Games for Artificial Intelligence and Machine Learning Education: Review and Perspectives

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Abstract
Digital games have gained significance as a new paradigm in education. Digital games are accessible and affordable to anyone and provide opportunities for at-scale teaching and learning. In recent years, there has been increasing interest in digital games to support computational thinking and programming in pre-college (K-12) schools. Artificial Intelligence (AI) and Machine Learning (ML) are a rapidly developing field, attracting an increasing number of learners in the past few years. Although the confluence of digital games and AI/ML is an important and challenging field for teaching and learning researchers, a literature review has not yet been conducted in this area. The purpose of this work is to present a review of recent research into games to support AI and ML education. After a thorough search, relevant papers and games were selected and included in our qualitative content analysis. On the basis of this review, we present an overview of the relevant research papers and games, as well as showcased how different games provide a unique opportunity to teach a number of different concepts and topics in AI and ML.

Keywords: Educational Games, AI Education, Machine Learning Education, Literature Review

1. Introduction

During the last few years, digital games have become increasingly popular in Computer Science (CS) and Information Technology (IT) education (Harteveld et al., 2014; Kordaki & Gousiou, 2016). Digital games have been a popular approach of several endeavors to enhance CS education. At K-12 schools, there are programs that engage students in playing games that include tasks and problems that must be solved in order to progress (Vahldick et al., 2014), or encourage students to develop games using visual and block-based programming environments

such as Alice (Cooper, 2010) or Scratch (Resnick et al., 2009). However, most of the game-based learning efforts focus on the craft and practice of programming, rather than higher-level CS concepts (Garneli et al., 2015).

In general, students are positive about game-related projects or game-based learning in the course curriculum or informal learning (Vahldick et al., 2014; Wallace et al., 2010). Moreover, such approaches have a positive impact on students' learning and motivation (Papastergiou, 2009). Leutenegger (2006) demonstrates how students regularly exceed project requirements in his game-based course, while the norm is that students just meet the specified requirements. Thus, in the CS education literature, the game-based approach seems to provide inherent benefits and justifies the intense utilization of such practices in the CS education discipline (Vihavainen et al., 2014).

Our motivation for this work lies in the natural connection between games and artificial intelligence (AI) methods. In particular, the emphasis on the introduction of game elements in CS education has focused on dedicated game design and development courses as well as on introductory courses (e.g., CS0, CS1, CS2), with great success (Vahldick et al., 2014; Wallace et al., 2010). In addition, games and puzzles have a long history as interesting problem domains for AI research (Wallace et al., 2010). Moreover, games have long been seen as the perfect test-bed for AI methods (Yannakakis & Togelius, 2018), therefore the confluence of game elements and the AI domain is meaningful and helpful for students to develop an interest and competence in the increasingly important field of AI.

Keeping the aforementioned benefits and challenges in mind, this chapter centers on a literature review with the goal to present an overview of recent research into games to support AI and machine learning (ML) education. AI is expected to play an even more pervasive and critical role in education. In 2018, UNICEF launched the "Generation AI" initiative (https://www.unicef.org/innovation/GenerationAI), aiming to address and discuss the challenges and opportunities emerging in the face of AI advances while limiting the risks and safeguarding the rights of children. A recent working paper by UNESCO (Division for Policies and Lifelong Learning Systems, UNESCO's Education, 2019) discusses the design of learning environments and learning management systems integrating AI, and the potential and challenges of AI for all education stakeholders such as students, teachers, administrators, and policy makers. Social and ethical concerns are raised, and the importance of the involvement of all stakeholders at the early stages of design rather than as mere beneficiaries or users is proposed. This chapter is situated in this field, the provision of tools for empowering students and educators to understand and become active participants in the design of AI and ML systems, and presents a general review of what game elements have been used to support AI and ML pre-college education and how. Although the confluence of game elements and AI/ML pre-college education is a relatively young area, enough work has already been done to conduct a review and provide insights.

2. Related Work

AI and ML are a rapidly developing field, attracting an increasing number of researchers and learners in the past few years. In response to this need, efforts in the USA, China, and many other countries are being developed to support AI education in K-12 schools (Touretzky et al., 2019a). In addition, during the last few years new curricula and online resources have been developed, focusing on pre-college students and professional development for K-12 teachers to learn the basics of AI (Touretzky et al., 2019a). In 2018, the Association for the Advancement of Artificial Intelligence (AAAI) and the Computer Science Teachers Association (CSTA) announced a joint initiative to develop national guidelines for supporting AI education among K-12 students. Moreover, initiatives such as the AI for K-12 working group (AI4K12) and AI4All (http://ai-4-all.org) were established to define what students should know and be able to do with AI, as well as to develop national guidelines and collect resources (e.g., videos, demos, software, and activity descriptions) for AI education in the USA (Touretzky et al., 2019b).

