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REVIEW

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# AI literacy in K-12: a systematic literature review

Lorena Casal-Otero[1], Alejandro Catala[2,3*], Carmen Fernández-Morante[1], Maria Taboada[2], Beatriz Cebreiro[1] and Senén Barro[3]

**Abstract**
The successful irruption of AI-based technology in our daily lives has led to a growing educational, social, and political interest in training citizens in AI. Education systems now need to train students at the K-12 level to live in a society where they must interact with AI. Thus, AI literacy is a pedagogical and cognitive challenge at the K-12 level. This study aimed to understand how AI is being integrated into K-12 education worldwide. We conducted a search process following the systematic literature review method using Scopus. 179 documents were reviewed, and two broad groups of AI literacy approaches were identified, namely learning experience and theoretical perspective. The first group covered experiences in learning technical, conceptual and applied skills in a particular domain of interest. The second group revealed that significant efforts are being made to design models that frame AI literacy proposals. There were hardly any experiences that assessed whether students understood AI concepts after the learning experience. Little attention has been paid to the undesirable consequences of an indiscriminate and insufficiently thought-out application of AI. A competency framework is required to guide the didactic proposals designed by educational institutions and define a curriculum reflecting the sequence and academic continuity, which should be modular, personalized and adjusted to the conditions of the schools. Finally, AI literacy can be leveraged to enhance the learning of disciplinary core subjects by integrating AI into the teaching process of those subjects, provided the curriculum is co-designed with teachers.

**Keywords** Secondary education, Teaching/learning strategies, Twenty-first century skills, Cultural and social implications

## Introduction

In recent years, the convergence of huge computing power, massive amounts of data and improved machine learning algorithms have led to remarkable advances in Artificial Intelligence (AI) based technologies, which are set to be the most socially and economically disruptive technologies ever developed (Russell, 2021). The irruption of AI-based technology in our daily lives (e.g., robot vacuum cleaners, real-time location and search systems, virtual assistants, etc.) has generated a growing social and political interest in educating citizens about AI. The scientific community has also begun to engage in this education after detecting a significant gap in the understanding of AI, based on comments and fears expressed by citizens about this technology (West & Allen, 2018). Therefore, integrating AI into curricula is necessary to train citizens who must increasingly live and act in a world with a significant presence of AI.

It is worth noting that AI education addresses not only the learning of the scientific and technological

*Correspondence:
Alejandro Catala
alejandro.catala@usc.es
[1] Pedagogy and Didactics Department, University of Santiago de Compostela, 15782, Santiago de Compostela, Spain
[2] Departamento de Electrónica e Computación, Universidade de Santiago de Compostela, 15782, Santiago de Compostela, Spain
[3] Centro Singular de Investigación en Tecnoloxías Intelixentes (CiTIUS), Universidade de Santiago de Compostela, 15782, Santiago de Compostela, Spain

foundations of AI, but also the knowledge and critical reflection on how a trustworthy AI should be developed and the consequences of not doing so. Hence, it is crucial to incorporate AI teaching from the earliest stages of education (Heintz, 2021). However, although some countries are making significant efforts to promote AI teaching in K-12 (Touretzky et al., 2019a), this is being implemented through highly varied AI training experiences, such as data-driven design (Vartiainen et al., 2021), interactive data visualizations (Chittora & Baynes, 2020; von Wangenheim et al., 2021), virtual reality and robotics (Narahara & Kobayashi, 2018), games (Giannakos et al., 2020), or even based on combined workshop series (Lee et al., 2021). To date, there are very few methodological proposals on how to introduce the AI curriculum in K-12 education (Lee et al., 2020).

Since the development of a field requires prior research, we propose in this paper to identify and examine the way in which AI literacy is developing in K-12 around the world, to draw conclusions and guide teaching proposals for AI literacy in K-12. By highlighting and discussing the pros and cons of the different approaches and experiences in the literature, we aim to inspire new initiatives and guide the actors involved, from decisions-makers, for example in education policy, to teachers involved in their conception, design and implementation. We also hope to raise awareness of the importance of learning about AI from an early age, emphasizing the key aspects of this training and, hopefully, fueling the debate that needs to be fostered in our research community.

## Integration of AI into the K12 curriculum

As a scientific-technological field, AI is just a few decades old. The name was coined in 1956, and since then different disciplines (such as computer science, mathematics, philosophy, neuroscience, or psychology) have contributed to its development from an interdisciplinary focus. AI is oriented to comprehend, model, and replicate human intelligence and cognitive processes into artificial systems. Currently, it covers a wide range of subfields such as machine learning, perception, natural language processing, knowledge representation and reasoning, computer vision, among many others (Russell & Norvig, 2021).

Starting in the 1970s, AI began to emerge in educational contexts through tools specifically designed to support learning, teaching, and the management of educational institutions. Since many jobs are now AI-related and will continue to increase in the coming years, some researchers believe that AI education should be considered as important as literacy in reading and writing (Kandlhofer et al., 2016). The highly interdisciplinary character is also another factor to consider. AI literacy can be defined as a set of skills that enable a solid understanding of AI through three priority axes: learning about AI, learning about how AI works, and learning for life with AI (Long & Magerko, 2020; Miao et al., 2021). The first axis focuses on understanding AI concepts and techniques to enable the recognition of which artifacts/platforms use AI and which do not. The second axis addresses the understanding of how AI works, to effectively interact with it. The third axis seeks to understand how AI can affect our lives, allowing us to critically evaluate its technology. Thus, AI literacy goes beyond the use of AI applications in education, such as Intelligent Tutoring Systems (ITS) (du Boulay, 2016).

The teaching of knowledge in AI has traditionally been carried out at the university level, focused on students who study disciplines closely related to computing and ICT in general. In recent years, AI learning has also started to be relevant both in university programs with diverse study backgrounds (Kong et al., 2021), as well as at the K-12 level (Kandlhofer & Steinbauer, 2021; Tedre et al., 2021). However, teaching AI at the K-12 level is not yet prevalent in formal settings and is considered challenging. Experts believe it is important to have some thought on what AI education should look like at the K-12 level so that future generations can become informed citizens who understand the technologies they interact with in their daily lives (Touretzky et al., 2019a). Training children and teenagers will allow them to understand the basics of the science and technology that underpins AI, its possibilities, its limits and its potential social and economic impact. It also stimulates and better prepares them to pursue further studies related to AI or even to become creators and developers of AI themselves (Heintz, 2021).

Nowadays, research on AI teaching is still scarce (Chai et al., 2020a, 2020b; Lee et al., 2020). The acquisition of knowledge in AI represents a great pedagogical challenge for both experts and teachers, and a cognitive challenge for students (Micheuz, 2020). Some countries are making significant efforts to promote AI education in K-12 (Touretzky et al., 2019b), by developing relatively comprehensive curriculum guidelines (Yue et al., 2021). Through interviews with practitioners and policy makers from three different continents (America, Asia and Europe), some studies report on continuing works to introduce AI in K-12 education (He et al., 2020). Some other work focuses on examining and comparing AI curricula in several countries (Yue et al., 2021). In addition, there are a growing number of AI training experiences that explore pathways to optimize AI learning for K-12 students. However, most of them are somehow thematically limited as they do not adequately address key areas of AI, such as planning, knowledge representation and automated reasoning (Nisheva-Pavlova, 2021). Additionally, due to the rapid growth of AI, there is a need to understand how educators can best leverage AI techniques for the academic success of their students. Zhai et al. (2021) recommend that educators work together with AI experts to bridge the gap between technique and pedagogy.

Using a systematic review method, our research aims to present an overview of current approaches to understand how AI is taught worldwide. Several studies have conducted systematic reviews concerning applications of AI in education. Zhai et al. (2021) analyzed how AI was applied to the education domain from 2010 to 2020. Their review covers research on AI-based learning environments, from their construction to their application and integration in the educational environment. Guan et al. (2020) reviewed the main themes and trends in AI research in education over the past two decades. The authors found that research on the use of AI techniques to support teaching or learning has stood the test of time and that learner profiling models and learning analytics have proliferated in the last two decades. Ng et al. (2022) examined learner types, teaching tools and pedagogical approaches in AI teaching and learning, mainly in university computer science education. Chen et al. (2020) covered education enhanced by AI techniques aimed to back up teaching and learning. All these studies have focused on the main role that AI has played in educational applications over the last decades. However, in light of the recent need to consider how AI education should be approached at the K-12 level (Kandlhofer et al., 2016; Long & Magerko, 2020; Miao et al., 2021; Touretzky et al., 2019b), it would be of great value to structure and characterize the different approaches used so far to develop AI literacy in K-12, as well as to identify research gaps to be explored. Recently, Yue et al. (2022) analyzed the main components of the pedagogical design in 32 empirical studies in K-12 AI education and Su et al. (2022) examined 14 learning experiences carried out in the Asian-Pacific region. These components included target audience, setting, duration, contents, pedagogical approaches to teaching, and assessment methods. Sanusi et al. (2022) reviewed research on teaching machine learning in K-12 from four perspectives: curriculum development, technology development, pedagogical development, and teacher training development. The findings of the study revealed that more studies are needed on how to integrate machine learning into subjects other than computer science. Crompton et al. (2022) carried out a systematic review on the use of AI as a supporting tool in K-12 teaching, which entails an interesting but narrower scope. Our study extends previous reviews on K-12 AI research by emphasizing how the current approaches are integrating AI literacy in K-12 education worldwide.

## Research question

To begin the systematic review, a single research question (RQ) was formulated.

RQ: How are current approaches integrating AI literacy into K-12 education worldwide?

In essence, the RQ aims to investigate the characterization of the different approaches being employed to incorporate AI education in K-12. The following subsections in the methodology describe the search and the data collection process in such a way that an answer to the RQ can be provided in a replicable and objective fashion.

## Methods

The research method chosen to conduct this research was the systematic literature review (SLR), following the guidelines posed by Kitchenham (2004). Accordingly, the following subsections summarize and document the key steps implemented in this research method.

### Search process

We used *Scopus* to implement the search process. Scopus provides an integrated search facility to find relevant papers in its database based on curated metadata. It includes primary bibliographic sources published by *Elsevier*, *Springer*, *ACM*, and *IEEE*, among others. It provides a comprehensive coverage of journals and top-ranked conferences within fields of interest. We did not limit our search to specific journals or regular conference proceedings, as there is not yet a clearly established body of literature on the subject. All searches were performed based on title, keywords and abstract, and conducted between 21 October 2021 and 9 March 2023.

