Artificial Intelligence in Primary and Secondary Education: a Review of Educational Activities Development

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Abstract. Intelligent systems are widespread in everyday life. Today, more than ever, artificial intelligence (AI) is being applied to many domains and its societal relevance is growing rather rapidly. It is therefore important to include AI early in education, as a subject for pupils to apprehend and learn. Future citizens must be capable to understand the technology behind intelligent systems, at least globally. This paper reviews the activities and tools that are being developed to teach AI to young pupils in primary and secondary schools. Its goal is to identify the various kinds of activities designed by researchers, like games, unplugged activities, workshops, etc. It also aims at analysing what are the subfields of AI covered by developed activities. To conclude, this paper draws up perspectives on future development the research community may investigate further, to better educate young pupils to AI.

Keywords: Artificial intelligence · Education · School.

1 Introduction

Intelligent systems are an integral part of the society and widespread in everyday life [23]. With the rise of cyber-physical systems, intelligent machines equipped with artificial intelligence (AI) are spreading [28]. A direct consequence is the need for current and future citizens to have some knowledge on these subjects.

Artificial intelligence has been established as an academic discipline in the 1950s [17]. It was only recently it left the scientific obscurity to reach the business world and the public at large. Text generation, image recognition, self-driving vehicles, intelligent household appliances, smartphones and smart speakers with embedded assistants are just a few examples of concrete applications of AI that can be used by anyone today [2]. On the one hand, many people know about the existence of devices and services based on AI but, on the other hand, only a few individuals understand the technology behind them. The underlying process used by artificial intelligence, and more specifically machine learning (ML), is a black box for many users [18]. Since AI and ML concepts are not trivial, there is a justified reason to “black box” them in consumer products.

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As a direct consequence of this invasion of "hidden" AI, everyone needs the competencies to better understand it. More precisely, people should be able to be aware of the impact, opportunities, and limits of AI on their personal lives and our society [27]. This also results in a big challenge for education, starting with younger pupils [20, 38]. Ever-younger children have indeed become active users of online services, like YouTube, WhatsApp, Instagram, Spotify, Snapchat and TikTok, which are using user data and machine learning for privacy-intrusive purposes. As AI-based services become more ubiquitous, it is increasingly urgent to build familiarity with AI technologies to all people, including children, since they will be interacting more and more often with them in the near future [41].

Learners should both be able to explain AI-related phenomena that they observe in their lives and, in some extent, to use AI-based tools to actively and creatively shape the so-called digital world in which they are living. However, learners should not be overwhelmed because of the complexity of an unknown subject [18, 24]. This is especially true for young learners, who do not have enough backgrounds nor prerequisites to be able to understand all the complexity of artificial intelligence. For early stage pupils, the need is therefore to introduce them to AI concepts without burdening them with inner complex details.

1.1 Related Work and Motivations

This paper is focused on teaching artificial intelligence to young pupils. Research on how to introduce AI concepts to them started in the eighties, with the focus mainly put on expert systems [33]. Later, in the nineties, the tic-tac-toe game was used, again with expert systems [31] or with artificial neural networks [14], to introduce AI to middle and high school pupils. Since then, AI has been developing rapidly, and it is crucial that its inclusion in education as a subject follows at least the same rhythm. There has been a growing interest in research proposing curricula to teach AI in schools. This paper is not focused on curricula, but on the design of activities to teach young pupils AI-related concepts. However, explaining these concepts to K-12 through traditional methodologies such as lectures and books is challenging [45]. Many researchers are developing numerous kinds of activities to overcome this challenge. However, what to teach learners, at what age, and how, are some of the open questions being explored.

The motivation of this paper is to offer researchers a global overview of the kinds of activities currently being developed to teach AI to young pupils. As detailed in [7], existing tools and resources to teach and learn computer science are not easy to find nor well advertised. The same observation applies for artificial intelligence, even if several reviews have been written. These latter are usually research-oriented and focused on a specific angle, missing the opportunity to bring a broader and more pragmatic vision. Several reviews and survey papers have already been realised by various researchers. Six pieces of research, published between 2020 and 2023, have been identified as roughly covering a similar goal as the present paper [26, 25, 34, 46, 10, 40]. The main differences are that the latter are either focused on a particular region of the world, or on a specific subfield of AI such as machine learning, or on a given age group.

