computational thinking	New knowledge, question asking, collaboration, model building, share and display evaluation feedback
16	Lin et al. (2023) [53]	China	AR-based contextualized dilemma discussion approach to foster students' AI ethics and behavior	AI ethical dilemmas	Observe simulations, inquire about ethics, play different roles, explore AI issues in real-life contexts using AR	Understanding ability for complex AI ethical issues. Contextualized discussing and social interaction	Scenario simulations, in-depth inquiry, transfer learning stages, promote ethical reasoning skills

Table A1. *Cont.*

No.	Reference	Country/ Region	Research Aim	Learning Content	Learning Activity	Learning Outcomes	Pedagogy of Activity or AI Tool
17	Ma et al. (2021) [28]	China	Design and implement a new teaching system for physical health promotion with "Internet +" and "Big data ML"	A user interest model based on DL algorithms, an optimization for health promotion model teaching	N/A	N/A	N/A
18	Mispa and Sojib (2020) [23]	Bangladesh	Robot Kiddo for Interactive Handwriting scenarios by providing a shared environment for writing	100 basic shapes from elementary, grades 1 and 2 textbooks of the National Curriculum and Textbook	Children and Kiddo write simultaneously on a shared whiteboard	Handwriting and drawing skills. Motor mimicry and cognitive development	Interactive handwriting, collaborative hands-on learning by teaching, playful and engaging learning
19	Napierala et al. (2023) [29]	Germany	Develop and test teaching material that integrates AI and ML concepts	AI, ML, and decision trees in computer science, the structure and features of leaves in the biology section	Memory game to identify leaf types, create and test decision trees based on leaf features and unknown leaves	AI-ML, leaf types, decision-making. Communication, biological terms, interactive work, connecting to mathematics	Action-oriented learning and design-based research, hands-on activities, discussions, and reflections
20	Omokawa and Matsuura (2018) [51]	Japan	Development of student notions about life from their dialogs with the humanoid robot NAO	Focus on the theme of "What is life for me?"	Collaborative discussions, watch a movie about a care robot, pretend to be NAO, individual reflective writing	Interest in NAO's mechanical functions. Empathy and emotional connections with NAO	Constructivist educational method, interactive and experiential learning

Table A1. *Cont.*

No.	Reference	Country/ Region	Research Aim	Learning Content	Learning Activity	Learning Outcomes	Pedagogy of Activity or AI Tool
21	Pareto (2014) [45]	Sweden	Teachable agent and engagement in math, mathematical skills and performance	Basic arithmetic understanding, the base-10 number system, fundamental mathematical concepts	Play the teachable agent game and become a tutor to teach the agent, answering situation-specific questions	In-game knowledge to traditional mathematics, engagement, reflection, and explanation	Reflect on decisions, prompt self-explanation, support the transfer of knowledge, and provide a role model
22	Podpečan (2023) [38]	Slovenia	Physical embodiment, anthropomorphism and the emotional aspects in child–robot social interaction	Use of robotics, engineering, and artificial intelligence to engage students in STEM	Develop and demonstrate applications based on the main topic and programming techniques for NAO robot	N/A	Integration of social robots into education and tutoring
23	Salas-Pilco (2020) [47]	China	AI and robotics Impact on learning and teaching activities, physical, social–emotional, and intellectual	AI and robotics technologies to design and create advanced robotic models to solve community problems	Brainstorm solutions, select a key problem, develop a robotic project to address it, and present solutions	Imagining, devising, testing. Self-confidence, teaching, committing, social responsibility, and presenting	Design-based research, integrated analytical framework, hands-on learning, problem-solving
24	Shalileh et al. (2023) [31]	Russian Federation	Propose a robust AI-based solution to identify dyslexia in primary school pupils	N/A	N/A	N/A	N/A
25	Shamir and Levin (2021) [42]	Israel	Course scaffolds and course outcomes in terms of motivation to learn and understanding ML	Machine learning (ML) and the 'machine learning process'	Students construct an ML-based artifact using a novel programmable learning environment (PLE)	Increase in students' understanding of AI concepts and the ML process	Constructionist learning method