To decide the search string, we ran an initial search and found only a few papers focused on 'literacy' whereas the vast majority referred to the broader term 'education'. Therefore, we decided to use both search terms (key issue 1 in Table 1). As some recent works combine the terms 'Artificial Intelligence' and 'education'/'literacy' into single terms such as 'AI literacy' or 'AI education', these were added to the search string (key issue 2 in Table 1). The educational stage was also included in the search string (key issue 3 in Table 1). As the search term 'education' also returns AI-based learning environments which are outside the scope of our review, we explicitly considered negated terms to leave out both computer-based learning and intelligent tutoring systems (key issue 4 in Table 1). A final decision was whether to use the term 'Artificial

**Table 1** Summary of search terms and issues associated with their choice

| Key issues | Search |
|---|---|
| 1 Education vs. literacy | literacy OR education |
| 2 Artificial Intelligence & Education/literacy | ((literacy OR education) AND ( ( artificial AND intelligence))) OR ( "AI literacy" OR "AI education")) |
| 3 Educational stage | ( "primary school" OR "secondary school" OR k-12 OR "middle school" OR "high school") |
| 4 Excluding Ai-based learning environments | Excluding Ai-based learning environments & NOT ( "computer-based learning") AND NOT ( "intelligent tutoring system")) |

**Table 2** Data extraction annotations definitions

| Annotations on extracted data | Definition |
|---|---|
| Study metadata information | Type of publication (journal or proceedings), publication details, primary study ID, author(s), title, abstract |
| Type of educational approach | Learning experience, theoretical perspective |
| Interdisciplinary nature | Yes, No |
| AI support tools | Yes (the study includes learning and acquiring skills in AI support tools), No |
| Student role | Yes (the study describes the role of the student in the AI education process), No |
| Teacher training | Yes (the study describes the training of teachers and their role in the teaching and learning process), No |
| Systemic experience | Yes (The study means a systemic experience/proposal rooted in country-wide education policies), No |

Intelligence' as a single umbrella term or to add narrower terms related to AI subfields (e.g., machine learning). After a preliminary inspection of a few relevant papers, we observed that such additional specific terms usually co-occur with the string 'Artificial Intelligence' in education, and they were therefore regarded as unnecessary. Thus, to capture the essence of our RQ and to build up the complete search string, we considered the search terms as shown in Table 1. Eventually, this resulted in the following complete search string in Scopus:

TITLE-ABS-KEY ( ( ( ( literacy OR education) AND ( ( artificial AND intelligence))) OR ( "AI literacy" OR "AI education")) AND ( "primary school" OR "secondary school" OR k-12 OR "middle school"

OR "high school") AND NOT ( "computer-based learning") AND NOT ( "intelligent tutoring system")).

We included peer-reviewed papers published on topics related to literacy and education on AI at school. Then we excluded papers whose usage of AI was limited to 1) supporting computer-based learning only, with no focus on learning about AI; 2) supporting assessment/tutoring based on AI. We also excluded papers that targeted college students and those that were limited to K-12 programming/CS concepts as a prerequisite for learning about AI in the future. Following these inclusion and exclusion criteria, our search in Scopus returned an initial list of 750 documents. After we inspected the title, abstract, keywords and full-text screening, we obtained a final list of 179 documents.

### Data collection extraction and synthesis strategy

Data collection extraction was performed, discussed, and coordinated through regular meetings. After inspecting and discussing 10% of the papers over multiple meetings, the authors agreed on the annotations presented in Table 2. This process is important as it allowed us to build a data annotation scheme empirically emerging from the sampled papers. A copy of the papers was also kept for easy review in case of doubts or disagreements.

The data resulted in a spreadsheet with the metadata of the papers which passed the inclusion and exclusion criteria, and a document with the list of paper IDs together with the rest of annotations. Some Python scripts were used to further process metadata (e.g., counting participating countries, frequencies, etc.) and produce a more complete bibliographic report with histograms and overview counting. A more qualitative analysis was carried out to answer the research question based on paper reading and annotations.

## Results

The results were organized into two subsections. The first subsection is a bibliometric analysis of the reviewed studies, which is based on the metadata provided by Scopus. The second subsection provides a qualitative analysis of the studies, which is based on the

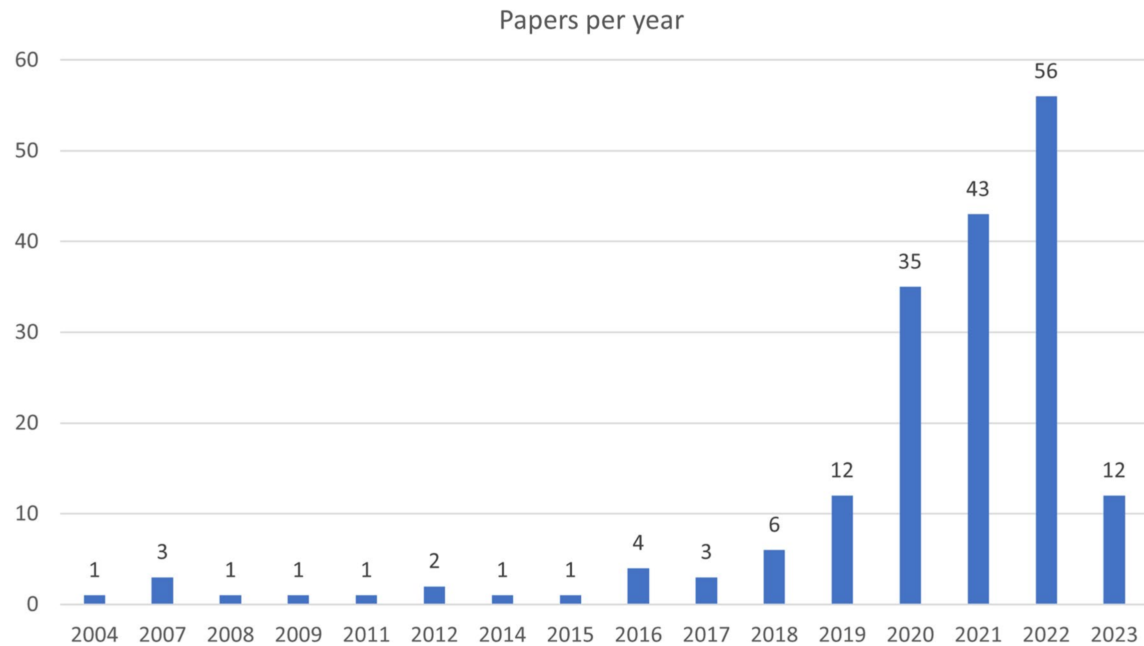


**Fig. 1** Annual scientific production: number of papers by year

extracted data annotations (see Table 2). Both analyses are complementary and together deliver a better understanding of the research articles retrieved.

### Bibliometric analysis

Figure 1 shows that the annual scientific production has been modest. It gained traction in 2016 and increased sharply in 2020.

Most of the contributions are conference publications (126 papers), while 52 are journal articles and one is a book chapter (Fig. 2).

Eighty out of 179 papers have at least a citation in Scopus. There are 13 papers that have 10 or more citations, and the most cited papers are Long and Magerko (2020) and Touretzky et al. (2019b). Figure 3 summarizes the number of contributions by publishers, where Springer, IEEE and ACM stand out, followed by Elsevier. As for journals, there are no single journals concentrating the publication of articles. Nevertheless, there are some journals that are especially relevant and well-known by the community such as the International Journal of Child-Computer Interaction, Computers and Education: Artificial Intelligence, International Journal of Artificial Intelligence in Education, or IEEE Transactions on Education.

As for conferences, Fig. 4 summarizes the main conference events where papers are published. It includes flagship conferences[1] such as CHI and AAAI, top-ranked conferences such as HRI or SIGCSE and several noteworthy events (IDC, ICALT, ITiCSE, VL/HCC, to name a few). It is worth mentioning that AAAI is receiving contributions from recent years, which confirms the interest in the field in broadening the discussion to education. There are some additional publications associated with satellite AAAI events, such as workshops in CEUR-WS that deal with the issue under study. Although such contributions may sometimes be short, we decided to include them as they were relevant. For instance, the works published in (Herrero et al., 2020) and (Micheuz, 2020) include the German countrywide proposal for educating about AI, through a 6-module course focusing on explaining how AI works, the social discourse on AI and reducing existing misconceptions. On the other hand, Aguar et al. (2016) talk about teaching AI via an optional course which does not contribute to the final grades.

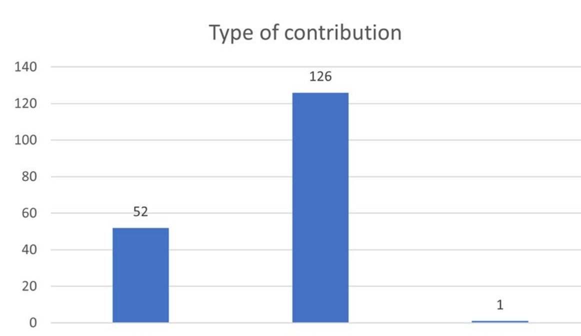


**Fig. 2** Type of contributions: number of papers by type

[1] [1]Conference categorization and ranking based on the GII-GRIN-SCIE (GGS) Conference Ratings: https://scie.lcc.uma.es/

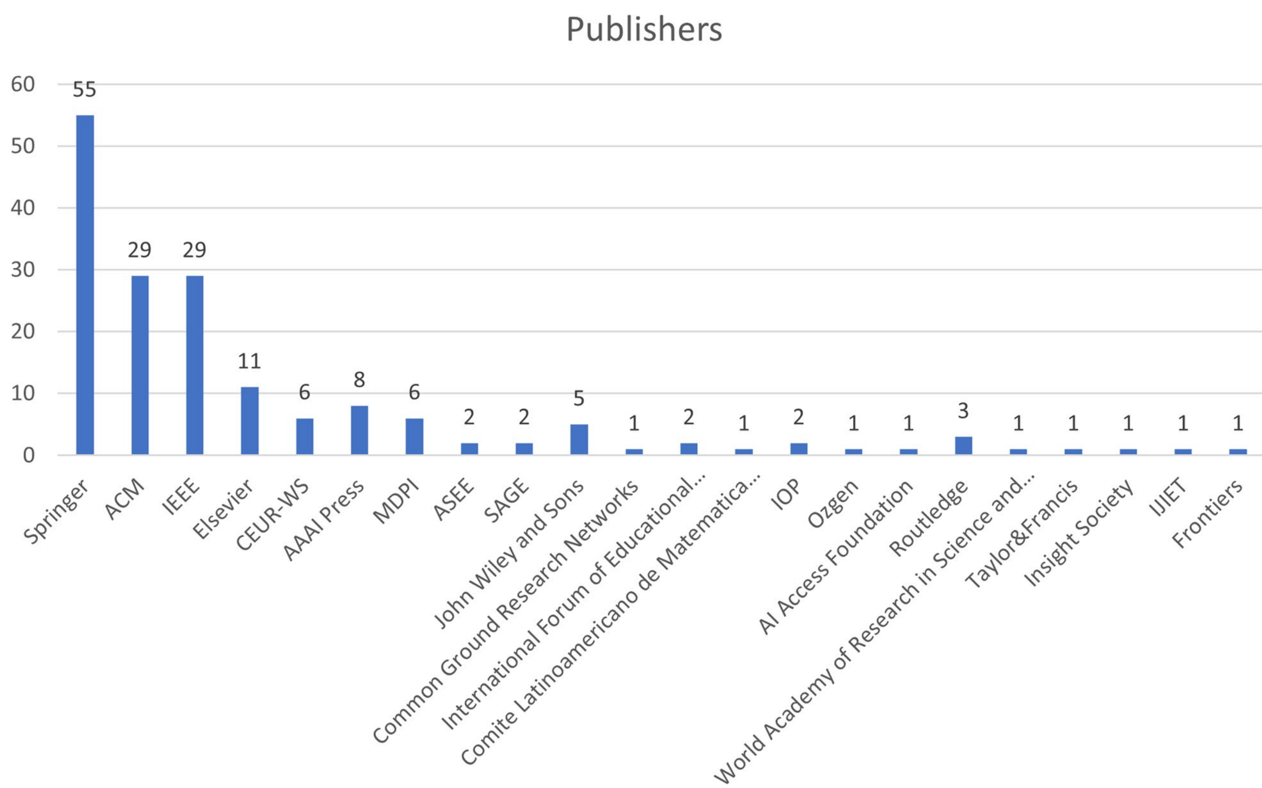


**Fig. 3** Frequency of publishers: number of papers by publisher

The analysis did not reveal particularly outstanding institutions (see Table 3 for a summary). Among the 299 affiliated institutions, we mostly find universities and research centers along with a few collaboration associations. The most active institutions are the Chinese University of Hong Kong, University of Eastern Finland and MIT, whose authors participated in a total of 19, 11 and 10 contributions, respectively.