1.2 Methodology

To fulfil the objectives of this paper, an extensive literature review has been conducted, following similar strategies to those used in [4]. Papers have been found on Google Scholar and on various widespread publishers, including ACM, IEEE, Springer and MDPI, using the following keywords on their search engine: "artificial intelligence K-12", "machine learning K-12", "children teaching artificial intelligence", "activity to learn artificial intelligence children." Relevant references of the papers found with those keywords have also been examined. Papers from the initial set have then been filtered out. Only those in English and published from the year 2000 have been kept. All the kinds of papers have been considered, whether they have been peer-reviewed or not and whatever type they are (full and short paper, poster, extended abstract, etc.). Then, only those related to the development of activities for children (up to 18 years old) have been used for this review. Some papers about the development of curricula have been filtered out, only those also containing propositions of activities have been kept.

After this introduction, the remainder of the paper is as follows. Section 2 presents the subfields of AI covered by the developed activities discovered by this review. Section 3 categorises them according to their kinds. Section 4 then summarises and discusses the findings. Finally, Section 5 concludes the paper.

2 Artificial intelligence subfields

The analysed papers reveal that many subfields of artificial intelligence (AI) are covered by activities to teach them. This section goes through them.

2.1 Data structure

Many AI algorithms are relying on specific *data structures*, like trees, graphs, forests and matrices. Going deep in their understanding is perhaps unsuitable for young children. However, it is worth teaching them about elementary AI algorithms since the explanations can be very visual thanks to the simple underlying data structure. For example, getting how some simple decision tree learning algorithms work is easy for people understanding the notion of tree. Not many pieces of research analysed for this review are focusing on the data structures used in AI. In [21], the authors present the development of unplugged activities to teach AI. The first one can be used to introduce the tree data structure, in the specific context of decision tree learning.

2.2 Learning

Nowadays, *machine learning* (ML) has become the new engine that revolutionises the practices of knowledge discovery [34]. As a consequence, it is important for everyone, in particular children, to be able to cope with the central paradigms of ML. The majority of recent research on activities to teach AI is about ML. Some developed activities are trying to explain the core concepts and intuitions, while others are focused on describing the technical parts. It has also been shown that making children involved in the training of accessible ML systems support them to better understand basic ML processes [19]. Several activities related to ML are therefore focusing on the training part.

Decision tree learning It is important for K-12 pupils to learn about the core ideas and principles of ML. However, it is an enormous challenge for this age group to directly delve into the complexity of ML. Focusing of *decision tree learning* (DTL) provides a more suitable entry point. More precisely, it can be used to exemplify the idea of supervised learning. In [27], the authors propose a teaching concept starting with the understanding of decision tree learning, combining several activities and tools.

Supervised learning Many of the developed activities do include content to teach about *supervised learning* techniques or applications. This is likely due to the fact that the training process can be easily transposed into interactive activities. In [32], the authors present a game they developed to teach supervised learning, gradient descent and k-nearest neighbour classification. Their approach is limited to teaching the definition and core concepts, without inner details like underlying mathematics or jargon. In [29], the authors report on the design of an activity using block-based programming to control educational robots to introduce supervised, unsupervised and reinforcement learning. In [43], the authors are focused on teaching the insights of image recognition and supervised learning to very young pupils, with direct demonstration of how a classifier can identify objects they drew. Finally, in [16], the activity presented by the authors is the development of a scavenger hunt game run on a smartphone. The application relies on machine learning to perform image recognition to identify whether the correct object has been detected or not.

Neural network learning Activities specifically dedicated to *neural network* (NN) learning are also being developed by researchers. The interest about NN is that explaining them can easily be done visually, which makes it more suitable for younger. In [36], the authors propose a three-part learning module for pupils to be taught about artificial neural networks. A constructionist approach is followed, leading pupils to first use neural networks, then modify predefined ones and finally construct their own. This module is carried on a programmable learning environment based on Scratch programming.

