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Artificial Intelligence in Education: Challenges and Opportunities for Sustainable Development

Education 2030

Artificial Intelligence in Education: Challenges and Opportunities for Sustainable Development

UNESCO Education Sector

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Abstract

Artificial Intelligence is a booming technological domain capable of altering every aspect of our social interactions. In education, AI has begun producing new teaching and learning solutions that are now undergoing testing in different contexts. This working paper, written for education policymakers, anticipates the extent to which AI affects the education sector to allow for informed and appropriate policy responses. This paper gathers examples of the introduction of AI in education worldwide, particularly in developing countries, discussions in the context of the 2019 Mobile Learning Week and beyond, as part of the multiple ways to accomplish Sustainable Development Goal 4, which strives for equitable, quality education for all.

First, this paper analyses how AI can be used to improve learning outcomes, presenting examples of how AI technology can help education systems use data to improve educational equity and quality in the developing world. Next, the paper explores the different means by which governments and educational institutions are rethinking and reworking educational programmes to prepare learners for the increasing presence of AI in all aspects of human activity. The paper then addresses the challenges and policy implications that should be part of the global and local conversations regarding the possibilities and risks of introducing AI in education and preparing students for an AI-powered context.

Finally, this paper reflects on future directions for AI in education, ending with an open invitation to create new discussions around the uses, possibilities and risks of AI in education for sustainable development.

Executive Summary

Artificial Intelligence is a booming technological domain capable of altering every aspect of our social interactions. In education, AI has begun producing new teaching and learning solutions that are now undergoing testing in different contexts. AI requires advanced infrastructures and an ecosystem of thriving innovators, but what about the urgencies of developing countries? Will they have to wait for the "luxury" of AI? Or should AI be a priority to tackle as soon as possible to reduce the digital and social divide?

These are some of the questions guiding this document. In this regard, this urgent discussion should be taken up with a clear picture of what is happening and what can be done. This document gathers examples of how AI has been introduced in education worldwide, particularly in developing countries. It also sows the seeds of debates and discussions in the context of the 2019 Mobile Learning Week and beyond, as part of the multiple ways to accomplish Sustainable Development Goal 4, which targets education.

This document was drawn up for education policymakers and anticipates the extent to which AI affects the education sector so that informed and appropriate policy responses can be made in this regard.

The *first section* of this document analyses how AI can be used to improve learning outcomes. It presents examples of how AI technology can help education systems use data to improve educational equity and quality in the developing world. The section is divided into two topics that address pedagogical and system-wide solutions:

i) AI to promote personalisation and better learning outcomes, exploring how AI can favour access to education, collaborative environments and intelligent tutoring systems to support teachers. We briefly introduce cases from countries such as China, Uruguay, Brazil, South Africa and Kenya as examples experimental solutions conceived from public policies, philanthropic and private organisations.

ii) Data analytics in Education Management Information Systems (EMIS). Here we present opportunities for improving a state's capacity to manage large-scale educational systems by increasing data from schools and learning, presenting cases from United Arab Emirates, Kenya, Bhutan, Kyrgyzstan and Chile.

The *second section* "Preparing learners to thrive in an AI-saturated future" explores the different means by which governments and educational institutions are rethinking and reworking educational programmes to prepare learners for the increasing presence of AI in all aspects of human activity. Based on examples from different contexts, the section is also divided into two main parts:

i) "A new curriculum for a digital and AI powered world" elaborates further on the importance of advancing in digital competency frameworks for teachers and students. Some current initiatives are presented such as the "Global Framework to Measure Digital Literacy" and "ICT Competencies and Standards from the Pedagogical Dimension". The discussion of the curricular dimension is broadened to include new experiences for developing computational thinking in schools with examples from the European Union, United Kingdom, Estonia, Argentina, Singapore and Malaysia.

ii) The second part is more focused on strengthening AI capacities through post-basic education and training. How can each country prepare the conditions for an AI-powered world? Here we present some of the most advanced cases from developed countries who are generating comprehensive plans to tackle this question, namely France, South Korea and China. We also present some cases from the technical and vocational education and training sector and some opportunities from non-formal and informal learning scenarios.

The *last section* addresses the challenges and policy implications that should be part of the global and local conversations regarding the possibilities and risks of introducing AI in education and preparing students for an AI-powered context. Six challenges are presented:

The first challenge lies in developing a comprehensive view of public policy on AI for sustainable development. The complexity of the technological conditions needed to advance in this field require the alignment of multiple factors and institutions. Public policies have to work in partnership at international and national levels to create an ecosystem of AI that serves sustainable development.

The second challenge is to ensure inclusion and equity for AI in education. The least developed countries are at risk of suffering new technological, economic and social divides with the development of AI. Some main obstacles such as basic technological infrastructure must be faced to establish the basic conditions for implementing new strategies that take advantage of AI to improve learning.

The third challenge is to prepare teachers for an AI-powered education while preparing AI to understand education, though this must nevertheless be a two-way road: teachers must learn new digital skills to use AI in a pedagogical and meaningful way and AI developers must learn how teachers work and create solutions that are sustainable in real-life environments.

The fourth challenge is to develop quality and inclusive data systems. If we are headed towards the datafication of education, the quality of data should be our chief concern. It´s essential to develop state capabilities to improve data collection and systematisation. AI developments should be an opportunity to increase the importance of data in educational system management.

The fifth challenge is to make research on AI in education significant. While it can be reasonably expected that research on AI in education will increase in the coming years, it is nevertheless worth recalling the difficulties that the education sector has had in taking stock of educational research in a significant way both for practice and policy-making.