Finally, the retrieved papers were co-authored by 643 different authors affiliated to research institutions from 42 countries. Figure 5 shows the histogram of participation by country. Of the 179 papers reviewed, most papers were written by authors affiliated with institutions in the same country. Only 32 papers involved authors from several countries. It is remarkable that in these cases at least one author is from the US, Hong Kong or China.

## Literature analysis

By analyzing the data extracted, the papers were classified into two broad thematic categories according to the type of educational approach, namely, learning experience and theoretical perspective. The first category covers AI learning experiences focused on understanding a particular AI concept/technique or using specific tools/platforms to illustrate some AI concepts. The second category involves initiatives for the implementation of AI education for K-12 through the development of guidelines, curriculum design or teacher training, among others. Each main category was further subdivided into other subcategories to structure the field and characterize the different approaches used in developing AI literacy in K-12. Figure 6 shows all the identified categories and subcategories.

### Learning experiences focused on understanding AI

This category covers learning experiences aimed at experimenting and becoming familiar with AI concepts and techniques. Based on the priority axes in AI literacy (Long & Magerko, 2020; Miao et al., 2021), we identified experiences aimed at acquiring basic AI knowledge to recognize artifacts using AI, learning how AI works, learning tools for AI and learning to live with AI.

#### *Learning to recognize artifacts using AI*

This subcategory refers to experiences that aim to understand AI concepts and techniques enabling the recognition of which artifacts/platforms use AI and which do not. Four studies were found in this subcategory. They are proposals aimed at helping young people to understand and demystify AI through different types of

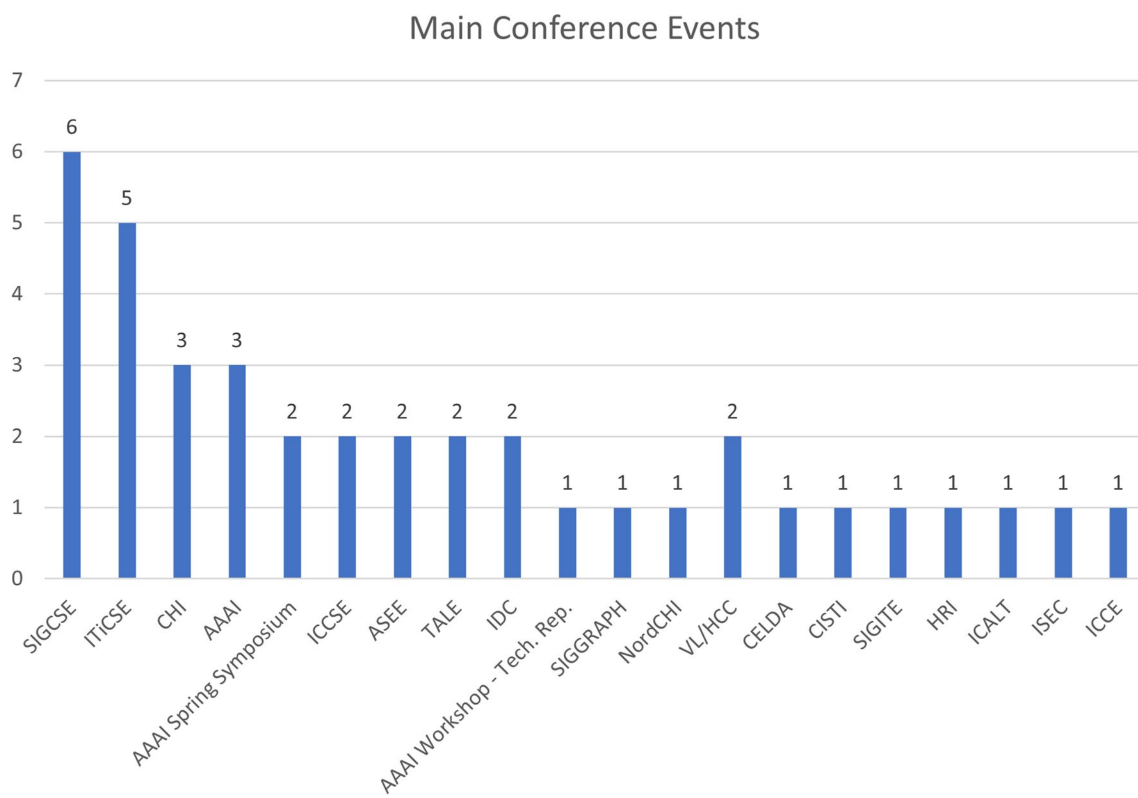


**Fig. 4** Main conference events: number of papers by conference

**Table 3** Most active institutions

| Institutions | Papers |
|---|---|
| The Chinese University of Hong Kong (Hong Kong) | 19 |
| University of Eastern Finland (Finland) | 11 |
| MIT (USA) | 10 |
| North Carolina State University (USA) | 8 |
| Beijing Normal University (China) | 6 |
| Carnegie Mellon University (USA) | 6 |
| Indiana University (USA) | 5 |
| University of California (USA) | 5 |
| University of Florida (USA) | 5 |
| University of Southern California (USA) | 5 |
| Graz University of Technology (Austria) | 4 |
| South China Normal University (China) | 4 |
| Austrian Computer Society (Austria) | 3 |
| Georgia Institute of Technology (USA) | 3 |
| Korea University (South Korea) | 3 |
| 18 institutions with 2 papers, and the rest with 1 | – |

activities. These activities included conducting discussions after watching AI-related movies (Tims et al., 2012), carrying out computer-based simulations of human-like behaviors (Ho et al., 2019), experimenting as active users of social robots (Gonzalez et al., 2017) and programming AI-based conversational agents (Van Brummelen et al., 2021b).

#### *Learning about how AI works*

This topic covers proposals designed to understand how AI works to make user interaction with AI easier and more effective. In this type of proposal, the focus is on methodology and learning is achieved through technology (Kim et al., 2023). The objective is to provide a better understanding of a particular aspect of reality in order to carry out a project or solve a problem (Lenoir & Hasni, 2016). The activities are supported by active experiences based on building and creating intelligent devices to achieve the understanding of AI concepts following the idea of Papert's constructionism.

These experiences are mainly focused on teaching AI subfields such as ML or AI algorithms applied to robotics. Understanding the principles of ML, its workflows and its role in everyday practices to solve real-life problems has been the main objective of some studies (Burgsteiner et al., 2016; Evangelista et al., 2019; Lee et al., 2020; Sakulkueakulsuk et al., 2019; Vartiainen et al., 2021). In addition, there are also experiences focused on unplugged activities that simulate AI algorithms. For

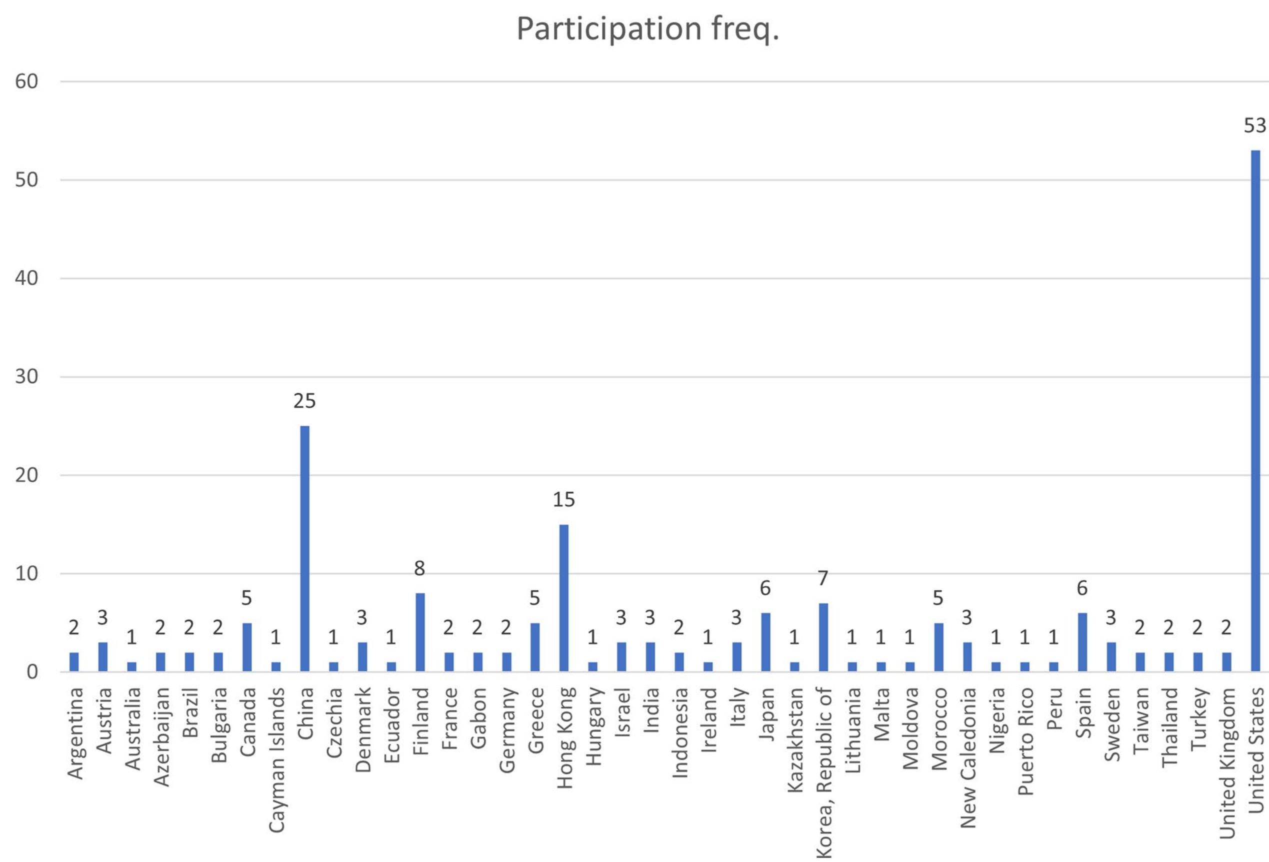


**Fig. 5** Country participation: number of papers by country

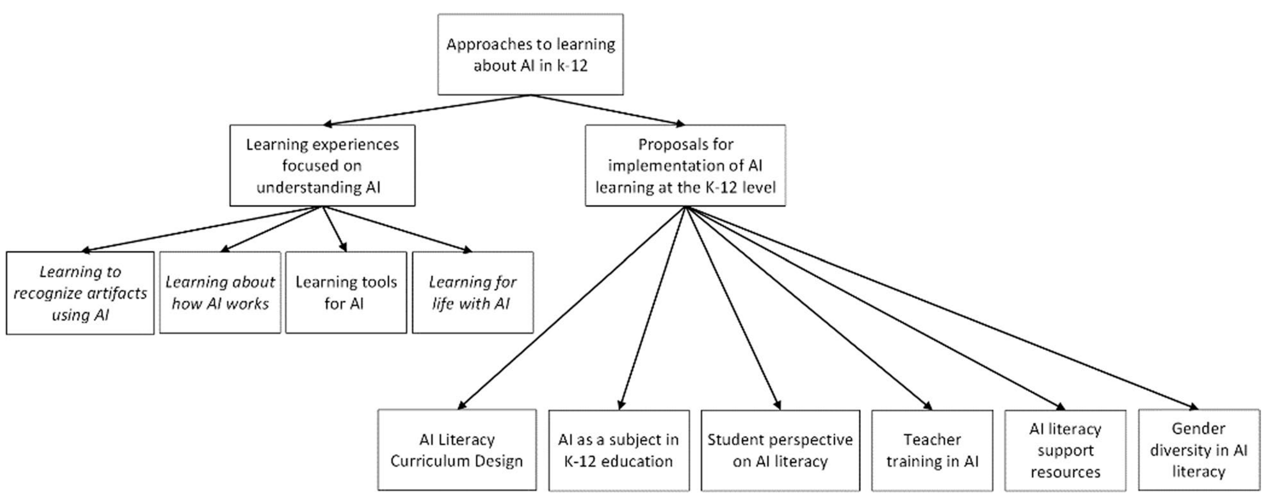


**Fig. 6** Taxonomy of approaches to AI learning in K-12

example, through classic games such as Mystery Hunt, one can learn how to traverse a graph without being able to see beyond the next path to be traversed (blind search) (Kandlhofer et al., 2016). Similarly, the AI4K12 initiative (Touretzky et al., 2019b) collects a large set of activities and resources to simulate AI algorithms.