Table A1. *Cont.*

No.	Reference	Country/ Region	Research Aim	Learning Content	Learning Activity	Learning Outcomes	Pedagogy of Activity or AI Tool
26	Shi and Rao (2022) [30]	China	Propose and realize a novel ability-oriented STEAM graded teaching system for high-quality teaching	Cultivation of diversified abilities with the development of cognitive and non-cognitive skills	Project-based learning in real problem situations, cultivating abilities to solve practical problems	Autonomous learning, problem-solving, critical thinking. Responsibility, communication, cooperation	Reverse design based on the ability goal, project-based learning methods to achieve the desired STEAM abilities
27	Toivonen et al. (2020) [48]	Finland	Investigate the technical and pedagogical feasibility of Google Teachable Machine	Machine learning principles and design of ML-powered Applications using Google Teachable Machine	Conduct co-design workshops, innovate and design ML-powered applications with Google Teachable Machine	Understanding core ML concepts and practical knowledge for training an ML model and build applications	Children as designers and creators in learning process
28	Villegas-Ch. et al. (2022) [37]	Ecuador	Design and create an image recognition system to learn natural numbers between 0 and 9	Recognition and writing of natural numbers 0–9	The child acts as the tutor for the system, interacting with it to practice the numbers	Recognize, write, and understand numbers, comprehend the quantities associated with each number	Gamification for motivation and engagement, system as a teaching aid and tutor for guidance and feedback
29	Wang et al. (2022) [44]	Singapore	AI coach, developed for EFL learning, can support language learning following the CoI framework	English as a foreign language (EFL)	Students listen to sentences read by the AI coach, repeat them, and receive feedback on their pronunciation	Improved pronunciation, listening comprehension, vocabulary. L2 enjoyment, affection for AI	Personalized feedback, virtual intelligent teacher

Table A1. *Cont.*

No.	Reference	Country/Region	Research Aim	Learning Content	Learning Activity	Learning Outcomes	Pedagogy of Activity or AI Tool
30	Wang et al. (2023) [43]	China	Cluster and epistemic network analysis to provide insights for interaction with AI coach for EFL learning	English as a foreign language (EFL), improve speaking and listening skills, vocabulary learning	Interact with the AI coach for EFL learning, practice speaking and listening, as well as vocabulary learning	Deep, surface and organized approach to learning. L2 learning enjoyment, intrinsic and extrinsic motivation	Feedback, problem-solving, agentic exploration, different approaches, motivation
31	Weiwei (2022) [26]	China	Design an auxiliary teaching system for preschool education specialty courses based on AI	PE course resources, curriculum information and teaching guidance function modules	N/A	N/A	Using AI technology to improve the shortcomings of existing PE courses and enhance the teaching quality
32	Weng et al. (2020) [27]	Taiwan	Develop robotic quiz games for self-regulated learning	Mathematics, specifically designing math questions for the program and reviewing knowledge learned in class	Participate in math quiz games with the AI robot, Zenbo, to review and practice math concepts	Improvement of technology application ability, enhancement of problem-solving, increase in learning	Integration of educational robots to enhance learning of programming and support self-regulated learning
33	Williams et al. (2019) [39]	United States	Interaction with social robots to learn AI	Knowledge-based systems, supervised ML, algorithms' basic functionality, edge cases and initialization	Children engage with the PopBots platform and answer multiple-choice questions	Understanding of AI, prediction and adjustment, perception of robots' autonomy and limitations	Engagement in learning and empowerment to reflect on AI. Participatory learning and critical thinking

Table A1. *Cont.*

No.	Reference	Country/ Region	Research Aim	Learning Content	Learning Activity	Learning Outcomes	Pedagogy of Activity or AI Tool
34	Wu and Yang (2022) [40]	Taiwan	AI science activities in informal curricula on students' AI achievement in popular AI science activities	AI knowledge, coding, AI visual recognition chip applications, and problem-solving through programming	AI education activity based on the STEM learning conceptual framework and project-based learning	Enhanced learning results and creativity, work quality, computational thinking and problem-solving skills	Combination of lectures, hands-on exercises, group problem-solving activities
35	Wu et al. (2022) [46]	Taiwan	Attitude, motivation, and cognitive load on continuous learning intention in STEAM education	STEAM (Science, Technology, Engineering, Arts, Mathematics) concepts and AI concepts	Design an AI-based STEAM game that uses computer vision and controls a robot to play a game	Development of technical skills. Enhanced attitude, motivation, and continuous learning intention in STEAM	STEAM engagement, exploration, explanation, engineering, enrichment, and evaluation

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