During the last few years, several software and hardware tools have been created to allow young students to engage with AI and ML. For example, Cognimates (http://cognimates.me) offers a set of Scratch extensions to provide access to speech generation, speech recognition, text categorization, object recognition, and robot control Application Programming Interfaces (APIs). Kahn and Winters (2017) developed a similar set of extensions called eCraft2Learn (https://ecraft2learn.github.io/ai). The ML for Kids portal (https://machinelearningforkids.co.uk) provides online demos for students to train classifiers using web apps or Scratch extensions. Google has also developed several software tools to support students in engaging with AI concepts. For example, it has developed the concept of an "online AI experiment" (https://experiments.withgoogle.com/collection/ai), which allows young students to train visual classifiers (i.e., Teachable Machine) or see how a neural network tries to guess what they are drawing (i.e., QuickDraw). Another example is Google's "AI and You" kits that offer affordable Raspberry Pi Zero–based image and speech recognition (using a neural network classifier). Another example that allows K-12 students to explore neural networks and back-propagation learning via an interactive graphical tool is TensorFlow Playground (https://playground.tensorflow.org). Therefore, during the last few years we have seen several initiatives resulting in software and hardware tools to support K-12 students in engaging with AI and ML.

Despite the rapid development of AI/ML education, novices find it hard and obscure to learn the fundamentals, such as game theory, machine learning, decision trees, and so on. During the 2014 Educational Advances in Artificial Intelligence (EAAI) conference, 68% of the participants indicated games and puzzles as a topic they teach in their AI courses (Wollowski et al., 2016). In addition, Eaton et al. (2018) indicate that the introduction of agent-based models through games and puzzles allows instructors to introduce concepts for later exploration such as search,

string-replacement iteration, planning, ML, and so on. It can therefore be agreed that games have long been seen as an ideal test-bed for understanding AI methods (Yannakakis & Togelius, 2018).

Games (and game-based curricula) provide a widespread medium to support the teaching and learning of CS and IT (Vihavainen et al., 2014). Games have been used to improve several aspects in CS and IT education, for example the lack of diversity in science, technology, engineering, and mathematics (STEM) fields, including CS, at both university and K-12 levels (Horn et al., 2016). Games have also been used as a means to enhance student engagement and motivation (Wallace et al., 2010). Another example comes from Clarke and Noriega (2003), who developed a war strategy game with hooks for the addition of AI modules. Their results indicate that students find AI much more interesting and accessible with examples and projects based on this game. Besides efforts to develop novel game-based curricula to enhance teaching and learning CS in the context of formal education, many efforts to reach younger students are made in informal contexts such as classroom visits, summer camps, and after-school programs (Vahldick et al., 2014).

In addition to several beneficial qualities of games, such as engagement, competition, and collaboration, they lead to greater student interest (Horn et al., 2016; Papastergiou, 2009). AI and ML, as content, certainly can benefit from games (e.g., a game engine that can be easily used or modified; Hartness, 2004). Moreover, Cook and Holder (2001) used a simple game to teach students about the need for internal representations of the world, natural language processing, look-ahead search, plan generation, and ML, demonstrating the power of games to support AI/ML education. Their students managed to significantly improve and modify the game to handle different problems.

In our view, ML and AI education can significantly benefit by introducing to students state-of-the-art algorithms, concepts, and methods related to game playing, for example game tree–based search, reinforcement learning, and neural networks. Such an approach has tremendous potential to successfully introduce those concepts to pre-college students. Looking in the literature we can find several studies that exploit the intersection between games and AI/ML to form the basis for a dedicated course or a module of a course (Zhou et al., 2017; Zhou et al., 2018; Li et al., 2019; Konen, 2019). In this work we provide a general review of games and software tools that can be used to support AI and ML pre-college education. This collection will provide a springboard for other scholars and practitioners to put into practice, experiment, compare, and adapt the games and software listed to meet the needs of their students.

3. Methods

To the best of our knowledge, no previous work has aimed to produce an overview of games and software tools that can be used to support AI and ML pre-college education. Thus, the aim of this

chapter is to collect and summarize the various games and software tools. The comprehensive review provided in this chapter could help and guide different stakeholders to explore and put into practice the games that meet their needs.