#### Learning tools for AI

This topic includes approaches that involve learning about AI support tools. The development of intelligent devices in the context of teaching AI requires specific programming languages or age-appropriate tools. Many of the tools currently available are focused on ML, with the aim of demystifying this learning in K-12 education (Wan et al., 2020). Some of them are integrated into block-based programming languages (such as Scratch or App Inventor) (Toivonen et al., 2020; von Wangenheim et al., 2021), enabling the deployment of the ML models built into games or mobile applications. Other approaches use data visualization and concepts of gamification to engage the student in the learning process (Reyes et al., 2020; Wan et al., 2020) or combine traditional programming activities with ML model building (Rodríguez-García et al., 2020).

This type of proposal aims to introduce AI through tools that enable the use of AI techniques. It is therefore an approach focused on learning by using AI-oriented tools. In this vein, different experiences have focused on learning programming tools for applications based on Machine Learning (Reyes et al., 2020; Toivonen et al., 2020; von Wangenheim et al., 2021; Wan et al., 2020), robotics (Chen et al., 2017; Eguchi, 2021; Eguchi & Okada, 2020; Holowka, 2020; Narahara & Kobayashi, 2018; Nurbekova et al., 2018; Verner et al., 2021), programming and the creation of applications (Chittora & Baynes, 2020; Giannakos et al., 2020; Kahn et al., 2018; Kelly et al., 2008; Park et al., 2021). Some of these tools use Scratch-based coding platforms to make AI-based programming attractive to children. In (Kahn et al., 2018), students play around with machine learning to classify self-captured images, using a block-based coding platform.

There are also experiences in which other types of environments are used to facilitate learning (Aung et al., 2022). In (Holowka, 2020; Verner et al., 2021), students can learn reinforcement learning through online simulation. In (Narahara & Kobayashi, 2018), a virtual environment helps students generate data in a playful setting, which is then used to train a neural network for the autonomous driving of a toy car-lab. In (Avanzato, 2009; Croxell et al., 2007), students experiment with different AI-based tasks through robotics-oriented competitions.

#### Learning for life with AI

This subcategory covers experiences aimed at understanding how AI can affect our lives thus providing us with skills to critically assess its technology. In (Vachovsky et al., 2016), technically rigorous AI concepts are contextualized through the impact on society. There are also experiences where students explore how a robot equipped with AI components can be used in society (Eguchi & Okada, 2018), program conversational agents (Van Brummelen et al., 2021b), or learn to recognize credible but fake media products (video, photos), which have been generated using AI-based techniques (2021b; Ali et al., 2021a).

The ethical and philosophical implications of AI have also been addressed in some experiences (2021b; Ali et al., 2021a; Ellis et al., 2005), whereas others focus on training students to participate in present-day society and become critical consumers of AI (Alexandre et al., 2021; Cummings et al., 2021; Díaz et al., 2015; Kaspersen et al., 2022; Lee et al., 2021; Vartiainen et al., 2020).

### Proposals for implementation of AI learning at the K-12 level

Some countries are making efforts to promote AI education in K-12. In the U.S., intense work is being carried out on the integration of AI in schools and among these schemes, AI4K12 stands out (Heintz, 2021). This scheme is especially interesting since it defines the national guidelines for future curricula, highlighting the essential collaborative work between developers, teachers and students (Touretzky et al., 2019a). This idea of co-creation is also stressed in other schemes (Chiu, 2021). In the U.S. we can also mention the proposal made by the Massachusetts Institute of Technology, which is an AI curriculum that aims to engage students with its social and ethical implications (Touretzky et al., 2019a). Although the United States is working intensively on the design of integrating this knowledge into the curriculum, so far AI is not widely offered in most K-12 schools (Heintz, 2021).

In China, the Ministry of Education has integrated AI into the compulsory secondary school curriculum (Ottenbreit-Leftwich et al., 2021; Xiao & Song, 2021). Among their schemes we can reference the AI4Future initiative of the Chinese University of Hong Kong (CUHK), which promotes the co-creation process to implement AI education (Chiu et al., 2021). In Singapore, a program for AI learning in schools has also been developed, where K-12 children learn AI interactively. However, the program is hindered by a lack of professionals (teachers) with adequate training (Heintz, 2021). In Germany, there are also several initiatives to pilot AI-related projects and studies (Micheuz, 2020), including the launch of a national initiative to teach a holistic view of AI. This initiative consists of a 6-module course aimed at explaining how AI works, stimulating a social discourse on AI and clarifying the abundant existing misconceptions (Micheuz, 2020). Canada has also designed an AI course for high schools. The course is intended to empower students with knowledge about AI, covering both its philosophical and conceptual underpinnings as well as its practical aspects. The latter are achieved by building AI projects that solve real-life problems (Nisheva-Pavlova, 2021).

The literature also highlights the different approaches that AI literacy should focus on: curriculum design, AI subject design, student perspective, teacher training, resource design and gender diversity. All these approaches are described in depth below.

#### AI literacy curriculum design

Approaches to curriculum development differ widely, ranging from the product-centered model (technical-scientific perspective) to the process-centered model (learner perspective) (Yue et al., 2021). AI literacy can be launched in primary and secondary education depending on the age and computer literacy of the students. To do this, it is necessary to define the core competencies for AI literacy according to three dimensions: AI concepts, AI applications and AI ethics and security (Long & Magerko, 2020; Wong et al., 2020). Research has focused on the understanding of the concepts, the functional roles of AI, and the development of problem-solving skills (Woo et al., 2020). This has led to proposing a redefinition of the curriculum (Han et al., 2019; Malach & Vicherková, 2020; Zhang et al., 2020) supported by different ideas that K-12 students should know (Chiu et al., 2021; Sabuncuoglu, 2020; Touretzky et al., 2019b). Several countries have already made different curricular proposals (Alexandre et al., 2021; Micheuz, 2020; Nisheva-Pavlova, 2021; Ottenbreit-Leftwich et al., 2021; Touretzky et al., 2019b; Xiao & Song, 2021), where they argue that the curricular design must include different elements such as content, product, process and praxis (Chiu, 2021). It is also convenient for learning in AI to follow the computational thinking model (Shin, 2021), contextualizing the proposed curriculum (Eguchi et al., 2021; Wang et al., 2020) and providing it with the necessary resources for teachers (Eguchi et al., 2021). In this sense, emerging initiatives highlight the need to involve teachers in the process of co-creating a curriculum associated to their context (Barlex et al., 2020; Chiu et al., 2021; Dai et al., 2023; Lin & Brummelen, 2021; Yau et al., 2022).

#### *AI as a subject in K-12 education*

Traditionally, including computer science or new technologies in the educational system has been carried out through a specific subject integrated into the curriculum or through the offer of extracurricular activities. In this sense, different proposals have suggested the integration of AI as a subject in K-12 education (Ellis et al., 2009; Knijnenburg et al., 2021; Micheuz, 2020; Sperling & Lickerman, 2012), in short-term courses (around 15 h) and divided into learning modules focused on classical and modern AI (Wong, 2020) or through MOOCs (Alexandre et al., 2021).

#### *Student perspective on AI Literacy*

Student-focused studies explore and analyze attitudes and previous knowledge to make didactic proposals adapted to the learner. Some of them measure their intention and interest in learning AI (Bollin et al., 2020; Chai et al., 2021, 2020a, 2020b; Gao & Wang, 2019; Harris et al., 2004; Sing, et al., 2022; Suh & Ahn, 2022), whereas others discuss their views on the integration of technologies in the education system (Sorensen & Koefoed, 2018) and on teaching–learning support tools in AI (Holstein et al., 2019).

#### *Teacher training in AI*

Teachers are key players for the integration of AI literacy in K-12, as proven by the numerous studies that examine this issue (An et al., 2022; Bai & Yang, 2019; Chiu & Chai, 2020; Chiu et al., 2021; Chounta et al., 2021; Judd, 2020; Kandlhofer et al., 2019, 2021; Kim et al., 2021; Korenova, 2016; Lin et al., 2022; Lindner & Berges, 2020; Oh, 2020; Summers et al., 1995; Wei et al., 2020; Wu et al., 2020; Xia & Zheng, 2020). This approach places teachers at the center, bearing in mind what they need to know so as to integrate AI into K-12 (Itmazi & Khlaif, 2022; Kim et al., 2021). The literature analyzed reports on the factors that influence the knowledge of novice teachers (Wei, 2021) and focuses on teacher training in AI (Lindner & Berges, 2020; Olari & Romeike, 2021). Thus, AI training proposals can be found aimed at both teachers in training (Xia & Zheng, 2020) and practicing educators. Training schemes focus on their knowledge in technologies to facilitate their professional development (Wei et al., 2020) through the TPACK (Technological, Pedagogical and Content Knowledge) teaching knowledge model (Gutiérrez-Fallas & Henriques, 2020). Studies focusing on teachers' opinions on curriculum development in AI are relevant (Chiu & Chai, 2020), as are their self-efficacy in relation to ICT (Wu et al., 2020), their opinions on the tools that support the teaching–learning process in AI (Holstein et al., 2019) and their teacher training in technologies (Cheung et al, 2018; Jaskie et al., 2021). These elements are central to the design of an AI literacy strategy in K-12. Both the co-design of ML curricula between AI researchers and K-12 teachers, and the assessment of the impact of these educational interventions on K-12 are important issues today. At present, there is a shortage of teachers with training in AI and working with teachers in training (Xia & Zheng, 2020) or with teachers in schools (Chiu et al., 2021) is proposed as an effective solution. One of the most interesting analyses of teacher competency proposes the acquisition of this skill for the teaching of AI in K-12, through the analysis of the curricula and resources of AI using TPACK. This model was formulated by (Mishra & Koehler, 2006) and aims to define the different types of knowledge that teachers need to integrate ICT effectively in the classroom. In this regard, it is suggested that teachers imparting AI to K-12 students require TPACK to build an environment and facilitate project-based classes that solve problems using AI technologies (Kim et al., 2021).

#### *AI literacy support resources*

Research using this approach focuses on presenting resources that support AI literacy (Kandlhofer & Steinbauer, 2021), considering that the creation of resources and repositories is a priority in supporting this teaching–learning process (Matarić et al., 2007; Mongan & Regli, 2008). However, these resources largely do not meet an interdisciplinary approach and do not embody a general approach to AI development (Sabuncuoglu, 2020).