The sixth challenge deals with ethics and transparency in data collection, use and dissemination. AI opens many ethical concerns regarding access to education system, recommendations to individual students, personal data concentration, liability, impact on work, data privacy and ownership of data feeding algorithms. AI regulation will thus require public discussion on ethics, accountability, transparency and security.

The document ends with an open invitation to create new discussions around the uses, possibilities and risks of AI in education for sustainable development.

Introduction

In this age of big data, we all leave behind individual information footprints, resulting in an abundance of data, allowing human and societal behaviour to be objectively quantified and, therefore, easily tracked, modelled and, to a certain extent, predicted. This phenomenon surrounding information footprints is referred to as 'datafication' (Mayer-Schönberger & Cukier, 2014) and also affects the education sector. While datafication certainly raises some ethical concerns, which also require a concerted policy response, it also brings a world of possibilities in terms of individualising learning and education governance. To date, little has been discussed about the possibilities and limitations of AI in education in the developing world, particularly regarding the extreme problems of the least developed countries. With a view to helping bridge this gap, this paper will discuss AI technologies that education systems worldwide are beginning to use and also explore how they have helped or can help improve learning outcomes.

In this context, this paper aims to identify the education policy implications of AI by examining four main challenges:

1. Ensuring inclusive and equitable use of AI in education
2. Leveraging AI to enhance education and learning
3. Promoting skills development for jobs and life in the AI era
4. Safeguarding transparent and auditable use of education data

This paper was drawn up to assist education policymakers, specifically in developing countries, in understanding and anticipating the extent to which AI impacts the education sector so they can determine appropriate policy responses. By examining the education sector's response to AI in various countries, this paper suggests critical considerations for public policies in developing countries to integrate AI-powered technologies. The overall goal is to ensure that learners acquire the competencies to thrive in an AI-powered society. In doing so, this paper also elaborates on the key risks and challenges that countries are facing in steering the use and development of AI.

This document was also drawn up to open urgent discussions on the role of AI in education in developing countries. To do so, this document is broad and simple in its style, open and careful in its suggestions, and full of examples to tackle these discussions in dialogue with real-world applications as they unfold in the present.

Given the complexity of the topic with changes happening at an exponential and unpredictable rate, public policy discussions have been elicited but postponed by the surrounding urgencies educational systems face worldwide. Nevertheless, in a world that is becoming AI-powered, education must prioritise this discussion for the public policy agenda in every context.

This paper is divided into three sections.

Section I, "Leveraging AI towards improving learning outcomes", presents examples of how AI technology can help education systems use data to improve teaching in the developing world. This section comprises two sub-sections that address pedagogical and system-wide solutions, namely (1) AI to promote personalisation and better learning outcomes, and (2) Data analytics in Education Management Information Systems (EMIS).

Section II, "Preparing learners to thrive in an AI-saturated future", explores different means by which governments and educational institutions are rethinking and reworking learning programmes to prepare learners for the increasing presence of AI in all aspects of human activity. It is based on examples from different contexts and also divided in two subsections, namely (1) A new curriculum for a digital and AI-powered world, and (2) Strengthening AI capacities through post-basic education and training.

Section III, "Challenges and policy implications ". The last section addresses the challenges and policy implications that need to be part of the global and local conversations surrounding the possibilities and risks of introducing AI in education and preparing students for an AI-powered context.

A brief introduction to AI

Since its 'birth' at the 1956 Dartmouth Conference, the field of artificial intelligence (AI) has continued garnering the interest of a and industries alike. Few technological developments in recent history have been as polarising as AI. While AI has be en around for nearly 60 years, it nevertheless remained a fringe technology until only recently because of sweeping changes in recent years (referred to as "the big leap"), entailing the abundance of data (big data), economic access to computing power and advances in Machine Learning. The present paper uses terms such as AI and Big Data, the two main technology buzzwords of the current decade, and other concepts such as machine learning, learning analytics, etc. as technologies that work well together. It should be borne in mind that these terms are sometimes used interchangeably in the news and articles, thus creating confusion. With a view to avoiding such confusion, this subsection contains a brief explanation of these concepts, clarifying their differences and how they work together (there is also a complementary definition in the annex hereto).

While there is no straightforward and consensual definition of AI, several classic definitions of AI are nevertheless provided from the different literature, including McCarthy (2006), Zhong (2006), ITU (2018).

In this paper, AI is best understood considering different dimensions **(see Figure 1)**

Figure 1. Different dimensions of AI

Thinking Humanly

'The exciting new effort to make computers think… *machines with minds*, in the full and literal sense.' (Haugeland, 1985)

'[The automation of] activities that we associate with human thinking, activities such as decision-making, problem-solving, learning…' (Bellman, 1978)

Thinking Rationally

'The study of mental faculties through the use of computational models.' (Charniak & McDermott, 1985)

'The study of the computations that make it possible to perceive, reason, and act.' (Winston, 1992)

Acting Humanly

'The art of creating machines that perform functions that require intelligence when performed by people.' (Kurzweil, 1990)

'The study of how to make computers do things at which, at the moment, people are better.' (Rich & Knight, 1991)

Acting Rationally

'Computational Intelligence is the study of the design of intelligent agents.' (Poole, et al., 1998)

'AI… is concerned with intelligent behavior in artifacts.' (Nilsson, 1998)

The table above contains some definitions of AI by Stuart J. Russell and Peter Norvig in their book "Artificial Intelligence: A Modern Approach (2010)" (Refer to the Annex for further details).

Research in AI has focused chiefly on the following components of intelligence: learning, reasoning, problem solving, perception and using language. There are two types of AI, namely data-driven AI through Machine Learning (see below) and knowledge-based AI, based on an explicit representation of domain knowledge that a machine reason about. The current success of AI is mostly due to advances in data-driven AI.