The selection phase determines the overall validity of the work, and thus it is important to define specific criteria. Games were eligible for inclusion if they focused on AI/ML education. To find those games, we searched various libraries and search engines (Google) as well as scientific publications (e.g., Google Search, ACM Digital Library, IEEE Xplore, Science Direct, Google Scholar).

The search string used during the search covers two main terms for content ("AI Education," "ML Education," "CS Education") and the medium ("Game-Based Learning," "Games for Learning"). The combination resulted in six different search strings. Due to the high number of irrelevant papers (i.e., false positives) returned using the search string "CS Education," the authors decided to narrow the search by combining it with the term "AI" or "ML".

4. Findings

Finally, after implementing the aforementioned search strategy, we reviewed the outcomes of the search and identified 17 games/projects. Then, we reviewed those games and projects and summarized their essential elements and focus (Table 1). These summaries allowed us to consolidate the essence and the main focus of the games/projects and their connection with AI/ML concepts.

Table 1: Summary of digital games for Artificial Intelligence (AI) and Machine Learning (ML) education

Name of the Game	Short Description	Reference
Bug Brain	Bug Brain is a game where children can experiment with the neurons and nodes that make up a brain. They build a brain for a ladybug to help it feed and survive. Not specifically aimed at learning AI and ML, Bug Brain features rendered graphics, challenging puzzles, and the opportunity to learn about neural networks (free).	http://www.biologic.com.au/bugbrain
Human Resource Machine	Human Resource Machine is a puzzle game. Players are required to solve problems through programming. Concepts relevant to AI such as automation and optimization are introduced. At each level, players have to automate work by programming the employees of an office environment (purchase required).	http://tomorrowcorporation.com/humanresourcemachine

7 Billion Humans	Following up on the "Human Resource Machine" game and developed by the same studio, players are required to solve puzzles by programming multiple agents (workers). Concepts such as parallel computing, debugging, and optimization are explored (purchase required).	https://tomorrowcorporation.com/7billionhumans
Machine Learning for Kids	Machine Learning for Kids introduces ML by providing hands-on experiences for training ML systems and building things with them. It provides an easy-to-use guided environment for training ML models to recognize text, numbers, images, or sounds. Machine Learning for Kids adds models to educational coding platforms Scratch and App Inventor, and helps children to create projects and build games with the ML models they train (free).	https://machinelearningforkids.co.uk
AI Machine Learning Education Tools	The platform (currently in beta) offers tools for teaching students the basic concepts of ML. It incorporates a number of Scratch extensions as a coding medium for children, such as a chatbot extension, home automation, image recognition, classification, and teaching the computer how to play the Flappy Bird game, accompanied by lesson plans and materials for educators (free registration required).	https://www.ai4children.org
While True: Learn()	This game aims to familiarize players with the concepts and processes of ML. Players take up the role of an ML specialist who uses visual programming to complete clients' projects. It includes elements such as neural networks, actual ML techniques, and ML-related problems such as self-driving cars (purchase required).	https://luden.io/wtl
ViPER	ViPER aims to teach concepts in ML to middle-school students. By programming a robot to solve pathfinding problems, players learn how machines learn, and engage with concepts such as algorithms, the testing and training phase, and identifying patterns in the data (for assessment of game design issues, see also Parker & Becker, 2014; purchase required).	https://wonderville.org/asset/ViPER
Minecraft Hour of Code: AI for Good	The game integrates a coding interface with Minecraft. By programming a robot to predict forest fires, players are introduced to basic coding concepts and learn about AI and its potential for protecting the environment. A lesson plan and supporting material for educators are also provided (free).	https://education.minecraft.net/hour-of-code
The Moral Machine	The players are asked to choose the lesser evil when facing an impending car crash. This platform is mainly situated in the field of ethical decision making. It aims to address the diversity of human perspectives in face of a moral dilemma and the	http://moralmachine.mit.edu