#### *Gender diversity in AI literacy*

AI education, as a broad branch of computer science, also needs to address the issue of gender diversity. Lack of gender diversity can impact the lives of the people for whom AI-based systems are developed. The literature highlights the existence of proposals designed with a perspective toward gender, where the activities designed are specifically aimed at girls (Ellis et al., 2009; Jagannathan & Komives, 2019; Perlin et al., 2005; Summers et al., 1995; Vachovsky et al., 2016; Xia et al., 2022).

## Discussion

The huge impact that AI is having on our lives, at work and in every type of organization and business sector is easily recognizable today. No one doubts that AI is one of the most disruptive technologies in history, if not the most. In recent years, the expectations generated by AI, far from being deflated, have only grown. We are still a long way from general-purpose AI, but the application of AI to solve real problems has already taken hold for a wide range of purposes. It is therefore necessary for young people to know how AI works, as this learning will make it easier for them to use these technologies in their daily lives, both to learn and to interact with others.

Like any other technology, the potential uses and abuses of AI go hand in hand with its disruptive capacity. Many social groups and governments are expressing concern about the possible negative consequences of AI misuse. Although it is crucial to adequately regulate the use of AI, education is as important, if not more important, than regulation. Everything, whether good or bad, stems from the education received. Thus, education systems must prepare students for a society in which they will have to live and interact with AI. AI education will enable young people to discover how these tools work and, consequently, to act responsibly and critically. Therefore, AI literacy has become a relevant and strategic issue (Chiu & Chai, 2020).

This systematic review has focused on analyzing AI teaching–learning proposals in K-12 globally. The results confirm that the teaching of basic AI- related concepts and techniques at the K-12 level is scarce (Kandlhofer et al., 2016). Our work shows that there have been, on the one hand, different AI learning experiences and, on the other hand, proposals for the implementation of AI literacy, made at the political level and by different experts. The learning experiences described show that AI literacy in schools has focused on technical, conceptual, and applied skills in some domains of interest. Proposals for AI implementation, especially those defined by the US and China, reveal that significant efforts are being made to design models that frame AI literacy proposals.

We also found that there are hardly any AI learning experiences that have analyzed learning outcomes, e.g., through assessments of learners' understanding of AI concepts. Obviously, this is a result of the infancy of these AI learning experiences at the K-12 level. However, it is important for learning experiences to be based on clearly defined competencies in a particular AI literacy framework, such as those proposed in the literature (Alexandre et al., 2021; Han et al., 2019; Long & Magerko, 2020; Malach & Vicherková, 2020; Micheuz, 2020; Ottenbreit-Leftwich et al., 2021; Touretzky et al., 2019a; Wong et al., 2020; Xiao & Song, 2021; Zhang et al., 2020). Recently, Van Brummelen et al. (2021a) designed a curriculum for a five-day online workshop based on the specific AI competencies proposed by Long and Magerko (2020). They used several types of questionnaires to assess the quality of the program through the knowledge acquired by the students in these competencies. Therefore, clearly defined competency-based learning experiences can provide a rigorous assessment of student learning outcomes.

The research shows that clear guidelines are needed on what students are expected to learn about AI in K-12 (Chiu, 2021; Chiu & Chai, 2020; Lee et al., 2020). These studies highlight the need for a competency framework to guide the design of didactic proposals for AI literacy in K-12 in educational institutions. This framework would provide a benchmark for describing the areas of competency that K-12 learners should develop and which specific educational projects can be designed. Furthermore, it would support the definition of a curriculum reflecting sequence and academic continuity (Woo et al., 2020). Such a curriculum should be modular and personalized

(Gong et al., 2019) and adjusted to the conditions of the schools (Wang et al., 2020). In the teaching of AI, an exploratory education should be adopted, which integrates science, computer science and integral practice (Wang et al., 2020). It should also address issues related to the ethical dimension, which is fundamental to the literacy of K-12 students as it enables them to understand the basic principles of AI (Henry et al., 2021). This training facilitates the development of students' critical capacity, and this is necessary to understand that technology is not neutral and to benefit from and make appropriate use of it. Ethics, complementary to legal norms, enhances the democratic quality of society by setting legitimate limits in the shaping of technological life. In this sense, different AI literacy proposals in K-12 already support the addressing of ethical, social and security issues linked to AI technologies (Eguchi et al., 2021; Micheuz, 2020; Wong et al., 2020). Moreover, considering designing for social good could foster or help to motivate learning about AI (Chai et al., 2021). Without a doubt, all this will impact on the achievement of a more democratic society. Due to the gender gap in issues related to computer science, it is also necessary to address the gender perspective. In this vein, the research proposes, among other strategies, to focus AI literacy on real-world elements since this approach favors the motivation of girls and greater involvement in learning (Jagannathan & Komives, 2019). However, little attention is paid to the undesirable consequences of an indiscriminate and insufficiently thought-out application of AI, both in higher education and especially in K-12. For example, the increase in socio-economic inequality between countries and within countries, resulting from the increasing automation of employment, is of particular concern. This is leading to growing inequality in wages and preservation of human employment, but it is not usually a subject of interest in education.

Currently, the challenges of this AI literacy require an interdisciplinary and critical approach (Henry et al., 2021). We believe that AI literacy can be leveraged to enhance the learning of disciplinary core subjects by integrating AI into the teaching process of those subjects. AI literacy should rely on transferring AI knowledge and methods to core subjects, allowing education to cross disciplinary boundaries, but staying within the framework of disciplinary core subjects. To achieve this change, educators need to take a closer look at the current capabilities of AI. This would enable them to identify all options to improve the core of educational practice and thus optimize the educational process. For example, understanding and using word clouds is a powerful educational strategy to enhance education in core subjects such as science (e.g., to facilitate object classification), language (e.g. to enable the matching of different topics or authors' works), music (e.g., to support the analysis of song lyrics) or social sciences (e.g., to assist in comparing different discourses). Since AI is highly interdisciplinary in nature, it has a broad projection on multiple fields and problems that require a transversal and applied approach. For example, the basic algorithms of ML could be taught in Mathematics and related disciplines, the design of supervised classifiers could be performed for the study of taxonomies in Biology, natural language processing could be used to make the study of a language more attractive, or the ethical issues surrounding AI could be discussed in Philosophy and Social Sciences subjects.

Finally, for this meaningful learning to take place, AI teaching must be addressed through holistic, active, and collaborative pedagogical strategies in which real problem solving is the starting point of the learning process. An important gap regarding the integration of AI in K-12 concerns teachers, as it is unclear how to prepare and involve them in the process (Chiu & Chai, 2020). Teachers' attitudes towards AI have a significant influence on the effectiveness of using AI in education. Teachers can swing between total resistance and overconfidence. The first could arise from inadequate, inappropriate, irrelevant, or outdated professional development. On the one hand, teachers must be digitally-competent enough to integrate AI into the teaching–learning processes of their subjects. Therefore, teacher training is also necessary following a framework of standard competencies. This should include new ways of organizing the professional role of teachers, as well as enhancing students' attitudes towards these changes. On the other hand, research reveals that it is essential for didactic proposals to be co-designed and implemented by the teachers at those schools involved (Henry et al., 2021), to undergo training in the specific AI subjects and for this knowledge to be integrated into non-computer subjects (Lin & Brummelen, 2021). To this end, it is crucial to identify the perception and knowledge that teachers have about AI and involve them in the design of curricular proposals (Chiu, 2021; Chiu & Chai, 2020; Chiu et al., 2021).

## Conclusion

This study aimed to understand how AI literacy is being integrated into K-12 education. To achieve this, we conducted a search process following the systematic literature review method and using Scopus. Two broad groups of AI literacy approaches were identified, namely learning experiences and theoretical perspective. The study revealed that learning experiences in schools have focused mainly on technical and applied skills limited to a specific domain without rigorously assessing student learning outcomes. In contrast, the US and China are leading the way in AI literacy implementation schemes which are broader in scope and involve a more ambitious approach. However, there is still a need to test these initiatives through comprehensive learning experiences that incorporate an analysis of learning outcomes. This work has allowed us to draw several conclusions that can be considered in the design of AI literacy proposals in K-12. Firstly, AI literacy should be based on an interdisciplinary and competency-based approach and integrated into the school curriculum. There is no need to include a new AI subject in the curriculum, but rather to build on the competencies and content of disciplinary subjects and then integrate AI literacy into those subjects. Given the interdisciplinary nature of AI, AI education can break disciplinary boundaries and adopt a global, practical, and active approach in which project-based and contextualized work plays an important role. Secondly, AI literacy should be leveraged to extend and enhance learning in curricular subjects. As a final point, AI literacy must prioritize the competency of teachers and their active participation in the co-design of didactic proposals, together with pedagogues and AI experts.

## Supplementary Information

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**Additional file 1.** Additional listing.


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#### Author contributions

All authors have contributed significantly to the authorship of this work in all stages of conceptualization, discussions, definition of the methodology, carrying out the analysis as well as writing—review & editing. All authors read and approved the final manuscript.


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#### Availability of data and materials

Last revision round required update the review. Thus, Additional file 1 contains a.csv file with the listing of papers that are not cited but are part of the reviewed papers. The papers cited in text already appear in the Reference section and, therefore, not in the Additional file.

## Declarations

#### Ethics approval and consent to participate

This research is carried out in accordance to ethics recommendations. As it focuses on a systematic literature review as a research method, ethics approval by the University ethics committee does not apply.

#### Competing interests

The authors declare that they have no competing interests. The authors have no other relevant financial or non-financial interests to disclose and no further competing interests to declare that are relevant to the content of this article.


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#### References


Aguar, K., Arabnia, H. R., Gutierrez, J. B., Potter, W. D., & Taha, T. R. (2016). Making cs inclusive: An overview of efforts to expand and diversify cs education. In *International Conference on Computational Science and Computational Intelligence (CSCI).* (pp. 321–326). https://doi.org/10.1109/CSCI.2016.0067

Alexandre, F., Becker, J., Comte, M. H., Lagarrigue, A., Liblau, R., Romero, M., & Viéville, T. (2021). Why, What and How to help each citizen to understand artificial intelligence? *KI Kunstliche Intelligenz, 35*(2), 191–199. https://doi.org/10.1007/s13218-021-00725-7

Ali, S., DiPaola, D., Lee, I., Hong, J., & Breazeal, C. (2021a). Exploring generative models with middle school students. In *Proceedings of the 2021a CHI Conference on Human Factors in Computing Systems.* (pp. 1–13). https://doi.org/10.1145/3411764.3445226

Ali, S., DiPaola, D., Lee, I., Sindato, V., Kim, G., Blumofe, R., & Breazeal, C. (2021b). Children as creators, thinkers and citizens in an AI-driven future. *Computers and Education Artificial Intelligence*. https://doi.org/10.1016/j.caeai.2021.100040

An, X., Chai, C. S., Li, Y., Zhou, Y., Shen, X., Zheng, C., & Chen, M. (2022). Modeling English teachers' behavioral intention to use artificial intelligence in middle schools. *Education and Information Technologies*. https://doi.org/10.1007/s10639-022-11286-z

Aung, Z. H., Sanium, S., Songsaksuppachok, C., Kusakunniran, W., Precharattana, M., Chuechote, S., & Ritthipravat, P. (2022). Designing a novel teaching platform for AI: A case study in a Thai school context. *Journal of Computer Assisted Learning, 38*(6), 1714–1729. https://doi.org/10.1111/jcal.12706

Avanzato, R. L. (2009). Autonomous Outdoor Mobile Robot Challenge. *Computer in Education Journal* (July-September 2009).

