Contributed Article

Broadening artificial intelligence (AI) education in K-12: Where to start?

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Abstract

Having moved through the eras of steam and hydropower, electricity and assembly lines, and then computerization, the world has now entered a new era, dubbed the Fourth Industrial Revolution, with the adoption of cyber-physical systems, the Internet of Things and the Internet of Systems implemented as intelligent machines. The implications of this new era for the education of current and future generations are now a focus of discussion. As artificial intelligence (AI), branching from computer science (CS), becomes ubiquitous and seamless behind the scenes of our daily lives, many countries are dedicating significant resources to fueling research on this continually developing technology. The renewed interest in AI has sparked discussion of the importance of teaching AI knowledge, concepts, and computational skills to young people, including whether we should begin considering how to introduce AI at K-12 level through CS education. This article aims to reshape the concepts of AI with reference to the historical development of the computing industry and CS education, and uncover a new direction for AI education in K-12 around the globe.

The Beginning of Computer Science

The history of computer science (CS) as a discipline can be traced back to the early 19th century, when Charles Babbage, who is considered a pioneer in the field of computing, designed a computational device: a calculator that was able to compute digits with up to eight decimal points. Working closely with him was Augusta Ada King, Countess of Lovelace, who is acknowledged as a pioneer in computer programming [21]. Although Babbage's invention was able to make mechanical calculations, Lovelace pushed its potential even further by designing an algorithm that could be executed by such a machine. This marks the beginning of what we know as "the computer," and the development of computing technology has shown no signs of waning since.

A recurring question in relation to computing innovation is how to prepare the next generations through education in K-12. A first wave of teaching computational thinking arose in the 1980s, with many projects built around the LOGO programming language. Since then, several major components of CS have been introduced into K-12 education, such as algorithms, data representation, devices and infrastructure, digital applications, and human factors in computing, while programming has been maintained as the key subject [3]. Although children are already learning how to code in school, and simultaneously developing their computational thinking skills, this might be insufficient for them to make a significant impact in the 21st century. It is time for students learning computational thinking to be introduced to the artificial intelligence (AI) technologies being designed and developed by computer scientists and engineers using these computational thinking principles. However, there are a series of questions surrounding the implementation of AI education at K-12 level, to which a few researchers have begun to pay attention. Where does AI come from? What does AI mean to us today? What should students in K-12 know before diving deeper into AI learning through CS education? How can we help students to gain more exposure to AI and prepare them for college studies in the field?

Trends in Computer Science Education

In the United States, CS was not widely taught at the K-12 level until 1993 [25]. A major event in CS that year was the birth of the World Wide Web (WWW), which prompted schools and educators to rethink the possibilities of prolonged exposure to CS for school children. Accordingly, the Association for Computing Machinery (ACM) developed the Model High School Curriculum [22], which was designed as a one-year course modeled on an existing college curriculum. Due to the fast-paced development of the field of CS following the invention of the WWW, the core topics within that model quickly became outdated and it was not widely implemented.

In 2003, the ACM published a report outlining a reformed model curriculum with the more ambitious aim of teaching computer science from primary to secondary school levels in the United States and abroad. One year later, the ACM founded the Computer Science Teachers Association (CSTA), which provides promotion and support for teaching the subject at the K-12 level, and published the CSTA K-12 Computer Science Standards, which serve as a guideline for schools to structure their curricula.

In the United Kingdom, CS existed in schools as early as the 1980s, albeit under the different name of Computer Studies. The emergence of home computers and the release of end-user software in the form of spreadsheets and word processors prompted the government to rethink the state of computer-related education. The Information and Communication Technology (ICT) curriculum was therefore introduced into schools with the purpose of developing students' digital literacy [2] and competency in using computer applications and computers in general. Computer programming and any deeper understanding of computer architecture or of the underlying processes through which a computer works were considered to be of secondary importance.

Consequently, the Royal Society identified several shortcomings within the ICT curriculum [2]. The first major shortcoming was that the recruitment of teachers specializing in ICT was a struggle, causing schools to hire non-specialists to teach the subject. This formed a cycle of students being trained by teachers who were not fully competent producing students who were equally incompetent. The second was that students were confusing ICT with computer science, thinking that they were one and the same. Ultimately, it failed to inspire students to pursue further education in the field, which gave it a poor reputation. In 2012, the ICT curriculum underwent intensive and fundamental reform. In 2014, the Department for Education introduced a new curriculum for computing in the U.K. [27], with the intention of addressing the national lack of a sufficiently competent and confident talent pool in the field.