In 1959, Arthur Samuel coined the term *machine learning* only a few years after AI's birth, defining the concept as "the ability to learn without being explicitly programmed". At its core, machine learning is simply a way to achieve AI. It is important to remark that you can get AI without using machine learning, but this would require building millions of lines of codes with complex rules and decision-trees. Refer to the annex for additional definitions.

Deep learning is another widely used term that is also one of the many approaches to machine learning. The long list of further approaches includes decision tree learning, inductive logic programming, clustering, reinforcement learning and Bayesian networks. Deep learning is a specific subfield of machine learning, viz. a new take on learning representations from data that puts an emphasis on learning successive layers of increasingly meaningful representations. In deep learning, these layered representations are (nearly always) learned via models called neural networks structured in literal layers stacked on top of each other. See annex for additional definitions.

AI thrives on data. AI application outcomes become more accurate with more data. AI needs data to build its intelligence (e.g., using machine learning). Given that big data enables AI to reach its full potential, it would be fair to say that there is no data-driven AI without big data. A modern definition of the term big data is: "Datasets whose size is beyond the ability of typical database software tools to capture, store, manage and analyse" (Manyika et al., 2011). Those datasets are a combination of structured and unstructured data, and big data is often said to be characterised by 3 Vs, namely Volume (of data), Variety (of types of data) and Velocity (at which data are or should be processed). Refer to the annex for additional definitions.

Educational data mining and learning analytics are two specific areas in which big data can be used for education:

Data mining: In computer science, data mining is the process of discovering interesting and useful patterns and relationships in large volumes of data. Refer to the annex for additional definitions. Educational Data Mining (EDM) develops methods and applies techniques from statistics, machine learning and data mining to analyse data collected during teaching and learning. EDM tests learning theories and informs on educational practice (US Department of Education, 2012).

Learning analytics: Learning Analytics (LA) is an emerging discipline seeking to improve teaching and learning by critically evaluating raw data and generating patterns to characterise learner habits, predict learner responses and provide timely feedback. Moreover, LA supports decision-making, tailors readable content, simplifies realistic assessments and provides personal supervision of learners' progress. The goal is to scale the real-time LA exploitation by learners, teachers/academics and educational computer-based systems to enhance learners' accomplishments at both course and individual levels. Refer to the annex for references.

Section I:

Leveraging AI towards improving learning and equity

While part of Artificial Intelligence (Clancey, 1987) since its very outset, AI in education has nevertheless faced many difficulties to grow because education systems around the world are more reluctant to technological changes in their traditional organisation. AI was part of the vision promising to transform education by creating tutor systems that could personalise learning. This promise is starting to unfold as present technology has begun experimenting with different models worldwide, bringing many questions to the field of education.

This first section focuses on the ways in which AI could be used to improve learning and equity in education in the developing world. The section addresses two main topics: one dedicated to improving personalisation through AI (pedagogical scale) and the other focused on education management information systems (systemic management scale).

Before discussing real experiences, a brief reference to a key technology that applies to the two main topics in this section: Learning analytics, while still a young field, is a powerful resource for informed decisions and getting better learning results. Learning analytics applies different areas of knowledge such as sociology, psychology, ethics, pedagogy, etc. and can now access the digital revolution to collect a lot of data that can be analysed to extract insights or even develop helpful smart tools for educational or administrative tasks.

Analysing and getting the most out of data is no easy task. For this purpose, advanced data analysis techniques are used, which in turn relay on other disciplines such as statistics-based big data technologies to efficiently handle large data volumes, machine learning algorithms that learn from the data and visualisation tools for efficient communication with people who must ultimately make decisions.

All these software layers for intelligent data processing will allow us to draw insights, detect learning patterns, predict future situations or give recommendations to optimise available resources. Analysis is also a very important step in developing future AI solutions that, with the help of powerful libraries, including yet not limited to natural language recognition, language translation and game theory, will enable us to, for instance, create avatars that simulate the behaviour of a virtual teacher for students or an assistant for teachers. The bright prospects of the future allow us to visualise an AI ecosystem that can help us overcome the different challenges in learning analytics.

Although the future of AI solutions is very promising in the medium term, current solutions are more focused on taking full advantage of data mining/analysis technologies.

The section hereunder provides examples of public policies, philanthropic engagements and private sector initiatives in developing countries as a glimpse into the first stages of implementation of AI-based interventions in education.

(1) AI to promote personalisation and better learning outcomes

In light of the existing initiatives and technologies to come, different studies (Laanpere et al., 2014; Luckin et al., 2016; Mayer-Schönberger & Cukier, 2014; Montebello, 2017) have recently contributed to the ways in which AI can help improve learning opportunities for students and management systems.

Sustainable Development Goal 4 aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. It emphasises equal learning opportunities for all throughout life. AI technologies are used to ensure equitable and inclusive access to education. It provides marginalised people and communities, people with disabilities, refugees, those out of schools, and those living in isolated communities with access to appropriate learning opportunities. For example, telepresence robotics allow students with special needs to attend schools at home or hospital, or maintain continuity of learning in emergencies or crises. In this way, it is able to support inclusion and ubiquitous access.

AI can help advance collaborative learning. One of the most revolutionary aspects of computer-supported collaborative learning is found in situations where learners are not physically in the same location. It provides students variable choices insofar as when and where they wish to study. In respect to computer-supported collaborative learning, online asynchronous discussion groups play a central role. Based on AI techniques such as machine learning and shallow text processing, AI systems are used to monitor asynchronous discussion groups, thus affording teachers with information about learners' discussions and support for guiding learners' engagement and learning.