Bai, H., & Yang, S. (2019, October). Research on the Sustainable Development Model of Information Technology Literacy of Normal Students Based on Deep Learning Recommendation System. In *2019 4th International Conference on Mechanical, Control and Computer Engineering (ICMCCE).* (pp. 837–840). https://doi.org/10.1109/ICMCCE48743.2019.00192

Barlex, D., Steeg, T., & Givens, N. (2020). Teaching about disruption: A key feature of new and emerging technologies. *Learning to Teach Design and Technology in the Secondary School, 4*, 137–154. https://doi.org/10.4324/9780429321191-9

Bollin, A., Kesselbacher, M., & Mößlacher, C. (2020). Ready for computing science? A closer look at personality, interests and self-concept of girls and boys at secondary level. In *Informatics in Schools. Engaging Learners in Computational Thinking: 13th International Conference, ISSEP.* (pp. 107–118). https://doi.org/10.1007/978-3-030-63212-0_9

Burgsteiner, H., Kandlhofer, M., & Steinbauer, G. (2016). IRobot: teaching the basics of artificial intelligence in high schools. *Proceedings of the AAAI Conference on Artificial Intelligence*. https://doi.org/10.1609/aaai.v30i1.9864

Chai, C.S., Lin, P.-Y., Jong, M.S.-Y., Dai, Y., Chiu, T.K., & Huang, B. (2020a). Factors influencing students' behavioral intention to continue artificial intelligence learning. In *2020a International Symposium on Educational Technology (ISET).* (pp. 147–150). https://doi.org/10.1109/ISET49818.2020.00040

Chai, C. S., Wang, X., & Xu, C. (2020b). An extended theory of planned behavior for the modelling of chinese secondary school students' intention to learn artificial intelligence. *Mathematics, 8*(11), 1–18. https://doi.org/10.3390/math8112089
Chai, C.S., Lin, P.-Y., Jong, M.S.-Y., Dai, Y., Chiu, T.K., & Qin, J. (2021). Perceptions of and behavioral intentions towards learning artificial intelligence in primary school students. *Educational Technology & Society*, *24*(3), 89–101. Retrieved from https://www.jstor.org/stable/27032858
Chen, S., Qian, B., & Cheng, H. (2017). Voice recognition for STEM education using robotics. In *Volume 9: 13th ASME/IEEE International Conference on Mechatronic and Embedded Systems and Applications.* ASME. https://doi.org/10.1115/DETC2017-68368
Chen, M., Zhou, C., & Wu, Y. (2020). Research on the model and development status of information literacy self-improvement ability of primary and secondary school teachers. In *Ninth International Conference of Educational Innovation through Technology (EITT).* (pp. 87–91). https://doi.org/10.1109/EITT50754.2020.00021
Cheung, S. K., Lam, J., Li, K. C., Au, O., Ma, W. W., & Ho, W. S. (Eds.). (2018). *Technology in Education. Innovative Solutions and Practices: Third International Conference, ICTE 2018.* Springer.
Chittora, S., & Baynes, A. (2020, October). Interactive Visualizations to Introduce Data Science for High School Students. In *Proceedings of the 21st Annual Conference on Information Technology Education.* (pp. 236–241). https://doi.org/10.1145/3368308.3415360
Chiu, T. K. F. (2021). A holistic approach to the design of artificial intelligence (AI) education for k-12 schools. *TechTrends, 65*(5), 796–807. https://doi.org/10.1007/s11528-021-00637-1
Chiu, T. K., & Chai, C.-S. (2020). Sustainable curriculum planning for artificial intelligence education: A self-determination theory perspective. *Sustainability (switzerland)*. https://doi.org/10.3390/su12145568
Chiu, T. K., Meng, H., Chai, C. S., King, I., Wong, S., & Yam, Y. (2021). Creation and evaluation of a pretertiary artificial intelligence (AI) curriculum. *IEEE Transactions on Education, 65*(1), 30–39. https://doi.org/10.1109/TE.2021.3085878
Chounta, I.-A., Bardone, E., Raudsep, A., & Pedaste, M. (2021). Exploring teachers' perceptions of artificial intelligence as a tool to support their practice in estonian k-12 education. *International Journal of Artificial Intelligence in Education, 32*, 725–755. https://doi.org/10.1007/s40593-021-00243-5
Crompton, H., Jones, M. V., & Burke, D. (2022). Affordances and challenges of artificial intelligence in K-12 education: a systematic review. *Journal of Research on Technology in Education*. https://doi.org/10.1080/15391523.2022.2121344
Croxell, J., Mead, R., & Weinberg, J. (2007). Designing robot competitions that promote ai solutions: Lessons learned competing and designing. *Technical Report of the 2007 American Association of Artificial Intelligence. Spring Symposia*, SS-07–09. (pp. 29–34).
Cummings D., Anthony M., Watson C., Watson A., & Boone S. (2021). Combating social injustice and misinformation to engage minority youth in computing sciences. In *Proceedings of the 52nd ACM Technical Symposium on Computer Science Education.* (pp.1006–1012). https://doi.org/10.1145/3408877.3432452.
Dai, Y., Liu, A., Qin, J., Guo, Y., Jong, M. S. Y., Chai, C. S., & Lin, Z. (2023). Collaborative construction of artificial intelligence curriculum in primary schools. *Journal of Engineering Education, 112*(1), 23–42. https://doi.org/10.1002/jee.20503
Díaz, J., Queiruga, C., Tzancoff, C., Fava, L., & Harari, V. (2015). Educational robotics and videogames in the classroom. In *2015 10th Iberian Conference on Information Systems and Technologies (CISTI)*. Aveiro, Portugal. (pp. 1–6). https://doi.org/10.1109/CISTI.2015.7170616
du Boulay, B. (2016). Artificial intelligence as an effective classroom assistant. *IEEE Intelligent Systems, 31*(6), 76–81. https://doi.org/10.1109/MIS.2016.93
Eguchi, A. (2021). AI-robotics and ai literacy. *Studies in Computational Intelligence, 982*, 75–85. https://doi.org/10.1007/978-3-030-77022-8
Eguchi, A., & Okada, H. (2018). If you give students a social robot? - world robot summit pilot study. In *Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction.* (pp. 103–104). https://doi.org/10.1145/3173386.3177038
Eguchi, A., & Okada, H. (2020). Imagine the Future with Social Robots - World Robot Summit's Approach: Preliminary Investigation. In M. Moro, D. Alimisis, & L. Iocchi, L. (Eds) *Educational Robotics in the Context of the Maker Movement. Edurobotics 2018. Advances in Intelligent Systems and Computing,* (p. 946). Springer. https://doi.org/10.1007/978-3-030-18141-3_10
Eguchi, A., Okada, H., & Muto, Y. (2021). Contextualizing AI education for k- 12 students to enhance their learning of ai literacy through culturally responsive approaches. *KI Kunstliche Intelligenz, 35*(2), 153–161. https://doi.org/10.1007/s13218-021-00737-3
Ellis, G., Ory, E., Bhushan, N. (2005). Organizing a K-12 AI curriculum using philosophy of the mind. Engineering: Faculty Publications, Smith College. Retrieved from https://scholarworks.smith.edu/egr_facpubs/96
Ellis, G., Silva, K., Epstein, T., & Giammaria, N. (2009). Artificial intelligence in pre-college education: Learning within a philosophy of the mind framework. *International Journal of Engineering Education, 25*(3), 511–522.
Evangelista, I., Blesio, G., & Benatti, E. (2019). Why are we not teaching machine learning at high school? a proposal. In *2018 World Engineering Education Forum - Global Engineering Deans Council (WEEF-GEDC).* (pp. 1–6). https://doi.org/10.1109/WEEF-GEDC.2018.8629750
Gao, J., & Wang, L. (2019). Reverse thinking teaching discussion in high school information technology under new curriculum standards. In *14th International Conference on Computer Science & Education (ICCSE)*. (pp. 222–226). https://doi.org/10.1109/ICCSE.2019.8845429
Giannakos, M., Voulgari, I., Papavlasopoulou, S., Papamitsiou, Z., & Yannakakis, G. (2020). Games for artificial intelligence and machine learning education: Review and perspectives. *Lecture Notes in Educational Technology*. https://doi.org/10.1007/978-981-15-6747-6_7
Gong, X., Zhao, L., Tang, R., Guo, Y., Liu, X., He, J., … Wang, X. (2019). AI education system for primary and secondary schools. In *2019 ASEE Annual Conference & Exposition*.
Gonzalez, A. J., Hollister, J. R., DeMara, R. F., Leigh, J., Lanman, B., Lee, S. Y., & Wilder, B. (2017). AI in informal science education: bringing turing back to life to perform the turing test. *International Journal of Artificial Intelligence in Education, 27*(2), 353–384. https://doi.org/10.1007/s40593-017-0144-1
Guan, C., Mou, J., & Jiang, Z. (2020). Artificial intelligence innovation in education: A twenty-year data-driven historical analysis. *International Journal of Innovation Studies, 4*(4), 134–147. https://doi.org/10.1016/j.ijis.2020.09.001
Gutiérrez, L. F., & Henriques, A. (2020). Prospective mathematics teachers' tpack in a context of a teacher education experiment. *Revista Latinoamericana De Investigación En Matemática Educativa, 23*(2), 175–202. https://doi.org/10.12802/relime.20.2322
Han, X., Hu, F., Xiong, G., Liu, X., Gong, X., Niu, X., … Wang, X. (2019). Design of AI + curriculum for primary and secondary schools in Qingdao. In *Chinese Automation Congress (CAC)*. (pp. 4135–4140). https://doi.org/10.1109/CAC.2018.8623310
Harris, E., Lamonica, A., & Weinberg. JB. (2004) Interfacing the public and technology: a web controlled mobile robot. In *Accessible hands-on artificial intelligence and robotics education: working papers of the 2004. AAAI spring symposium series.* AAAI Press. (pp.106–110)
He, Y.-T., Guo, B.-J., Lu, J., Xu, Y.-P., & Gong, M. (2020). Research of scratch programming recommendation system based on med and knowledge graph. In *2020 5th International Conference on Mechanical, Control and Computer Engineering (ICMCCE)*. (pp. 2158–2163). https://doi.org/10.1109/ICMCCE51767.2020.00469
Heintz, F. (2021). Three interviews about k-12 ai education in america, europe, and singapore. *KI Kunstliche Intelligenz, 35*(2), 233–237. https://doi.org/10.1007/s13218-021-00730-w
Henry, J., Hernalesteen, A., & Collard, A.-S. (2021). Teaching artificial intelligence to k-12 through a role-playing game questioning the intelligence concept. *KI Kunstliche Intelligenz, 35*(2), 171–179. https://doi.org/10.1007/s13218-021-00733-7
Herrero, Á., Cambra, C., Urda, D., Sedano, J., Quintián, H., & Corchado, E. (Eds) (2020). *11th International Conference on European Transnational Educational (ICEUTE 2020). ICEUTE 2020. Advances in Intelligent Systems and Computing, 1266*. Springer. https://doi.org/10.1007/978-3-030-57799-5_8
Ho, J. W., Scadding, M., Kong, S. C., Andone, D., Biswas, G., Hoppe, H. U., & Hsu, T. C. (2019). Classroom activities for teaching artificial intelligence to primary school students. In *Proceedings of international conference on*