Similar issues and reforms in national curricula regarding computing and technology education have emerged worldwide. In Australia's National Innovation and Science Agenda, proposed in 2015 [1], AUD$64 million was allocated in support of early learning and STEM initiatives in schools with the intention of promoting digital literacy among its citizens. A portion of that sum (AUD$1.5 million) was allocated under the Australian Technology and Science Growth Plan to delivering AI education in schools. Singapore's education system now has a major focus on developing 21st century competencies [23] to enhance young people's competitiveness in the digital age. In Hong Kong, the government has recently announced in its budget speech a significant increase in funding, totaling HK$500 million, for secondary schools in the hope of encouraging local talent to prosper [10]. Each secondary school is entitled to HK$1 million to acquire the necessary equipment and professional services to conduct extracurricular activities that will increase students' knowledge of the latest technologies, such as block chain, big data, cloud computing, and artificial intelligence.

Over the last few decades, there has been great emphasis on ensuring that education systems are able to provide for the needs of young people. Governments have been trying their best to keep up with the ongoing and dynamic developments in the field of technology. As the world dives into the Fourth Industrial Revolution, bringing smarter cities with intelligent computing systems, it demands yet further evolution in the provision of education.

The Dawn of Artificial Intelligence

John McCarthy coined the term "artificial intelligence" at a Dartmouth conference in the summer of 1955. Many early CS scholars, including Marvin Minsky and Seymour Papert, then began the quest for the philosophical and technological development of AI. In this early period of AI research, "AI" was often understood as referring to a machine or computing system with the ability to perform any task that humans can accomplish using their intelligence or cognitive behaviors. This interpretation of AI is usually referred to as *strong AI* or *Artificial General Intelligence (AGI)*. With AGI technology proving elusive, practitioners and CS researchers now concentrate on *weak AI* or *narrow AI*, in which the machine is designed to perform a narrow range of specific tasks. Such a machine might partially demonstrate the computational behaviors of reasoning, planning, decision making, learning, motion and perception through sensing, knowledge representation, problem solving, and manipulation. Behind the scenes of these intelligent behaviors is computational thinking applied through programming techniques.

As several initiatives emphasize the need to equip every citizen with computational thinking skills, it may be useful to clarify the relationship between these skills and those required for the development of AI. Basically, the latter is a subset of the former: "computational thinking skills" refers to the ability to reason with any algorithm, while AI is a specific family of algorithms. Some computing algorithms, such as many sorting algorithms, are not associated with AI. In addition, many AI approaches have a particular character, often including a non-deterministic aspect, using a cognitive metaphor, etc. Algorithms are at the core of AI technology development and are strongly linked to many of today's most popular applications—for example, Naïve Bayes for text classification and k-nearest neighbors for similar documents search. It is not a question of choosing between computational thinking or AI, but rather of the need to devote special attention to some of these application-driven AI algorithms as part of an effort to enable K-12 students to explore how AI works behind the scenes.

Many young people might be unaware of the extent to which this kind of technology has penetrated our everyday lives through many existing applications, such as machine learning, robotics, facial recognition, and voice assistants, or of how important it will inevitably remain in the future as AI develops in sophistication and complexity. Beyond the technical orientation, major challenges remain in the areas of ethics and safety. We suggest that the focus of K-12 education could be placed on building *AI literacy* across three dimensions: *AI concepts*, *AI applications*, and *AI ethics/safety* (see Table 1).

Dimension	Description
AI concepts	Understand the basic AI concepts and their origins, including machine learning, deep learning, and neural networks.
AI applications	Appreciate the real-world applications of AI concepts, in areas including speech recognition, robotics, and “smart” machines.
AI ethics	Understand the ethical challenges and safety issues involved in applying AI technologies to real-world applications.