AI can help personalise learning through various ways. AI can help create a better professional environment for teachers to work more on students with difficulties. Teachers spend plenty of time on routine and administrative tasks such as making assignments and answering frequently asked questions over and over again in school settings. A dual-teacher model entailing a teacher and a virtual teaching assistant, which can take over the teacher's routine task, frees up teachers' time, enabling them to focus on student guidance and one-to-one communication. Teachers have already started working together with AI assistants for the best outcomes for their learners.

The Computer Assisted Learning (CAL) field creates alternatives to support students´ learning strategies with digital and AI technology (Schittek Janda et al., 2001). AI can help map each student's individual learning plans and trajectories, their strengths and weaknesses, subjects that cost more and are easily assimilated or learned, and learning preferences and activities. Using algorithms to help students navigate through different content paths, AI can personalise learning and improve opportunities for students with the help of their teachers and schools. Intelligent Tutoring Systems are part of the new technological possibilities to expand educational learning in developing countries as shown in recent reviews (Nye, 2015).

Moreover, when considering the tremendous amount of time spent on grading tests and homework, AI as an assessment tool can be applied to learn how a teacher grades and thus free up the teacher's time. AI is not only being used to grade multiple choice tests, but also to assess essays[1].

These opportunities are starting to unfold in developed countries. There is a myriad of applications presently undergoing tests across public and private initiatives alike[2]. This section presents some examples from developing countries to open a discussion regarding the possibilities and risks involved in bringing AI-powered software to personalise learning. We will begin with the case of China, unique in its scope, dimension and level of comprehensive perspective with cutting-edge technology and public-private partnerships, followed by Uruguay, a small developed country that became a bellwether in Latin America. Next, we will present some other state-based, philanthropic and private initiatives in developing countries. These cases have been included as examples to illustrate the state of the art in this field in developing countries and do not aim to be an exhaustive list of every initiative worldwide.

China is a good country to start with, since it is in many ways unique insofar as its size and recent technological development, and also in its recent economic growth (although it remains a developing country in formal definitions). China has 730 million internet users. In 2016, the government launched a plan to become the largest pole of AI development in the world by 2030. China set its national AI strategy for education as part of this technological vision (Jing, 2018).

The state-centred initiative will rely on private pillars. Hujiang, a private digital education company, is developing image and voice recognition software capable of understanding student facial expressions to give AI feedback online. Liulishuo is an adaptive platform that teaches English to 600,000 students at the cost of a single teacher. Master Learner is developing a "Superteacher" capable of answering 500 million simultaneous questions from students preparing for the Gaokao university entrance examination.

In 2016, China's Ministry of Education established that every educational branch of local governments must allocate at least 8% of its budget to the digitisation of education. With 95% of schools connected to the internet, the country is ready for the largest digital education experiment in the world. One of the biggest breakthroughs so far in China is the experimental design to correct essays with AI. The country started to work with 60,000 schools for automatic essay correction with a level of precision matching humans in 92% of the cases. The essay grading machine is based on neural network AI and is improving its ability to understand human language by using deep learning algorithms to plough through essays written by Chinese students and compare notes with human teachers' grading and comments. "It has evolved continuously and become so complex, we no longer know for sure what it was thinking and how it made a judgment," said one of the project researchers (Chen, 2018).

In Latin America, several initiatives have been pushing the introduction of computers in education at a large scale in recent years (Sunkel & Trucco, 2012). **Plan Ceibal** in Uruguay is probably the most advanced state agency

1 For example, in the United States, the Educational Testing Service developed automatic an NLP assessment system to co-grade essays in standardised tests.

2 Refer to the examples presented during Mobile Learning Week 2019: https://en.unesco.org/mlw/2019.

devoted to digital education from the region. One of its main initiatives is an online adaptive learning solution called "Mathematics Adaptive Platform" (PAM for its Spanish acronym). PAM's content has been adapted to the national curriculum and it is a tool that provides personalised feedback according to each student's skill level based on an analysis of student experiences. Some studies have already shown how the program has already had a positive impact on learning (Perera & Aboal, 2018).

PAM was developed by the German company Bettermarks and began to be used in 2013 as part of the One Laptop Per Child program, offering students over 100,000 activities to give personalised assistance to students according to their level of knowledge. PAM provides students with help through a set of over 25 thousand step-by-step exercises and 2800 feedback patterns to explain the solutions of each exercise.

According to Plan Ceibal's official website, the PAM platform offers the following advantages for learning: immediacy of the response; student independence; ease of correction; learning personalisation; classroom gamification; promoting group work; adaptation to the rhythms of class and each student, and a large number of activities.

Some other cases of public endeavours to promote the use of AI in education also come from Latin America[3]. In Brazil, the federal government created **Mec Flix** as a state educational platform. It is a video content platform designed to prepare students for the national higher education examination (ENEM). It has some emergent elements of AI: students have to log in and they can create personalised playlists of video-lessons and get recommendations based on their preferences.

Projects with AI elements in education also come from philanthropic initiatives that work in the developing world. **IBM** is using technology to make an impact on eradicating poverty through the 'Simpler Voice: Overcoming Illiteracy' project. This project uses AI to help adult learners who are illiterate or have low literacy skills, navigate texts with more confidence by translating texts and presenting the basic meaning through visuals or simple spoken word. This will help users overcome difficult obstacles in their day-to-day lives.

Learning Equality is a non-profit initiative that started as an extension of the Kahn Academy to use the contents of the platform in developing countries. Learn Equality launched Kolibri, an open-source educational platform and toolkit designed for low-resource communities.