	implications of machine intelligence designed to make similar moral decisions (e.g., self-driving cars; free).	
PopBots (Preschool-Oriented Programming Platform)	The applications included in this platform aim to familiarize young children with the main concepts and processes of AI, such as programming, classification, training, and testing datasets, through simple activities such as training models to recognize healthy and unhealthy food or different types of music. It also includes supporting material (e.g., lesson plans) for teachers (for more details and related study, see also Williams et al., 2019a; 2019b).	https://www.media.mit.edu/projects/pop-kit/overview
Universal Paperclips	Not quite a game for teaching AI concepts, but rather for triggering discussion on the role and potential of AI in society. Based on the philosophical thought experiment "paperclip maximizer" about AI design and machine ethics, this is a clicker game where the player takes up the role of an AI machine making paperclips. After several upgrades such as the possibility to "interpret and understand human language" or buy "autonomous aerial brand ambassadors," the game ends when 100% of the universe is explored and all matter is turned to paperclips (web version free).	https://www.decisionproblem.com/paperclips
Gladiabots: AI combat arena	A game not specifically aiming to teach AI to students, but, as the designers describe, the players have to assemble a "perfect team of robots and set their AI strategy with the simple to use but satisfyingly deep visual AI editor." Players are introduced to the logic and structure of AI programming (purchase required).	https://gladiabots.com
Tynker: Coding for Kids	Platform including applications and games, separated by age groups, for children as young as 5. Children can create games through block programming, and share their artifacts (subscription required).	https://www.tynker.com
Scratch Jr.	The younger version of Scratch, aiming at children ages 5–7. Through a simple, visual, drag-and-drop interface, children create code, program, and share their own projects with the community (free, available for Android and iOS devices).	https://www.scratchjr.org
Code.org	The platform, aimed at children and educators, includes applications, games, and courses for learning coding, creating new projects, and sharing them with the community, as well as a curriculum and lesson plans for CS education. Code.org also organizes the annual Hour of Code campaign engaging students in coding around the world (free).	https://code.org
LightBot	LightBot is a puzzle game based on coding, aiming to teach	

	programming logic to children as young as 4 and above. It is translated into multiple languages. Web (free), iOS and Android devices (purchase required) versions.	
Codespark Academy	A platform aiming at children aged 5–9 that includes games, puzzles, and applications for learning coding and creating new games, as well as resources for parents and educators (subscription required).	https://codespark.com

In Table 1 we summarize games and platforms for supporting AI/ML pre-college education. Many of them focus on the wider area of CS education, with applications in AI/ML education as well. In particular, we identified only a small number of games, applications, and platforms specifically aimed at explicitly supporting AI and ML education for children and young people. Coding seems to be the main goal of most of the existing environments. However, environments aiming to enhance AI and ML pre-college education mainly address concepts such as training a model for image, text, or audio recognition (e.g., Machine Learning for Kids and AI Machine Learning Education Tools) and programming logic (e.g., Minecraft Hour of Code: AI for Good), while games not aimed at formal children's education address more abstract, ethical, and social implications (e.g., The Moral Machine, Universal Paperclips).

When it comes to the age those environments are focusing on, we found that they address the whole range from kindergarten to high school (K-12), with some of them addressing even younger ages (appropriate for 4 years old). In addition, there are environments supporting parents and teachers in teaching AI and ML to children (e.g., lesson plans such as Minecraft Hour of Code: AI for Good). Although most of the materials have been implemented primarily in the English language, we also see environments and materials supporting multiple languages (a good example is Code.org).

Looking at the types of platforms utilized from the environments identified, we noticed that there is a wide variety, such as proper applications, applications running on the web, as well as applications that are developed for mobile devices such as mobile phones and tablets. As with any applications, those requiring installation (e.g., While True: Learn(), Human Resource Machine) are more robust and do not necessarily rely on an internet connection, compared to those that run online and do not require installation (e.g., The Moral Machine). Another important dimension of AI/ML learning environments is the cost. Looking the identified environments, we note that many of them are free, or have a free version (e.g., The Moral Machine, Code.org); however, there is also a reasonable number of games where purchase or a paid subscription is required (e.g., Codespark Academy, Gladiabots: AI combat arena); in most cases the teacher/parent can have a free trial with the game.

In order for pre-college students, instructors, and parents to understand the fundamental ideas of AI and ML, they also need to be able to engage with them practically. Most of the identified games have been developed during the last few years and schools and teachers have just started to adopt them. In the near future, we expect further development of the available environments, but also more environments to be accessible. Moreover, besides games, we have also seen an increasing number of daily products and tools that demonstrate AI's capabilities (Google Assistant, Apple's Siri, Microsoft's Cortana), and there are a number of home appliances with similar functionality (Google Home, Amazon Echo, Apple HomePod). Most of them are used by young children, and will help them to familiarize themselves with AI technologies. Going a step further, a variety of new software and hardware tools are providing AI components to young programmers who can incorporate them into their own creations.

5. Discussion

Despite their increasing role in everyday life and society, AI and ML are not being fully explored in schools. Opportunities for teaching relevant skills and competences through novel approaches have the capacity to revolutionize the contemporary teaching of computational and algorithmic thinking and CS overall. Skills and competences relevant to AI and ML, such as abstract thinking, problem solving, and management of data and information, will empower students to adopt a more critical and inquisitive approach toward existing systems (e.g., recognizing bias, disinformation, biased search rankings, filter bubbles) and to participate in the design of new ones (Turchi et al., 2019).