Table 1. The three dimensions of AI literacy

Significance of AI concepts, applications and ethics

Gaining a broader understanding of AI and a range of skills related to AI and its development can be considered essential for young people to succeed in an AI-saturated society. Governments are slowly beginning to acknowledge this fact. In the United Kingdom, on June 29, 2017, a Select Committee on Artificial Intelligence was appointed by the House of Lords. In a report published in 2018 [13], it suggested that regardless of the pace of its development, AI will inevitably have an impact on future generations. Thus, it is necessary for the education system to adapt and ensure that it addresses the needs of students, for which we suggest three main objectives. The first goal is to prepare young people to live with AI, and to groom them for a possibly unpredictable labor market. The second goal is to allow students to acquire an understanding of how everyday technologies function, and potentially to inspire a new generation of software developers and AI researchers to prevent a lack of talent supply [13, 24]. The third goal is to train future professionals in a variety of fields, such as finance, medicine, natural sciences, and even the entertainment industries, who will need to understand enough about AI to integrate it into their fields ethically and safely. As stated in a report comparing Asian countries' competitiveness and readiness in relation to AI, “The next generation of workers and entrepreneurs must be equipped with skills that enable them to work with and manage computers and intelligent systems, solve problems that are non-routine and unpredictable, and learn to understand and interpret more complex data” [20]. The prospects for young people are changing, and AI-related skills will give them a competitive edge.

Beyond understanding the concepts and recognizing the broader applications of AI, ethics is an equally important aspect of technological development. Complex systems of healthcare, transportation, and aerospace need to be carefully designed and implemented for safety [15]. Testing an autonomous vehicle, whether on an actual road or a testing track, for instance, is still controversial. How can the driverless vehicle or even a person learn without making a mistake? Would it be ethical to put the AI machine through a real-world “clinical trial”? Not only legal liability, but also ethical and safety-related challenges should be regarded as the central drivers of the future of AI. Several initiatives have been set up and advocacy work is being performed by various organizations, including the Alan Turing Institute and the Stanford Center for AI Safety, to help safeguard the well-being of our communities when developing and applying AI technologies.

As the spread of AI continues toward ubiquity, some countries are beginning to allocate significant resources into leveraging the technology. Universities have already embraced AI, and are now offering specific courses to future professionals in the field. Carnegie Mellon University's Bachelor's degree in Artificial Intelligence, offered by the College of Computer Science, was announced in fall 2018 as the first of its kind in the United States [26]. Massachusetts Institute of Technology announced in October 2018 ambitious plans to establish an independent college specifically for AI, with allocated funds adding up to US$1.4 billion. The University of Rhode Island opened its AI lab, operating as part of its college library, in fall 2018. On June 8, 2018, a press conference was held at Zhejiang University presenting the *Action Plan on Promoting Artificial Intelligence in Universities.* This initiative sets out plans to make Chinese universities and colleges leaders in AI innovation worldwide. Ambitious milestones have been set for achievement within the next two decades, aiming to position China as the global leader in AI-related developments by 2030 and to ensure that China perseveres with AI talent cultivation and innovation [19].

New Trends in AI Education at the K-12 Level

AI education has begun to progressively trickle down towards the K-12 range. Researchers have engaged in a number of discussions over the past year, at SIGCSE 2019 and in a session at ISTE 2019, discussing the K-12 guidelines for AI and what students should be taught. However, this process is still in its infancy, with some major concerns still unaddressed. These concerns include insufficient funding and resources and the question of how CS educators will be trained to teach AI competently. The latter concern emerges from the fact that there is a massive deficit in AI talent [16, 28]. In 2017, it was reported by Tencent, the Chinese tech giant, that there were only 300,000 AI engineers worldwide but the demand for such talent had already reached the millions. On the one hand, this enormous talent gap is one of the main reasons why AI is being strongly considered as a subject to be taught to children. On the other hand, the same gap provokes us to wonder whether our K-12 schools are prepared for the task.

A possible solution is collaboration between educators and AI researchers and professionals. In an effort to find a standardized solution for AI education at the K-12 level, the U.S. has established a joint working group, involving the Association for the Advancement of Artificial Intelligence (AAAI) and the CSTA, to develop national guidelines to teach AI to K-12 students, which will be highly influenced by the current CSTA nationwide standards for K-12 computing education. David E. Williams Middle School in the Montour school district has implemented a pilot AI curriculum spanning three weeks that makes use of the AI-in-a-Box kit provided by ReadyAI, and is promoting itself as the first middle school capable of delivering the curriculum [17]. It hopes to expose students to potential careers in robotics and automation, and to give them the opportunity to examine technologies that are being used every day in applications like Amazon’s Alexa and Apple’s Siri. They will also be encouraged to raise ethical questions regarding the potential dangers of the proliferation of AI.