Other philanthropic international initiatives use prizes as a way to innovate. The $15 million **Global Learning XPRIZE** (XPrize Foundation, 2019) challenges teams from around the world to develop open-source, scalable software that will enable children in developing countries to teach themselves basic reading, writing and arithmetic within 15 months. One of the solutions, RoboTutor (XPrize Foundation, 2019) was developed by Carnegie Mellon specialists to create a learning machine based on AI with robot tutors, voice recognition and data driven algorithms to personalise learning at a large scale.

Finally, many of these "first-generation AI initiatives in education in developing countries" come from the private sector with a lucrative perspective or in partnership with public authorities. In **Brazil**, an EdTech company Geekie – the adaptive learning platform in Brazil accredited by the country's Ministry of Education – is used by over 5,000 schools across the country to provide customised learning experiences for students (WISE, 2011; Rundle, 2015; Rigby, 2016). Through machine learning, the software provides more personalised content as the student uses it more often. It also becomes better at flagging learning difficulties encountered by students, which human educators can then use to determine the necessary interventions.

Daptio is a South African solution that uses deep analytics and provides personalised learning to teachers, students and content creators in Africa and other emerging markets through its online software service. Founded in 2013 and based in Cape Town, Daptio uses artificial intelligence to help students, mentors and teachers to understand the proficiency level of each student and then match the relevant content. Daptio's key local competitors are Get Smarter, Funda and ReThink Education.

M-Shule was launched in **Kenya** in 2016 as a mobile platform filled with lessons based on national curriculum standards delivered via SMS that adapt to each student's skills and abilities using AI technology. As students use the

3 In Guayaquil, Ecuador, the project "**Más Tecnología**" introduced computers for students with a software that personalises curriculums based on the results of assessments in language and mathematics. The project was accompanied by a teacher training plan to implement computer-based lessons three hours per week. A study by the IDB showed that after two years the programme had a positive impact on mathematics test scores (Carrillo, Onofa & Ponce, 2010).

platform, M-Shule tracks and analyses learner performance to empower parents and schools with insights and recommendations.

Some further EdTech initiatives in developing countries also promise to use some elements of AI in education, although they are no strictly AI based, e.g. **SkoolDesk** (Uganda), **Siyavula** (South Africa and Nigeria), **Virtual Learning Africa** and **TopDog** (South Africa), private companies that develop educational content for students of all levels in Africa; and **Zaya Learning Labs** (India).

(2) Data analytics in Education Management Information Systems (EMIS) and the evolution to Learning Management Systems (LMS)

An Education Management Information System (EMIS) is an organised group of information and documentation services that collects, stores, processes, analyses and disseminates information for educational planning and management. It is widely used for education leaders, decision-makers and managers at the regional, local and school levels and for the generation of national statistics. Data-Driven Decision Making (DDDM) applied to student achievement testing data is a central focus of many school and district reform efforts, in part because of federal and state test-based accountability policies. With massive data collected from EMIS, AI algorithms are able to make data-driven decisions to improve school education.

A well-designed and well-functioning EMIS lets members across all levels of the education community access useful information for managing and administering an education system more efficiently, developing feasible and cost-effective plans, formulating responsive policies, and monitoring and evaluating educational outcomes. In countries where data are complete, reliable, regularly collected, and can be aggregated and disaggregated, AI-enhanced EMIS would have a much stronger capacity to automatically analyse the data and generate data dashboards at both the school and national levels. Moving forward, EMIS even opens up a potential for developing predictive decision-making algorithms. While this remains a very nascent area in EMIS development, more countries, both developed and developing, are interested in **transforming their current EMIS** from a school-based aggregated administrative data management system **into an integrated and dynamic learning management systems** that can effectively support real-time decision-making in every aspect of education sector management.

In the **United Arab Emirates (UAE)**, the Ministry of Education rolled out an advanced data analytics platform with over 1,200 schools and over 70 higher education institutions, totalling over 1.2 million students. This data analytics system contains data on curricula, teachers' professional development, learning resources, financing, operations, performance reports, teacher, student and parent feedback, and scores from international assessments like PISA and TIMSS (Leading Countries of the World, 2018). UAE has a data analytics section in its Ministry of Education, dedicated to developing machine learning algorithms in support of strategic studies on the country's education system.

Middle and lower-income countries are also exploring the potential of AI-enhanced EMIS. For instance, **iMlango** is an educational technology program delivered by a partnership of public and private sector organisations in Kenya. Schools measure daily attendance using sQuid's digital attendance system, enabling quick and easy attendance monitoring, real-time data reporting and high reliability and insight into complex student data patterns. Class and school attendances are tracked and reported using advanced analytics, which are then used by teachers and a field team to identify low-attending pupils. sQuid's interactive learning platform delivers learning content in multiple formats for students and teachers. Pupils can access Maths Whizz, the personalised virtual math tutor that tailors the pupils' learning experiences depending on their ability, and other content such as Africa-focused stories, the world's first children's encyclopaedia, and curriculum-aligned revision guides.

While still at a very nascent stage, countries such as **Bhutan** and **Kyrgyzstan** are aspiring to create integrated education information management systems based on individual student tracking that can allow for personalised learning support, and efficient and effective school and sector management. This opens the possibilities of introducing AI-enhanced learning analytics in their systems in the near future.

The school mapping initiative **UNICEF Innovation** is exploring the potential of Deep Learning (DL) algorithms in collaboration with academic institutions and private companies. Their studies show that DL algorithms are useful for example to recognise schools in satellite imagery, thus rendering unmapped schools visible.