*computational thinking education*. The Education University of Hong Kong. (pp. 157–159).
Holowka, P. (2020). Teaching robotics during COVID-19: Machine learning, simulation, and aws deepracer. In *17th International Conference on Cognition and Exploratory Learning in Digital Age, CELDA*.
Holstein, K., McLaren, B. M., & Aleven, V. (2019). Designing for complementarity: Teacher and student needs for orchestration support in ai-enhanced classrooms. In S. Isotani, E. Millán, A. Ogan, P. Hastings, B. McLaren, & R. Luckin (Eds.), *Artificial intelligence in education. AIED 2019. Lecture notes in computer science* (p. 11625). Springer. 10.1007/978-3-030-23204-7_14.
Itmazi, J., & Khlaif, Z. N. (2022). Science education in Palestine: Hope for a better future. *Lecture Notes in Educational Technology*. https://doi.org/10.1007/978-981-16-6955-2_9
Jagannathan, R. K., & Komives, C. (2019). Teaching by induction: Project- based learning for Silicon Valley. *Journal of Engineering Education Transformations, 33*(1), 22–26. https://doi.org/10.16920/jeet/2019/v33i1/149003
Jaskie, K., Larson, J., Johnson, M., Turner, K., O'Donnell, M., Christen, J.B., & Spanias, A. (2021). Research experiences for teachers in machine learning. In *IEEE Frontiers in Education Conference (FIE)*. Lincoln, NE, USA. (pp. 1–5). https://doi.org/10.1109/FIE49875.2021.9637132
Judd, S. (2020). Activities for Building Understanding: How AI4ALL Teaches AI to Diverse High School Students. In *Proceedings of the 51st ACM Technical Symposium on Computer Science Education*. (pp. 633–634). https://doi.org/10.1145/3328778.3366990
Kahn, K., Megasari, R., Piantari, E., & Junaeti, E. (2018). AI programming by children using Snap! block programming in a developing country. In *Thirteenth European Conference on Technology Enhanced Learning*. (p. 11082). https://doi.org/10.1007/978-3-319-98572-5
Kandlhofer, M., Steinbauer, G., Hirschmugl-Gaisch, S., & Huber, P. (2016). Artificial intelligence and computer science in education: From kindergarten to university. In *IEEE Frontiers in Education Conference*. (pp. 1–9). https://doi.org/10.1109/FIE.2016.7757570
Kandlhofer, M., Steinbauer, G., Lasnig, J.P., Baumann, W., Plomer, S., Ballagi, A., & Alfoldi, I. (2019). Enabling the creation of intelligent things: Bringing artificial intelligence and robotics to schools. In *IEEE Frontiers in Education Conference (FIE)*. (pp. 1–5). https://doi.org/10.1109/FIE43999.2019.9028537
Kandlhofer, M., & Steinbauer, G. (2021). AI k-12 education service. *KI Kunstliche Intelligenz, 35*(2), 125–126. https://doi.org/10.1007/s13218-021-00715-9
Kandlhofer, M., Steinbauer, G., Lassnig, J., Menzinger, M., Baumann, W., Ehardt-Schmiederer, M., & Szalay, I. (2021). EDLRIS: A European driving license for robots and intelligent systems. *KI Kunstliche Intelligenz, 35*(2), 221–232. https://doi.org/10.1007/s13218-021-00716-8
Kaspersen, M. H., Bilstrup, K. E. K., Van Mechelen, M., Hjort, A., Bouvin, N. O., & Petersen, M. G. (2022). High school students exploring machine learning and its societal implications Opportunities and challenges. *International Journal of Child-Computer Interaction, 34*, 1–12. https://doi.org/10.1016/j.ijcci.2022.100539
Kelly, J., Binney, J., Pereira, A., Khan, O., & Sukhatme, G. (2008). Just add wheels: Leveraging commodity laptop hardware for robotics and ai education. In *Proceedings of AAAI Education Colloquium*, 22.
Kim, K., Kwon, K., Ottenbreit-Leftwich, A., Bae, H., & Glazewski, K. (2023). Exploring middle school students' common naive conceptions of Artificial Intelligence concepts, and the evolution of these ideas. *Education and Information Technologies*. https://doi.org/10.1007/s10639-023-11600-3
Kim, S., Jang, Y., Choi, S., Kim, W., Jung, H., Kim, S., & Kim, H. (2021). Analyzing teacher competency with tpack for k-12 ai education. *KI Kunstliche Intelligenz, 35*(2), 139–151. https://doi.org/10.1007/s13218-021-00731-9
Kitchenham, B. (2004). *Procedures for performing systematic reviews* (Vol. 33, pp. 1–26). Keele: Keele University.
Knijnenburg, B., Bannister, N., & Caine, K. (2021). Using mathematically-grounded metaphors to teach ai-related cybersecurity. In *IJCAI-21 Workshop on Adverse Impacts and Collateral Effects of Artificial Intelligence Technologies (AIofAI)*.
Kong, S. C., ManYinCheung, W., & Zhang, G. (2021). Evaluation of an artificial intelligence literacy course for university students with diverse study backgrounds. *Computers and Education: Artificial Intelligence*. https://doi.org/10.1016/j.caeai.2021.100026
Korenova, L. (2016). Digital technologies in teaching mathematics on the faculty of education of the Comenius University in Bratislava. In *15 Conference on Applied Mathematics*. Slovak University of Technology in Bratislava. (p. 690–699).
Lee, S., Mott, B., Ottenbriet-Leftwich, A., Scribner, A., Taylor, S., Glazewski, K.,…Lester, J. (2020). Designing a collaborative game-based learning environment for ai-infused inquiry learning in elementary school class- rooms. In *Proceedings of the 2020 ACM conference on innovation and technology in computer science education*. (pp. 566–566). https://doi.org/10.1145/3341525.3393981
Lee, I., Ali, S., Zhang, H., Dipaola, D., & Breazeal, C. (2021). Developing middle school students' ai literacy. In *Association for Computing Machinery, Inc.* (pp. 191–197). https://doi.org/10.1145/3408877.3432513
Lenoir, Y., & Hasni, A. (2016). Interdisciplinarity in primary and secondary school: Issues and perspectives. *Creative Education, 7*(16), 2433–2458. https://doi.org/10.4236/ce.2016.716233
Lin, P., & Brummelen, J. (2021). Engaging teachers to co-design integrated ai curriculum for k-12 classrooms. In *CHI '21: Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. (pp.1–12). https://doi.org/10.1145/3411764.3445377
Lin, X. F., Chen, L., Chan, K. K., Peng, S., Chen, X., Xie, S., & Hu, Q. (2022). Teachers' perceptions of teaching sustainable artificial intelligence: A design frame perspective. *Sustainability, 14*(13), 1–20. https://doi.org/10.3390/su14137811
Lindner, A., & Berges, M. (2020). Can you explain ai to me? teachers' pre-concepts about artificial intelligence. In *IEEE Frontiers in Education Conference (FIE)*. (pp. 1–9). https://doi.org/10.1109/FIE44824.2020.9274136
Long, D., & Magerko, B. (2020). What is AI literacy? Competencies and design considerations. In *Proceedings of the 2020 chi conference on human factors in computing systems*. (pp. 1–16). https://doi.org/10.1145/3313831.3376727
Malach, J., & Vicherková, D. (2020). Background of the Revision of the Secondary School Engineering Curriculum in the Context of the Society 4.0. In M. Auer, H. Hortsch & P. Sethakul (Eds). *The Impact of the 4th Industrial Revolution on Engineering Education. ICL Advances in Intelligent Systems and Computing,* vol 1135. Springer. https://doi.org/10.1007/978-3-030-40271-6_27
Matarić, M.J., Koenig, N., & Feil-Seifer, D. (2007). Materials for enabling hands-on robotics and stem education. In *AAAI Spring Symposium: Semantic Scientific Knowledge Integration*. (pp. 99–102). http://www.aaai.org/Papers/Symposia/Spring/2007/SS-07-09/SS07-09-022.pdf
Miao, F., Holmes, W., Huang, R., & Zhang, H. (2021). *AI and education: A guidance for policymakers*. UNESCO Publishing.
Micheuz, P. (2020). Approaches to Artificial Intelligence as a Subject in School Education. In T. Brinda, D. Passey, & T. Keane (Eds), *Empowering Teaching for Digital Equity and Agency. OCCE 2020. IFIP Advances in Information and Communication Technology, 595.* Springer. https://doi.org/10.1007/978-3-030-59847-1_1
Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x
Mongan, W.M., & Regli, W.C. (2008). A cyber-infrastructure for supporting k-12 engineering education through robotics, WS-08-02, 68–73.
Narahara, T., & Kobayashi, Y. (2018). Personalizing homemade bots with plug & play ai for steam education. In *SIGGRAPH Asia 2018 technical briefs*. (pp. 1–4). https://doi.org/10.1145/3283254.3283270
Ng, D. T. K., Lee, M., Tan, R. J. Y., Hu, X., Downie, J. S., & Chu, S. K. W. (2022). A review of AI teaching and learning from 2000 to 2020. *Education and Information Technologies*. https://doi.org/10.1007/s10639-022-11491-w
Nisheva-Pavlova, M.M. (2021). Ai courses for secondary and high school - comparative analysis and conclusions. In *CEUR Workshop Proceedings, 3061.* (pp. 9–16).
Nurbekova, Z., Mukhamediyeva, K., & Assainova, A. (2018). Educational robotics technologies in Kazakhstan and in the world: Comparative analysis, current state and perspectives. *Astra Salvensis, 6*(1), 665–686.
Oh, W. (2020). Physics teachers' perception of it convergence-based physics education. *New Physics: Sae Mulli, 70*(8), 660–666. https://doi.org/10.3938/NPSM.70.660
Olari, V., & Romeike, R. (2021). Addressing ai and data literacy in teacher education: A review of existing educational frameworks. In *WiPSCE '21: The 16th Workshop in Primary and Secondary Computing Education, 17.* (pp. 1–2) https://doi.org/10.1145/3481312.3481351