2.3 Data mining

Since the rise of big data, it is interesting for people to grasp how algorithms can extract valuable knowledge from them. *Data mining* (DM) is another subfield of AI that can be taught to young pupils. Other subjects like privacy issues can also be discussed in relation with DM. In [11], the authors develop a learning module based on the RapidMiner tool to provide an introduction to DM to young pupils. Their module includes a Hollywood Movie Recommendation activity to make learners understand how to collect, analyse and use data.

2.4 Data science

Analysing data to make decisions with data analytics and machine learning is becoming a widespread activity in the industry. It is therefore also important to teach pupils about what is *data science* and decisions that can be made based on the results of data analyses. Understanding data-driven intelligence is consequently an interesting competency for today's youth to acquire. In [37], the authors present a half-day camp tutorial in which they expose pupils to the full cycle of a typical supervised learning approach used for data analyses. They designed the tutorial as an exciting hands-on introduction to data science.

3 Activities and tools

A second analysis that has been performed on the analysed papers made it possible to highlights the kinds of activities that have been or are being developed, and in which context they are organised.

3.1 Activities

Various kinds of activities are being developed to teach pupils AI-related concepts. Some of them rely on software systems, others on tangible devices, and still others only on pen and paper.

Programming AI concepts can be taught through *programming*. Several activities have been developed where pupils have to experiment by themselves, creating or configuring an AI model. In [29], the authors develop activities for pupils to learn ML concepts by writing programs with a block-based programming tool. Following constructionism ideas, making them programming helps them to experience the concepts in practice. In [16], the authors explain how they designed an activity where pupils are asked to develop a smartphone-based game with AppInventor. In [13], the authors present a workshop using Scratch programming to teach pupils data clustering and artificial NN learning. Their idea is to get learners to partially code AI algorithms to make them aware of how intelligent systems work through construction and experimentation.

Game *Games* have been used for educational purposes for decades, as they contribute to increase their players' motivation to learn [30, 5]. In particular, they are a good mean to have pupils learn about programming, but it is also true for AI. There are various kinds of games that can be used, including tangible, computer and video games. Teaching concepts through them makes learning fun without overwhelming learners with inner details of the concept In [35], the authors present a prototype tangible toy pupils can play with to understand some basic concepts on ML and on the internet of things. The toy consists of two cubes, one being a sensor and the other one an actuator, both communicating the MQTT protocol. Computer and video games are also being used. For example, *ML-Quest* is a 3D video game with a quest theme designed to teach the definition and working of three concepts of ML [32]. Each level of the game ends with the definition of a concept and a mapping of it with the task performed by the player in the level. The authors tested the game with higher-secondary pupils, the majority considering that playing it contributed to enhance their understanding of machine learning. Programming can be learned on online game platforms, such as *Leek Wars*, which is focused on writing an IA to win a fight [5].

Robotics As it is the case with programming, programmable robots are being used to teach AI, should they be physical or virtual. In [47], the authors reports on an activity where pupils are taught about reinforcement learning by building controllers for both physical and virtual robots. The physical robot comes from the LEGO SPIKE Prime robotics kit, and the virtual one was from a web-based platform developed by the authors. In [29], pupils are writing programs to control virtual educational robots in the Open Roberta Lab.

Device AI is being embedded in many *devices* of everyday life, or at least accessible to the public at large. Therefore, it is relevant to develop activities manipulating similar intelligent devices. Direct experience with physical objects can facilitate the understanding of abstract concepts [48]. In [19], the authors present an activity based on the manipulation of a digital stick-like device. Pupils are asked to produce gestures and label them, to train an ML model. Thanks to this activity, pupils learn the two core concepts of ML that are data labelling and evaluation. Other approaches based on sticks are being developed [1].