AI has begun unveiling its potential in research for sustainable development. The contest "**New debates.**

Data for development" organised by the Inter-American Development Bank financed the study "Big Data for public policy in education: the Chilean case". In this study, Chilean researchers used open data published by the government regarding social, geographical and educational contexts. The study was able to predict student dropout by localising the geographical distances from houses to schools. Using 127 characteristics of students and their geographical locations, researchers created an algorithm to develop a "geography of educational opportunities", with a detailed map of schools, access, academic results and dropout predictions.

Section II:

Preparing learners to thrive in the future with AI

Businesses are generally quick to adopt AI-based solutions. This means an increasing demand for new types of jobs and skills that are linked to the use of AI in industry. As such, there is strong imperative for the education sector to respond in that curricula must be reworked and policies reformulated. However, no country in the world is genuinely ready for intelligent automation; not even those traditionally conceived as leaders in the field as policy response to intelligent automation remains nascent (The Economist Intelligence Unit, 2018). Nevertheless, there is exemplary work being done by countries across the world to ensure that their education systems are promoting the acquisition of competencies required by an AI-powered society. Their efforts can serve as starting points towards the development of a concerted policy framework for education's response to AI.

(1) A new curriculum for a digital and AI-powered world

Education plays a critical role in efforts to make future workforces AI-ready. Bridging the AI skills gap goes beyond the adoption of increasingly powerful technologies to facilitate learning. It also means rethinking the content and methods used to deliver instruction at all levels of education. The curricular reform efforts cited in this paper show a clear need to define 'AI competencies' beyond basic ICT competencies, which is how many countries defined them when incorporating 21st century skills in their respective educational programs, towards skills that would allow learners to identify and solve problems using computing techniques, methods and technologies.

In the context of a near future society empowered by AI, it is important to develop new skills to create and decode digital technologies. To approach this topic, we will focus on new frameworks that characterise digital skills for students and teachers and some cases from different countries. The objective is to reveal the power of digital competencies that can analyse, use and decode Artificial Intelligence as a powerful technology, to which we must necessarily think in a context to understand its scope, limitations, potential and challenges.

Digital competencies frameworks

The need to collect data for the SDG 4 Education indicators sets the table for a collective work of developing a Global Framework to Measure Digital Literacy. This has been the priority of a task force of experts and country representatives established by the Global Alliance to Monitor Learning (GAML) and chaired by the GEM Report. The main definition of digital literacy is: "the ability to access, manage, understand, integrate, communicate, evaluate and create information safely and appropriately through digital devices and networked technologies for participation in economic and social life. It includes competencies that are variously referred to as computer literacy, ICT literacy, information literacy, and media literacy" (Antoninis & Montoya, 2018). The following table shows the set of competencies defined as part of this framework.

As a parallel initiative, the Information and Communication Technologies Competency Framework for Teachers (ICT-CFT) was developed by UNESCO (2011) in consultation with major private actors such as ISTE, Cisco, Intel and Microsoft, and has been regularly updated since. The framework was updated in 2018.[4] This framework specifies the competencies that teachers need to integrate in their professional practices to develop critical knowledge and awareness with their students in the digital era.

The framework emphasises the role that digital technologies have in supporting six key areas of knowledge: 1-Understanding ICT in education; 2-Curriculum & Assessment; 3-Pedagogy; 4-ICT; 5-Organisation & Administration; 6-Teacher Professional Learning. The framework sets three phases of knowledge acquisition: 1-technology literacy; 2-knowledge deepening; 3-knowledge creation.

This framework underlines that it´s not enough for teachers to have certain skills to manage digital technologies and to teach them to their students, but also that teachers must help their students be capable of collaborating, solving problems and being creative in the use of digital technologies. In a growing technological world, these skills become part of their citizenship training to participate in the digital society where they will live.

Another framework along this same line of support to teachers in the integration of digital technologies to their practices is "ICT Competencies and Standards from the Pedagogical Dimension", developed by UNESCO Santiago and the Universidad Javeriana (2016).

This framework was created to contribute in the vision of teacher training to face the challenge of teaching in

4 The corresponding publication can be accessed via this link: https://unesdoc.unesco.org/ark:/48223/pf0000213475

Table 1: Proposed digital literacy competency areas and competencies

Competency area	Competencies
0. Fundamentals of hardware and software	0.1 Basic knowledge of hardware such as turning on/off and charging' locking devices 0.2 Basic knowledge of software such as user account and password management, login and how to do privacy settings, etc.
1. Information and data literacy	1.1 Browsing, searching and filtering data, information and digital content 1.2 Evaluating data, information and digital content 1.3 Managing data, information and digital content
2. Communication and collaboration	2.1 Interacting through digital technologies 2.2 Sharing through digital technologies 2.3 Engaging in citizenship through digital technologies 2.4 Collaborating through digital technologies 2.5 Netiquette 2.6 Managing digital identity
3. Digital content creation	3.1 Developing digital content 3.2 Integrating and re-elaborating digital content 3.3 Copyright and licenses 3.4 Programming
4. Safety	4.1 Protecting devices 4.2 Protecting personal data and privacy 4.3 Protecting health and well-being 4.4 Protecting the environment
5. Problem solving	5.1 Solving technical problems 5.2 Identifying needs and technological responses 5.3 Creatively using digital technologies 5.4 Identifying digital competency gaps 5.5 Computational thinking
6. Career-related competencies	6. Career-related competencies refers to the knowledge and skills required to operate specialised hardware/software for a particular field such as engineering design software and hardware tools, or the use of learning management systems to deliver fully online or blended courses.