Australia has undertaken similar steps in their drive to teach AI at the kindergarten and primary levels [12]. Under the Scientists-in-Schools program, a senior AI researcher is paired with K-6 teachers to deliver an AI course. This kind of collaboration has allowed for the teaching of AI concepts using methods that are appropriate for young children. The emphasis is on age-appropriateness, with the curriculum taking into consideration pupils’ capabilities and limitations at certain ages. Under Level 1, for pupils aged five to six, the curriculum emphasizes imaginative play with robots. Under Level 2, for Grades 1 and 2, the curriculum exposes pupils to Lego Mindstorms (programmable robots). The pupils learn about the robot’s use of sensors and how a robot can be controlled. At this point, pupils are introduced to computer programming, although actual programming experience is not included. At Level 3, for Grades 3 and 4, pupils begin to modify existing AI programs and are encouraged to observe the results and develop their own ideas of how they want their robots to behave. Java is also introduced at this level, as a contrast to the native programming language used for Lego Mindstorms. At Level 4, for Grades 5 and 6, more complex issues surrounding AI begin to be tackled, including understanding cognition, the Turing Test in the context of video game opponents, and errors. The major goal of the curriculum design is to allow students to engage with AI whilst avoiding the impression of AI as intimidating and overly complex.

Based on the ai4k12.org wiki, there are five key ideas in AI, echoing our three areas of AI learning, that are important for a K-12 audience:

> AI1. **Perception:** Computers perceive the world using digital sensors.
> AI2. **Representation and reasoning:** Agents maintain representations (and models) of the world, and use these for the process of reasoning.

AI3. **Machine learning:** Computers can learn from data and make appropriate decisions to respond to the environment.
AI4. **Natural interaction:** AI developers aim to develop agents that interact naturally and seamlessly with humans.
AI5. **Societal impact:** AI can make both a positive and negative impact on our society.

Although there is no universal consensus as to whether this is a comprehensive list of AI concepts for the K-12 level, we recognize each item's importance and their role in allowing children in K-12 to build on their knowledge in computational thinking and programming for learning about AI.

K-12 AI Education: How can it be done?

There is now some experience of AI education at university level to draw on. A key observation is that students have found the scope and complexity of AI to be quite daunting, sometimes causing them to feel that the subject is incomprehensible. As a solution, elements of fun, exploration, exposure, and even gamification can be or have been embedded into existing AI courses, both at the undergraduate and graduate levels. At the University of California, an introductory AI course was designed to teach AI concepts using the classic game Pac-Man and taking a project-centered approach focusing on closely related topics. The success of this program is shown by an enrollment increase of up to 69% after the first year of adding Pac-Man to the curriculum. Key strategies include "scaffolding," where a sufficient amount of code, graphics, and other elements are provided to give structure to the project, with students proceeding to manipulate or add to the scaffolding. The idea behind this is that it allows students to focus more on the actual AI concepts. Also, because pedagogically designed games may appear dull to some students, project extensions are available to students once they have accomplished some of the core tasks required [9]. At the University of Oklahoma, introductory AI courses are being taught using Java-based games and robots, with an emphasis on visualization. The approach of implementing a fun learning environment through games and robots keeps the students' interest and engagement levels high throughout the course [14, 18]. At the University of Southern California, under the Bachelor's degree in Computer Science (Game) and Master's degree in Computer Science (Game Development), the use of games to teach computer science and standard AI concepts has been implemented, while incorporating a project-based approach [29].

A similar approach could be considered in implementing AI education at the K-12 level. Students at the undergraduate level tend to feel intimidated when dealing with AI concepts; this phenomenon may also be apparent among younger students who are working with AI for the first time. Although there are lessons to be learned from the experiences of AI education at the university level, K-12 schools cannot fully implement AI lessons in the same way. Adjustments to the "scaffolding" will need to be made, especially for young children in preschools and elementary schools who lack prior programming experience.

Our research group has conducted studies of children's computational thinking development through block-based programming in Hong Kong. Basic concepts and techniques, such as sequencing, looping, conditional, debugging, and algorithmic thinking processes, are in general able to be taught to young children. Through the concepts of embodied cognition, we are aware that children understand abstract concepts quickly when various sensorimotor capacities are used, such as through bodily movement. For example, an elementary school pupil can explore the concept of conditionals by playing the role of an agent trying to escape a real maze. Given a stack of two-sided cards (one side has a symbol, and the other side has a direction), he/she needs to choose a card that matches the sign at each branch to make a correct turn. Through narration and post-activity dialogue, pupils can then come to understand how a robot solves a simple maze. After this, showing them a very high-level program containing only the essential steps can expose the pupil to what instructions the robot is given to solve the maze problem. Nonetheless, learning design with scaffolding techniques for AI education in K-12 is relatively new, and more empirical cases will need to be collected to build evidence for how the practices for developing children's computational thinking may be applied to building up their AI literacy.