Ottenbreit-Leftwich, A., Glazewski, K., Jeon, M., Hmelo-Silver, C., Mott, B., Lee, S., & Lester, J. (2021). How do elementary students conceptualize artificial intelligence? *In SIGCSE '21: Proceedings of the 52nd ACM Technical Symposium on Computer Science Education*. (pp. 1261). https://doi.org/10.1145/3408877.3439642
Park, K., Mott, B., Lee, S., Glazewski, K., Scribner, J., Ottenbreit-Leftwich, A., & Lester, J. (2021). Designing a visual interface for elementary students to formulate ai planning tasks. In *IEEE Symposium on Visual Languages and Human-Centric Computing (VL/HCC).* (pp. 1–9). https://doi.org/10.1109/VL/HCC51201.2021.9576163
Perlin, K., Flanagan, M., & Hollingshead, A. (2005). The Rapunsel Project. In Subsol, G. (Eds). *Virtual Storytelling. Using Virtual Reality Technologies for Storytelling. ICVS 2005. Lecture Notes in Computer Science*, 3805. Springer. https://doi.org/10.1007/11590361_29
Reyes, A., Elkin, C., Niyaz, Q., Yang, X., Paheding, S., & Devabhaktuni, V. (2020). A preliminary work on visualization-based education tool for high school machine learning education. In *IEEE Integrated STEM Education Conference (ISEC).* (pp. 1–5). https://doi.org/10.1109/ISEC49744.2020.9280629
Rodríguez-García, J., Moreno-León, J., Román-González, M., & Robles, G. (2020). Introducing artificial intelligence fundamentals with learning ML: Artificial intelligence made easy. In *TEEM'20: Eighth International Conference on Technological Ecosystems for Enhancing Multiculturality*. (pp. 18–20). https://doi.org/10.1145/3434780.3436705
Russell, S. (2021). The history and future of AI. *Oxford Review of Economic Policy, 37*(3), 509–520. https://doi.org/10.1093/oxrep/grab013
Russell, S., & Norvig, P. (2021). *Artificial Intelligence, global edition a modern approach*. Pearson Deutschland.
Sabuncuoglu, A. (2020). Designing one year curriculum to teach artificial intelligence for middle school. In *Proceedings of the 2020 ACM conference on innovation and technology in computer science education*. (pp. 96–102). https://doi.org/10.1145/3341525.3387364
Sakulkueakulsuk, B., Witoon, S., Ngarmkajornwiwat, P., Pataranutapom, P., Surareungchai, W., Pataranutaporn, P., & Subsoontorn, P. (2019). Kids making ai: Integrating machine learning, gamification, and social context. In *2018 IEEE international conference on teaching, assessment, and learning for engineering (TALE)*. (pp. 1005–1010). https://doi.org/10.1109/TALE.2018.8615249
Sanusi, I. T., Oyelere, S. S., Vartiainen, H., Suhonen, J., & Tukiainen, M. (2022). A systematic review of teaching and learning machine learning in K-12 education. *Education and Information Technologies*. https://doi.org/10.1007/s10639-022-11416-7
Shin, S. (2021). A study on the framework design of artificial intelligence thinking for artificial intelligence education. *International Journal of Information and Education Technology, 11*(9), 392–397. https://doi.org/10.18178/ijiet.2021.11.9.1540
Sing, C. C., Teo, T., Huang, F., Chiu, T. K., & Xing Wei, W. (2022). Secondary school students' intentions to learn AI: Testing moderation effects of readiness, social good and optimism. *Educational Technology Research and Development, 70*(3), 765–782. https://doi.org/10.1007/s11423-022-10111-1
Sorensen, L., & Koefoed, N. (2018). The future of teaching—what are students' expectations. In *2018 11th CMI International Conference: Prospects and Challenges Towards Developing a Digital Economy within the EU*. (pp. 62–66). https://doi.org/10.1109/PCTDDE.2018.8624771
Sperling, A., & Lickerman, D. (2012). Integrating AI and machine learning in software engineering course for high school students. In *Proceedings of the 17th ACM annual conference on Innovation and technology in computer science education*. (pp. 244–249). https://doi.org/10.1145/2325296.2325354
Su, J., Zhong, Y., & Ng, D. T. K. (2022). A meta-review of literature on educational approaches for teaching AI at the K-12 levels in the Asia-Pacific region. *Computers and Education: Artificial Intelligence, 3*, 1–18. https://doi.org/10.1016/j.caeai.2022.100065
Suh, W., & Ahn, S. (2022). Development and validation of a scale measuring student attitudes toward artificial intelligence. *SAGE Open, 12*(2), 1–12. https://doi.org/10.1177/21582440221100463
Summers, B.G., Hicks, H., & Oliver, C. (1995). Reaching minority, female and disadvantaged students. In *Proceedings Frontiers in Education 1995 25th Annual Conference. Engineering Education for the 21st Century*, *1*. (992a4–16). https://doi.org/10.1109/FIE.1995.483030
Tedre, M., Toivonen, T., Kahila, J., Vartiainen, H., Valtonen, T., Jormanainen, I., & Pears, A. (2021). Teaching machine learning in k-12 classroom: Pedagogical and technological trajectories for artificial intelligence education. *IEEE Access, 9*, 110558–110572. https://doi.org/10.1109/ACCESS.2021.3097962
Tims, H., Turner III, G., Cazes, G., & Marshall, J. (2012). Junior cyber discovery: Creating a vertically integrated middle school cyber camp. In *2012 ASEE Annual Conference & Exposition.* (pp. 25–867). Retrieved from https://peer.asee.org/21624
Toivonen, T., Jormanainen, I., Kahila, J., Tedre, M., Valtonen, T., Vartiainen, H. (2020). Co-designing machine learning apps in k-12 with primary school children. In *2020 IEEE 20th International Conference on Advanced Learning Technologies (ICALT).* IEEE. (pp. 308–310). https://doi.org/10.1109/ICALT49669.2020.00099
Touretzky, D., Gardner-McCune, C., Breazeal, C., Martin, F., & Seehorn, D. (2019a). A year in k-12 ai education. *AI Magazine, 40*(4), 88–90. https://doi.org/10.1609/aimag.v40i4.5289
Touretzky, D., Gardner-McCune, C., Martin, F., & Seehorn, D. (2019b). Envisioning ai for k-12: What should every child know about ai? *Proceedings of the AAAI Conference on Artificial Intelligence, 33*(01), 9795–9799. https://doi.org/10.1609/aaai.v33i01.33019795
Vachovsky, M., Wu, G., Chaturapruek, S., Russakovsky, O., Sommer, R., & Fei-Fei, L. (2016). Towards more gender diversity in cs through an arti- ficial intelligence summer program for high school girls. In *Proceedings of the 47th ACM technical symposium on computing science education.* (pp. 303–308). https://doi.org/10.1145/2839509.2844620
Van Brummelen, J., Heng, T., & Tabunshchyk, V. (2021a). Teaching tech to talk: K-12 conversational artificial intelligence literacy curriculum and development tools. *Proceedings of the AAAI Conference on Artificial Intelligence, 35*(17), 15655–15663. https://doi.org/10.1609/aaai.v35i17.17844
Van Brummelen, J., Tabunshchyk, V., & Heng, T. (2021b). Alexa, can i program you? Student perceptions of conversational artificial intelligence before and after programming Alexa. In *IDC '21: Interaction Design and Children-June.* (pp. 305–313) https://doi.org/10.1145/3459990.3460730
Vartiainen, H., Tedre, M., & Valtonen, T. (2020). Learning machine learning with very young children: Who is teaching whom? *International Journal of Child-Computer Interaction, 25*, 1–11. https://doi.org/10.1016/j.ijcci.2020.100182
Vartiainen, H., Toivonen, T., Jormanainen, I., Kahila, J., Tedre, M., & Valtonen, T. (2021). Machine learning for middle schoolers: Learning through data-driven design. *International Journal of Child-Computer Interaction, 29*, 1–12. https://doi.org/10.1016/j.ijcci.2021.100281
Verner, I., Cuperman, D., & Reitman, M. (2021). Exploring robot connectivity and collaborative sensing in a high-school enrichment program. *Robotics, 10*(1), 1–19. https://doi.org/10.3390/robotics10010013
von Wangenheim, C. G., Hauck, J. C., Pacheco, F. S., & Bueno, M. F. B. (2021). Visual tools for teaching machine learning in K-12: A ten-year systematic mapping. *Education and Information Technologies, 26*(5), 5733–5778. https://doi.org/10.1007/s10639-021-10570-8
Wan, X., Zhou, X., Ye, Z., Mortensen, C., & Bai, Z. (2020). Smileyclus- ter: Supporting accessible machine learning in k-12 scientific discovery. In *proceedings of the Interaction Design and Children Conference.* (pp. 23–35). https://doi.org/10.1145/3392063.3394440
Wang, H., Liu, Y., Han, Z., & Wu, J. (2020). Extension of media literacy from the perspective of artificial intelligence and implementation strategies of artificial intelligence courses in junior high schools. In *2020 International Conference on Artificial Intelligence and Education (ICAIE).* (pp. 63–66). https://doi.org/10.1109/ICAIE50891.2020.00022
Wei, Y. (2021). Influence factors of using modern teaching technology in the classroom of junior middle school teachers under the background of artificial intelligence-analysis based on HLM. *Advances in Intelligent Systems and Computing, 1282*, 110–118. https://doi.org/10.1007/978-3-030-62743-0_16
Wei, Q., Li, M., Xiang, K., & Qiu, X. (2020). Analysis and strategies of the professional development of information technology teachers under the vision of artificial intelligence. In *2020 15th International Conference on Computer Science & Education (ICCSE).* (pp. 716–721). https://doi.org/10.1109/ICCSE49874.2020.9201652
West, D.M., & Allen, J.R. (2018). How artificial intelligence is transforming the world. *Report*. Retrieved April 24, 2018, f rom https://www.brookings.edu/research/how-artificial-intelligence-is-transforming-the-world/

Wong, K.-C. (2020). Computational thinking and artificial intelligence education: A balanced approach using both classical AI and modern AI. *CoolThink@ JC*, 108.

Wong, G. K., Ma, X., Dillenbourg, P., & Huen, J. (2020). Broadening artificial intelligence education in k-12: Where to start? *ACM Inroads, 11*(1), 20–29. https://doi.org/10.1145/3381884

Woo, H., Kim, J., Kim, J., & Lee, W. (2020). Exploring the ai topic composition of k-12 using nmf-based topic modeling. *International Journal on Advanced Science, Engineering and Information Technology, 10*(4), 1471–1476. https://doi.org/10.18517/ijaseit.10.4.12787

Wu, D., Zhou, C., Meng, C., & Chen, M. (2020). Identifying multilevel factors influencing ICT self-efficacy of k-12 teachers in China. In *Blended Learning. Education in a Smart Learning Environment: 13th International Conference, ICBL 2020.* (pp. 303–314). Springer International Publishing. https://doi.org/10.1007/978-3-030-51968-1

Xia, Q., Chiu, T. K., & Chai, C. S. (2022). The moderating effects of gender and need satisfaction on self-regulated learning through Artificial Intelligence (AI). *Education and Information Technologies*. https://doi.org/10.1007/s10639-022-11547-x

Xia, L., & Zheng, G. (2020). To meet the trend of AI: The ecology of developing ai talents for pre-service teachers in China. *International Journal of Learning, 6*(3), 186–190. https://doi.org/10.18178/IJLT.6.3.186-190

Xiao, W., & Song, T. (2021). Current situation of artificial intelligence education in primary and secondary schools in China. In *The Sixth International Conference on Information Management and Technology.* (pp. 1–4). https://doi.org/10.1145/3465631.3465980

Yau, K. W., Chai, C. S., Chiu, T. K., Meng, H., King, I., Wong, S. W. H., & Yam, Y. (2022). Co-designing artificial intelligence curriculum for secondary schools: A grounded theory of teachers' experience. In *2022 International Symposium on Educational Technology (ISET).* (pp. 58–62). https://doi.org/10.1109/ISET55194.2022.00020

Yue, M., Dai, Y., Siu-Yung, M., & Chai, C.-S. (2021). An analysis of k-12 artificial intelligence curricula in eight countries. In *Proceedings of the 29th International Conference on Computers in Education.* (pp. 22–26).

Yue, M., Jong, M. S. Y., & Dai, Y. (2022). Pedagogical design of K-12 artificial intelligence education: A systematic review. *Sustainability, 14*(23), 15620. https://doi.org/10.3390/su142315620

Zhai, X., Chu, X., Chai, C. S., Jong, M. S. Y., Istenic, A., Spector, M., & Li, Y. (2021). A review of artificial intelligence (AI) in education from 2010 to 2020. *Complexity*. https://doi.org/10.1155/2021/8812542

Zhang, N., Biswas, G., McElhaney, K.W., Basu, S., McBride, E., & Chiu, J.L. (2020). Studying the interactions between science, engineering, and computational thinking in a learning-by-modeling environment. In *International conference on artificial intelligence in education.* (pp. 598–609). Springer.

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