Source: A Global Framework for Reference on Digital Literacy Skills for Indicator 4.4.2 (UIS, 2018a) an information and knowledge society. This aims to be a benchmark in training for the improvement of educational quality in educational institutions at any level of training base on an approach of levels of appropriation of ICT and its educational uses. This framework describes the contextual elements where the proposal is framed. The ICT Competencies and Standards model is presented from the pedagogical dimension based on levels of appropriation of ICT, its meaning and use from the training route.

The relevance of this proposal is its constitution as a guiding base for any teacher and educational institution facing the appropriation of ICT in their practices and educational strategies. The educational institution or the teacher in particular can evaluate their practices and educational strategies with use of ICT regarding the expected standards and, from this process of identification and recognition, continue with a process of training, support and evaluation based on their level of ICT appropriation.

Finally, another framework is **DigComp** (Joint Research Centre, 2018), designed by the European Union to support the development of digital skills of individuals.[5] The framework describes what competencies are needed today to use digital technologies in a critical, reliable, collaborative and creative way, so that individuals can achieve their goals related to work, learning, leisure, inclusion and participation in the digital society.

This framework is structured in five competency areas that describe the key components of digital competencies, namely Information and data literacy; Communication and collaboration; Digital content creation; Safety; and Problem solving. The framework takes these dimensions and maps them through four proficiency levels: foundation, intermediate, advanced, highly specialised.

Computational thinking

Computational Thinking (CT) has emerged as one of the key competencies to enable learners to thrive in an AI-powered society. There is clear acknowledgement of the importance of CT skills: The countries examined in this paper have either laid out plans to incorporate CT in their educational curricula or have already done so. The Computer Science Teachers Association (USA) defines CT as a problem-solving process possessing the following characteristics (International Society for Technology in Education and Computer Science Teachers Association, 2011):

- Formulating problems in a way that enables us to use a computer and other tools to help solve them;
- Logically organising and analysing data;
- Representing data through abstractions such as models and simulations;
- Automating solutions through algorithmic thinking (a series of ordered steps);
- Identifying, analysing and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources; and
- Generalising and transferring this problem-solving process to a wide variety of problems.

While distinctly belonging to the domain of computer science, CT is therefore a competency that finds applications in other disciplines. Given the increasing presence of AI in the workplace, CT becomes a critical competency if learners are to cope with changing labour market demands. Many countries have thus begun incorporating CT in their respective educational curricula.

A survey conducted by the European Commission shows that while **European Union (EU)** Member States are at different stages of integrating CT in their respective educational curricula, each one has begun working on it (European Commission, 2016). The survey found three clusters in terms of the level of CT integration in curricula:

1. countries that have started a curriculum review and redevelopment over the past three to five years such as the United Kingdom, France, Italy, Portugal and Finland
2. countries that are planning to introduce CT into their curricula such as Greece, Sweden, Norway and the Czech Republic; and
3. countries that have a longstanding tradition of computer science education, particularly in secondary school such as Austria, Poland and Lithuania.
4. In other words, there is universal recognition across the EU of the importance of integrating CT in educational programs.

In the **United Kingdom (UK)**, for instance, the Royal Society published a report in 2012 that described the

5 See also https://schools-go-digital.jrc.ec.europa.eu/.

shortcomings of computing instruction in the country. This report described how instruction on ICT at the time merely aimed for students to acquire basic digital literacy skills, i.e. the general ability to use computers, and recommended a curricular shift towards information technology, computer science, programming and computing (The Royal Society, 2012). The Royal Society argued for the importance of CT and its applications to natural and artificial systems. They posited that CT skills were also useful and applicable to domains outside computer science (The Royal Society, 2012). Based on the findings of this report, the UK redesigned and implemented a new computing curriculum in 2014, whose aims were more oriented towards fostering an understanding of fundamental principles and concepts in computer science and their applications, and the ability to analyze problems in computational terms and to create computer programs that would solve those problems (UK Department for Education, 2013). Instruction proceeds along four key stages, spanning preschool, primary school, lower secondary school and upper secondary school, with well-defined target competencies for each stage (Yadav, 2016). Computer science and computing instructors are able to share ideas and resources through communities of practice like "Computing at School", an affiliate organisation of the British Computer Society, the Chartered Institute for IT (Heintz, Mannila & Färnqvist, 2016).

Estonia launched a similar initiative in 2012 called the "ProgeTiger Programme", which aims to introduce programming and robotics in educational curricula (HITSA, n/d), spanning pre-school, primary and vocational education (HITSA, n/d). This programme is managed by the Education Information Technology Foundation (*Hariduse Infotehnoloogia Sihtasutuse*, HITSA), which is in turn funded by the Estonian Ministry of Education and Research. The Government of Estonia set HITSA's objective of "[ensuring] that sufficient age-appropriate digital competency necessary for further studies and to succeed in society is acquired at all levels of education by integrating the use of digital solutions into the entire process of teaching and learning" (HITSA, 2015). The ProgeTiger Programme approach has three axes, two of which directly relate to the development of AI-related competencies: Engineering Sciences, encompassing programming, robotics and electronics; and Information and Communications Technology, encompassing computer science and digital communications (HITSA, 2015).

The push to integrate CT in educational curricula from as early as preschool is not exclusive to Europe. **Argentina's** Ministry of Education, for instance, recently announced a plan called 'Aprender Conectados', which aims to incorporate digital learning across all levels of compulsory education. One component of this plan is to integrate programming and robotics in the country's educational program, beginning from preschool all the way to secondary school, in all schools by 2019. The learning curriculum prescribes specific, age-appropriate learning competencies at each level of education, from preschool to secondary school, building towards full competency in using computing methods and techniques, individually and collaboratively, to solve problems (Ministerio de Educación, 2017).