Although games that support AI and ML seem to be in their infancy, in this literature review we identified a good number of games and applications, for various ages, school levels, and learner expertise, aiming to teach AI and ML concepts to young children, by providing either guided environments for practice or more open-ended environments where children can create their own projects and creatively express their ideas. Although the number of environments specifically aiming to teach AI, ML, and related concepts to young children is still limited, it is steadily increasing, following the general interest (UNESCO's Education, 2019). For instance, games such as PopBots, Minecraft Hour of Code: AI for Good, and While True: Learn(), and environments incorporating game elements such as the Teachable Machine, AI Machine Learning Education Tools, and Machine Learning for Kids, are indicative examples that have a particular focus on AI and ML concepts.

Both guided and open-ended environments have been identified in the literature. Both types can be used to support different learning designs and to scaffold AI and ML concepts. For instance, guided environments can help students by directing them to master concrete concepts, practices, and processes, while open-ended environments empower students to utilize and further their understanding of AI and ML concepts by deeply engaging in active learning and even by constructing artifacts.

Supporting material for students and educators is an extremely useful resource that can enhance the attainment of their learning objectives. AI and ML are still a new topic in pre-college education, therefore students and teachers require more than an educational game to approach, understand, and be able to discuss the relevant concepts. Learning about the subject matter by only playing a game may be challenging for both the student and the teacher, as well as insufficient for deep conceptual understanding, and might therefore lead students to develop misconceptions (Muehrer et al., 2012; Parker & Becker, 2014). Environments such as Minecraft Hour of Code: AI for Good and AI Machine Learning Education Tools provide good practices by offering lesson plans, additional activities, and other resources for teachers. In this framework, Camilleri et al. (2019) recently published a practical guide, financed by the Ministry for Education of Malta, with lesson plans and resources for teachers aiming to teach AI to young people. It is important for both the student and the teacher to have proper learning designs and materials around these games that support AI and ML holistically.

Easy access, price, and technical requirements constitute further critical factors for the effectiveness, adoption, and impact of these learning environments. Not all pre-college education schools and families have the budget or the technological infrastructure and competence to access sophisticated games or platforms (Marklund & Taylor, 2016). The effectiveness of a game-based curriculum in schools relies upon multiple context-related factors, such as the game literacy of students, the technological skills of teachers, class schedule restrictions, the computers available and their specifications, and the available bandwidth. Games with low technical demands and requiring fewer technical skills, such as Minecraft Hour of Code: AI for Good and Code.org, which require no installation, student accounts, or cutting-edge technology computers, seem more appropriate for formal school settings.

This preliminary work should not be seen as a systematic review, but as an early effort to provide a general overview and inspire instructors and future researchers. Although we tried to identify most of the relevant games and projects, we recognize that different search strategies and selections (e.g., databases, query) might bring additional useful results. In addition, the selection of projects and games might also pose another possible limitation. However, the focus of the selected games and projects was clearly on AI and ML education; the summary was undertaken by two researchers and included the main qualities. Many of the reported games have not been extensively used and evaluated (as is the case in games reported in scientific publications), leading to some missing information about their effectiveness and acceptance by students. This is mainly based on the fact that AI and ML in K-12 schools are a relatively young field of research, and we expect to see more empirical studies and projects addressing these issues in the near future.

6. Conclusions

General game playing is an exciting topic, still young but on the verge of maturing, which touches upon a broad range of aspects of AI and ML. In this chapter we created a general overview of games for pre-college AI/ML education, in an attempt to show its many facets and highlight the fact that it provides a rich source of interesting and challenging qualities for pre-college students and instructors who want to introduce their students to AI/ML concepts. We also showed how different games provide a unique opportunity to teach a number of different concepts and topics in AI and ML.

Although research on the use of games or other applications teaching AI and ML to children and young people is still very limited, early results show great potential for teaching even pre-school children basic AI and ML concepts, as well as for engaging them in conversations about the role and implications of technology and AI in our everyday lives (Druga et al., 2017; Williams et al., 2019a, 2019b). Nevertheless, game design for engaging students and achieving an understanding of the concepts can be challenging, requiring appropriate metaphors and easy-to-understand interactions (Parker et al., 2014). Children interact daily with applications and devices integrating AI (e.g., smart toys, smart home applications, video-sharing and streaming platforms) with potential privacy, safety, and bias risks (McReynolds et al., 2017; Chu et al., 2019). Understanding the processes and factors involved in the design of such systems can help children to develop a more accurate mental model of their limitations and potential (of AI/ML).

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