A Program for K-12 Education in AI Essentials

There is no one-size-fits-all solution to implementing AI education for developing pupils' AI literacy, but incorporating elements of interaction through fun activities and games will prove an excellent starting point. With these elements, the field of AI becomes less intimidating and pupils can proceed with confidence rather than doubt. Indeed, the limited examples of AI education at the K-12 level are following this strategy already. However, the CSTA and Scientists-in-Schools programs are vastly different, making it essential to identify the strengths and weaknesses of each. Taking the insights from the latest practices of AI education both at university and K-12 level, we have developed a generic AI program structure that takes these strengths and weaknesses into consideration. It is practically challenging to introduce every important AI concept at these levels, and researchers have not come up with a consensus on what should and should not be in such a program. Our example program structure, presented in Table 1, takes the basic concepts of computational thinking and links these to AI literacy outcomes through learning activities. We follow up with some observations and suggestions for implementation at different levels.

GRADE LEVEL	PREREQUISITE FROM COMPUTATIONAL THINKING	EXAMPLARY PEDAGOGICAL APPROACHES	GENERIC LEARNING OUTCOMES FOR AI LITERACY
K-GRADE 2 (Age 4-7)	N/A	• Learning through play • Role-playing • Pen-and-paper exercises • Storytelling	Low-Order Thinking Skills • Explore how to interact with sensors • Discuss why AI has an impact on everyday living • Recognize different AI applications and why safety may be an issue in our society
GRADES 3-6 (Age 8-11)	1. Compare and modify algorithms to do the same or different tasks 2. Create programs using control structures, such as sequences and conditionals	• Modifying existing source code • Fill-in-the blanks exercises • Unplugged activities • Problem-based learning	Low-Order Thinking Skills • Explore simple processes of making inferences • Examine existing AI applications and identify their design issues High-Order Thinking Skills • Create and modify perception-based applications • Distinguish between artificial intelligence and natural intelligence
GRADES 7-9 (Age 11-14)	1. Aware of how to perform systematic tests 2. Design and refine algorithms 3. Identify how certain algorithms can be applied to problems in different disciplines	• Modifying, observing, and designing algorithms • Hypothesis testing • Graphical- and syntax-based coding • Critical evaluation	Low-Order Thinking Skills • Perform the Turing Test with intelligent agents • Examine graphs and data structures • Explore the concept of neural networks High-Order Thinking Skills • Create inference algorithms • Create a chatbot • Critically evaluate the ethical and social impacts of AI technologies • Apply acquired AI concepts as potential solutions to real-world problems

Table 1. Proposed program structure for K-12 AI education

K-Grade 2

At this level, engaging with AI should take a playful and imaginative approach. It has been noted that we begin constructing a view of the world at an early age through observation and imagination and, at the same time, start to develop our technological capability [22]. Play is one of the best ways to exercise a young mind's capacity for imagination [22]. Although play has not been extensively explored within the context of teaching technology, it has been argued that the type of play that may contribute most to technology education for students at this age is *functional play*, through which "children acquire knowledge of objects, materials and physical phenomena, and learn to master the use of tools and techniques through explorations and rehearsals" [11]. That being said, complicated AI concepts should not be introduced at this level. Rather, students should be given the opportunity to experience AI applications through play, which does not necessarily require screen-based tools and could be implemented in roleplay or pen-and-paper exercises.

It is not necessary to introduce programming to pupils at this level. Pupils can simply learn how to interact with an AI robot's computer vision and with voice-based AI applications, and will make connections to their own human senses by engaging with AI in this manner. However, pupils might have a tendency to attribute human characteristics to robots [12], perhaps failing to understand why a robot does not respond when it is spoken to. Pupils thus begin to witness the limitations of AI technology. Understanding the reasons for these limitations can be addressed at a subsequent level of the curriculum. Pupils can also begin to be exposed to how computers are able to learn from data: for example, an AI robot could be used that can learn and remember people's faces and recall names according to who they capture through their vision.