Unplugged Activities not requiring any technology to be run, referred to as *unplugged activities*, are a common way to teach computer science. They have become valuable for many reasons: low cost, ease of implementation, possibly playful, possibly relying on physical interaction, easily deployable, etc. Unplugged activities served as a low-barrier entry to the topic [32]. In the context of AI, they can be used to broaden the access for educators to AI-related learning experiences at a lower cost. Such activities are also usually more engaging for novice audiences, which is often the case for AI in schools. For example, in [22], the authors present two unplugged assignments to broadly understand AI on the one hand and to be introduced to knowledge representation and reasoning on the other hand. In [44], the author presents an activity where pupils are physically acting out different generative adversarial networks. The goal of the activity is to lead their participants to sketch realistic-looking fake images. Until now, approaches to make AI tangible for students without actually programming an AI system have been rare. AI Unplugged provides unplugged activities presenting AI ideas and concepts without using computers [21].

3.2 Tools

Researchers are implementing *tools* based on which activities can be developed to teach AI. For example, *Google Teachable Machine* is used to design workshops where pupils are creating their own ML application [42, 12]. *Teachable machine* refers to interfaces that do not require programming but makes it possible for its users to train and test an algorithm iteratively [12]. In [39], the authors test an approach using several tools to teach machine learning through design fiction. They used Scroobly (an AR tool), Teachable Machine and Adacraft (a Scratch-based coding environment compatible with ML extension blocks).

3.3 Contexts

The aforementioned activities can be organised in diverse *contexts* where pupils are learning, which can either be in schools or outside of them. This section presents various contexts where the presented activities can be organised.

Course One possible approach to teach artificial intelligence is to develop a teaching unit that includes both theoretical and hands-on components. For example, in [3], the authors present an AI course called *IRobot* and that covers major topics of artificial intelligence. Their goal is to have this seven weekly teaching units of two hours course integrated in secondary science education.

Competition Competitions are a motivating and challenging way to teach concepts, in particular to young people [9]. They are often used to learn programming skills, for example as online game platforms [5]. One example of a challenge targeted to young pupils and through which AI concepts can be taught is the *Bebras Challenge* [8, 15]. Other competitions include games such as Leek Wars [5], where players have to implement an intelligent behaviour for their leeks.

Event Organising *workshops* is also an interested way to teach AI. They can either be organised with pupils in the classroom or at events external to the school context, depending on the workshop total duration. For example, in [42] the authors propose a workshop based on Google Teachable Machine to teach machine learning principle to primary school pupils with three 2.5 hours-session workshop spread over three days. In [43], the authors report on a workshop they designed and held in SciFest, the largest science fair for children, in Finland. This 15-minute workshop was open to any visitor, without needing to book a time slot nor a seat. It consists of an activity where children were drawing animals and then presented them to an image recognition system to identify the drawn animal. The goal of the workshop is to teach basic concepts related to image recognition and supervised learning. Other kinds of event can be thought of to teach AI, like escape games or rooms, for example [6].

4 Discussion

The conducted review shows many different kinds of activities have been or are being developed to teach artificial intelligence (AI) to young pupils, covering several subfields of AI. Without surprise, machine learning (ML) is the most popular subfield. It is probably due to the fact that ML is a large part of modern AI. This popularity is also probably related to the fact that ML is the most used subfield in broad applications available to the public at large, and in particular young people. Data structure is not of direct interest for pupils as a broad subject, but it is an easy and possibly visual way to introduce AI-related concepts. Data mining and data science related activities are not very common, possibly because they may require basic AI knowledge beforehand.

Regarding the activities, the most common ones are related to programming, either with physical objects or in virtual simulation environments. Programming simple AIs to control agents in games is also quite popular. Unplugged activities are also developed, more specifically for younger pupils. The main advantage is that they can be more easily organised, without specific equipments. Competitions and games to teach AI are also quite popular, as they are very motivating ways to learn. All these activities can be organised in several contexts, courses offering the longest training time. Short workshops are also interesting since they can put pupils into action during a small amount of time, keeping them focused on the activity. Of course, other contexts may be explored, such as summer camps and other trainings outside of schools.

5 Conclusions

To conclude, the review presented in this paper covers recent pieces of research related to the development of activities to teach artificial intelligence (AI) to young pupils. This paper reveals both the subfields of AI that can be taught and the different kinds of activities used to teach them.

Future work includes refining the analysis of the existing activities to take into account their targeted age groups. Further research should also be conducted to identify whether some activities are best-suited for a given subfield of AI, or a given age group, when used in a specific context.

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