Grades 3-6

At the next stage, pupils can begin to build on the concepts and ideas that they have witnessed at the earlier level by being given some exposure to applications and ethical considerations. Rather than merely observing and playing with robots that embody AI concepts, such as visual or voice recognition, students now should be able to modify existing programs in AI. Under the CSTA's standards for CS at K-12 level [4], pupils at this age should already be able to comprehend programs and modify them using block-based programming tools. Taking the example of the University of California's implementation of Pac-Man, pupils at this level can be taught with the same technique of "scaffolding." Essential sections of the code can be given to the pupils so they can gain a brief understanding of how the program is supposed to work; they can then be put be in charge of setting and changing values that will affect the behavior of their robots or programs. After they have more exposure to the basic applications, brief discussions of AI ethics/safety could be conducted around issues that will be meaningful to the children, such as the issues that would arise from testing a driverless car in crowded civilian areas in Hong Kong.

At this age, pupils are also expected to understand conditional statements [4]. Pupils can utilize this knowledge to modify their programs or robots to react according to specific conditions. For example, they could instruct the robot to execute specific commands when they encounter various visual cues, such as faces, colors, and landmarks, or auditory cues, such as verbal commands and sounds. Pupils at this age can also engage with how their programs or robots are able to learn what their sensors detect, and to how applications can be taught to recognize specific objects in their field of vision. Pupils can also begin to engage with inference algorithms using simple exercises, such as the use of decision trees according a series of yes/no questions. At this stage, the pupils' tendency to anthropomorphize robots can rectified; students can be shown how robots will only respond according to specific commands, and why deviations from these commands are likely to be ineffective.

There is a limited choice of open resources (especially with multi-language interfaces). AI learning platforms, such as the Cognimates platform (http://cognimates.me) developed by the MIT Media Lab, can serve as prototype learning tools, on which children can build games, program robots, and train AI models. Further developing these kinds of platforms may be appropriate to allow pupils to engage in AI development in a more controlled environment. Additional educational technology designed specifically for developing AI literacy would be very useful, whether targeting this level or later levels.

Grades 7-9

As pupils dive deeper into AI, it is imperative to understand that at this point it might be difficult to predict or assess a pupil's individual ability to comprehend these concepts. Therefore, throughout these levels, a certain level of flexibility needs to be considered. The previous two levels should have provided a basic understanding of AI concepts through the examination of existing AI programs. However, pupils who show more prowess will begin to be encouraged to create their own programs independently. This serves as a perfect opportunity for students to subject their AI programs or prototypes to systematic assessments and refine their programs according to their findings [4]. Pupils can also begin delving into syntax-based programming to create their AI applications, along the lines of the AI curriculum implemented in Australia that introduced pupils to Java in Grades 3 and 4 [12]; it was even noted in regard to that program that some students were able to write syntax-based programs independently by Grade 6.

Figure 1. Hong Kong students are already learning how to write computer programs in Grade 9 or above.

The main intention, however, would be merely to emphasize that there are different programming languages, and that these come in the forms of graphical-based coding and syntax-based coding. The ability of pupils to perform syntax-based coding may vary, thus necessitating the need to engage with both forms. Pupils should be able to identify how well trained a system is, and how biases will affect its overall performance. At the more advanced level, pupils should now be able to use data structures, such as lists and dictionaries, to independently create simple AI applying concepts like Bayesian inference, rules engines, and clustering. Pupils should also now be aware of the constraints and limitations of perception-based systems, and they should be able to utilize machine learning techniques to enhance the abilities of their perception-based applications. They should now be able to critically evaluate the implications of AI on a much broader scale, including possible ethical or societal concerns.

Beyond Grade 9 the program could be made more flexible in collaboration with CS educators at universities. Pupils could be exposed to additional technologies and given a chance to try to understand the know-how behind them. In some countries, pupils beyond Grade 9 may begin their preparation for college by choosing electives (e.g. information and communication technology (ICT) in Hong Kong, or AP CS in the U.S.) in their existing curriculum. Schools can therefore consider what AI concepts could be introduced in line with preparation for college study (see Figures 1 and 2).

Figure 2. Introducing machine learning to a group of students in Hong Kong for the first time.

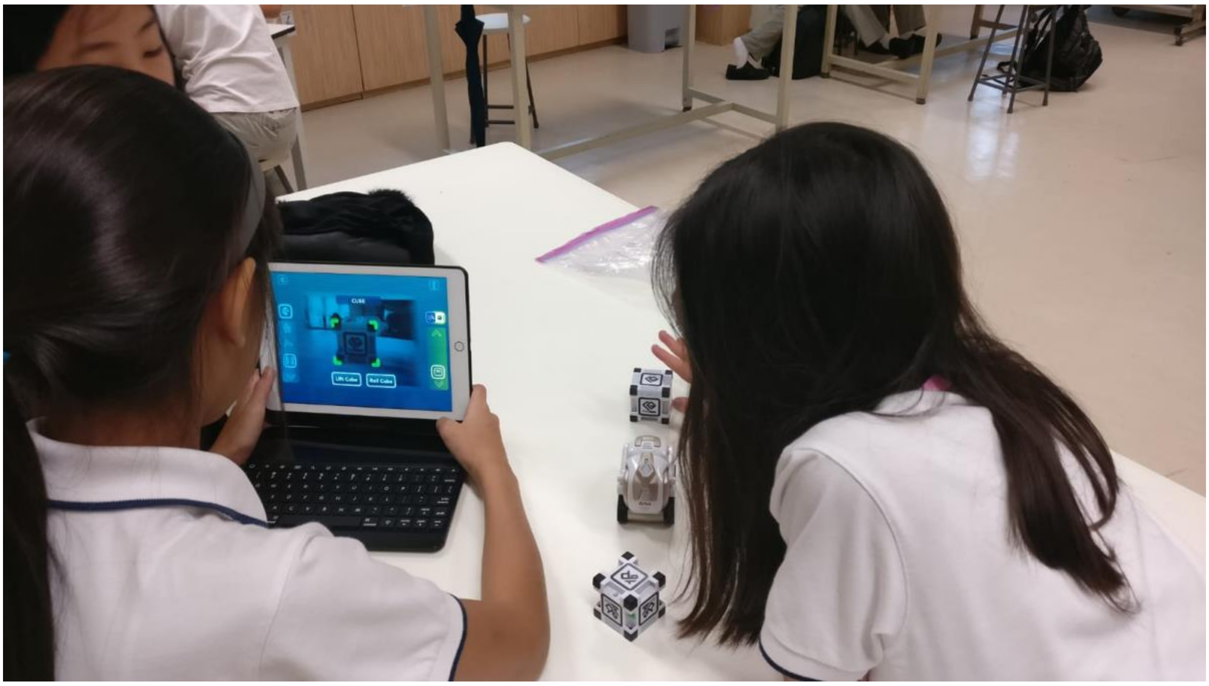

Figure 3. Hong Kong students use the Anki Cozmo to explore the use of computer vision in robots.

The Next Step

It is certain that AI will continue to attract immense attention far into the future, and it will not cease in its integration into our everyday lives. Children find it exciting to interact with AI tools (see Figure 3). It is also imperative for communities around the world to begin discussing the impact of AI on society. To prepare future generations for a world filled with this kind of technology, CS educators need to consider how AI education should be implemented at the K-12 level in a way that does not intimidate children but rather instills in them a natural curiosity to learn more and to become more engaged with AI technology.

Hong Kong as an Example

As an example, we have inserted the AI program structure into Hong Kong's current K-12 curricula and mapped it to the AI framework provided by ai4k12.org. Table 2 below shows areas where AI topics are able to supplement the existing learning expectations at the different levels of K-12. The age groupings in Hong Kong's curricula are slightly different, so the program has been adjusted according to the expected capabilities emerging from the pre-existing technology education curricula. The AI program is inserted such that it does not interfere with the expected learning outcomes that are currently in place. The number of hours across the different age groups may vary, and the allocation of time to the different AI concepts will entirely depend on a school's preference provided that the learning objectives outlined by the current curricula are being addressed. The program can therefore be implemented with a significant amount of flexibility.

While we are at the early discussion stages of bringing this structure into school-based learning, the authors have collaborated to introduce a completed AI program in out-of-school settings for different age groups. Nonetheless, Table 2 shows what pupils in K-12 are capable of learning under the Hong Kong curriculum, and that this can be mapped seamlessly onto the ai4k12.org framework. The next essential step in our agenda is to develop a set of learning designs and activities to help pupils develop AI literacy at each level.

As the Hong Kong government is constantly developing its technology education policy and has introduced computational thinking into primary and secondary education, we believe that adding AI education to the existing curriculum is a natural step. Nonetheless, effort must be made to bring policymakers together in looking at its importance for future generations in Hong Kong and for building the global competitiveness of K-12 graduates. It is our intention to help support the government's initiative through research and practice. Although we are still investigating the optimal approach to develop the details of an AI program for K-12 that is sensitive to the age and experience of children at different levels, through different pedagogical approaches and different learning tools, our goal is to conduct pilot studies in various settings based on this structure in the next academic year. We believe that this is the right time to bring CS researchers and educators throughout the world together to push forward AI education for K-12 with a clear theoretical and methodological orientation. We hope that this call can encourage CS teachers to join the worldwide community and contribute to the future of AI education.

Conclusion: Program and Implementation

Several steps can be taken in the process of implementing this AI program structure. First, identify whether the CS curriculum currently in place is able to provide pupils with the foundational knowledge necessary to digest AI concepts. The AI program structure can be modified and adjusted to supplement the learning objectives of the current CS curriculum. Second, identify what tools will be utilized for specific grade levels. Although there is no standardized and universal tool specifically designed to teach AI at the K-12 level, educators can source specific tools that will be able to fulfil the learning objects at different levels. Third, it is essential to ensure that individuals assigned to deliver the AI curriculum receive the necessary training, through workshops or information sessions, regarding AI education. Depending on location, this may be difficult to achieve, as AI education at K-12 level has made the most progress in China and the U.S.; it is thus paramount to ensure that sufficient resources are available for educators to receive the appropriate training.

The proposed program structure serves as an starting point for the implementation of AI education at the K-12 level. However, it is well understood that the process of implementation will be affected by a given school's facilities and available resources. It is necessary for communities to be more involved and vocal about the need for children to attain AI literacy, and collaboration between multiple stakeholders is essential to transforming school systems to accommodate the teaching of AI. As AI technology advances, we have a responsibility to ensure that students become well equipped to manipulate and utilize these emerging technologies, and to enter the workforce with all of the essential skills for them to excel in their careers.

<table>
<tr><th>GRADE LEVELS</th><th>ENTRY POINT IN EXISTING CURRICULUM</th><th>RELATED AI CONCEPTS</th><th>AI FRAMEWORK</th></tr>
<tr><td>K1-K3</td><td><u>Learning Objectives Under Learning Area: Nature and Living [5]:</u>
- To explore the world with multiple senses: sight, hearing, taste, smell and touch
- To express their thoughts towards nature and surroundings, and to experience the relationship among nature, technology and our everyday life, through observation, prediction and comparison</td><td rowspan="2"><u>Low-Order Thinking Skills</u>
● Understand how to interact with sensors
● Understand that AI has an impact on everyday life</td><td rowspan="2">AI1, AI5</td></tr>
<tr><td>Grade 1-3 (Primary School)</td><td><u>Core Learning Objectives Under Science and Technology in Everyday Life (General Studies) [4]:</u>
- How science and technology contribute to everyday life
- Using science and technology to solve problems at home</td></tr>
<tr><td>Grade 4-6 (Primary School)</td><td><u>Learning Objectives Under Technology Education Curriculum [6]:</u>
- Be aware of the approaches used in solving problems
- Know how to write simple program with templates
- Be aware of the use of abstraction and pattern recognition in solving problems</td><td><u>Low-Order Thinking Skills</u>
● Understand simple processes of making inferences
<u>High-Order Thinking Skills</u>
● Create and modify perception-based applications
● Analyze the difference between artificial intelligence and natural intelligence</td><td>AI1, AI4</td></tr>
<tr><td>Grade 7-9 (Secondary School)</td><td><u>Learning Objectives Under Technology Education Curriculum [6]:</u>
- Apply different approaches in solving problems
- Develop skills to solve problems systematically
- Know how to develop simple problems</td><td><u>Low-Order Thinking Skills</u>
● Understand graphs and data structures
<u>High-Order Thinking Skills</u>
● Create a chatbot</td><td>AI1, AI2, AI4</td></tr>
<tr><td>Grade 10-12 (Secondary School - Optional)</td><td><u>Topics Under Information, Communication and Technology Curriculum [7]:</u>
- Under Compulsory Part (D. Basic Programming Concepts):
  - Problem-Solving Procedures
  - Algorithm Design
  - Algorithm Testing
- Under Elective D. Software Development
  - Under the Topic: Programming
    - Problem definition and analysis
    - Design of solution
    - Implementation
    - Testing and Evaluation
    - Documentation</td><td><u>Low-Order Thinking Skills</u>
● Understand the Turing Test
● Understand neural networks
<u>High-Order Thinking Skills</u>
● Create inference algorithms
● Create a chatbot with syntax programming e.g. Python
● Apply acquired AI concepts as potential solutions to real-world problems</td><td>AI1, AI2, AI3, AI4, AI5</td></tr>
</table>

Table 2. Implementation of K-12 AI Education in Hong Kong

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