Singapore also starts young in its effort to develop CT competencies amongst learners. In 2016, the country's Info-communications Media Development Authority (IMDA) launched the PlayMaker Programme, which introduced robots to 160 preschool centres to develop very young learners' appetite for and competency in robotics, programming and computer science through play (Graham, 2018). A mid-test and post-test study involving a sample of preschool children using KIBO – one of the robotics kits used in the PlayMaker Programme – showed high success in developing foundational programming concepts among children in the sample group (Sullivan & Bers, 2017). The PlayMaker Programme is part of a broader movement, called CODE@SG, to integrate coding and CT in Singapore's formal education system through Infocomm clubs, student competitions, enrichment programmes and gamified approaches to learning (Infocomm Media Development Authority, 2017). This initiative aims to build a "Smart Nation for the future", whose citizens are "familiar with tech skills and … also sensitive to how tech can be applied to improve living", acknowledging that CT is "[becoming] an increasingly essential part of our lives and careers" (Infocomm Media Development Authority, 2017).

Malaysia has also embedded CT in its educational programme. During the launch of Malaysia's *#mydigitalmaker* movement in 2016, Malaysia Digital Economy Corporation (MDEC) CEO Yasmin Mahmood emphasised that the integration of CT in educational curricula meant "embedding thinking skills – not IT skills – […] to then apply to problem-solving" (Singh, 2016). The #mydigitalmaker Movement is a partnership across the private sector, public sector and academia to "help create and encourage the development of digital making curriculums that are mapped to the objectives set by the Ministry of Education" (Ministry of Education & Malaysia

Digital Economy Corporation, 2017). In 2018, 22 schools in Malaysia have been selected as #mydigitalmaker Champion Schools, i.e. schools funded by MDEC to implement the #mydigitalmaker framework, including the establishment of a Digital Maker Hub, which is a key feature of the #mydigitalmaker Movement (My Digital Maker, 2018). A Digital Maker Hub functions like a workshop or laboratory with a structured learning programme, whereby students have access to various tools to create and collaborate on tech projects (Ministry of Education & Malaysia Digital Economy Corporation, 2017). All Digital Maker Hubs contain a 'creative lab' where students can convert their ideas into code in any programming language, and a prototyping studio, where they can test and see their products at work.

It must be noted, though, that the examples provided are only illustrative and are in no way exhaustive. The incorporation of CT in educational curricula is a reform that pervades across several countries and regions worldwide. This shows a clear shift from basic digital literacy to higher-order (computational) thinking skills. While the push to integrate 'ICT competencies' into educational curricula has long existed, particularly since the movement towards 21st century skills, 'ICT competencies' were defined so broadly that their incorporation into educational curricula across countries ranged from basic digital literacy to algorithmic skills. The increasing presence of AI in all aspects of human activity clearly conveys a need to operationalise 'ICT competencies' as being more than digital literacy, in which regard CT becomes critical.

Beginning CT-related instruction from early education is a common thread across these countries. The acquisition of CT skills thus becomes a cumulative process with well-defined target competencies for learners as they progress through a ladder of proficiency levels. These proficiency levels need not necessarily have to be associated with specific grade levels such as the case with Estonia, since educators may simply use proficiency levels as a framework to identify learners' individual progress in acquiring CT skills and subsequently provide individual interventions as needed, regardless of a learner's formal grade level.

(2) Strengthening AI capacities through post-basic education and training

The number of countries that have developed a national AI strategy is increasing. France in Europe, China in Asia and lately the United States in North America are examples of the kind of comprehensive strategies that, despite a huge focus on R&D, assign a major role to the development of an AI-capable workforce. In all these three cases, most attention is given to higher education, because of its obvious links with R&D, but also to technical and vocational education. Yet Finland has chosen a different pathway by creating a national platform to rapidly achieve the goal of 1% of the total population being AI-literate.

Higher education

The pressing need to adapt to rapid developments in AI exerts itself on post-compulsory educational institutions as well. Building AI expertise through higher education and research is one of the main approaches used by governments to address their respective skill gaps. In an effort to boost their respective capacities in AI and become leaders in the field, many countries are seeking to make professions in AI research and practice more attractive.

France, for example, published a report that laid out a strategic framework for AI domestically and in Europe. Research and human resource development are key components of this strategy, with France envisioning, among others:

- the creation of research laboratories to study how AI transforms the workplace;
- increased incentives for AI researchers to attract both domestic and international talent; and
- the development of AI programmes at the bachelor's, master's and doctoral levels, as well as in technical and vocational education and training (TVET) (Villani, 2018).

The country also aims to build more academia-industry collaborations and forge more partnerships between universities and other research institutes, in effect creating a university network for AI studies. Towards this end, French President Emmanuel Macron committed €1.5 billion, which will be managed by the *Institut National de Recherche en Informatique et en Automatique* (Campus France, 2018).

South Korea also published a master plan to prepare the country for what it calls the 'Fourth Industrial Revolution'. Education forms an important part of this master plan: The Government of the Republic of Korea aims to produce 5,000 new graduates trained in AI every year, beginning in 2020, thus adding 50,000 new AI specialists to its talent pool by 2030 (Government of the Republic of Korea, 2016). Moreover, the country also intends to provide 10-year support to 'topnotch graduate-schools-turned-research-centres to lead the development of intelligent IT, including AI' through Research Innovation Grants, resource provision and subsidies for hiring scholars and professors internationally. The government has committed around 4.3 million USD to fund this research initiative (Sharma, 2018). Furthermore, the country aims to allocate 2 billion USD towards the establishment of six new AI graduate institutions, the strengthening of academia-industry partnerships and the creation of 4,500 domestic scholarships for AI students (Sharma, 2018).

China has also developed a *Next Generation Artificial Intelligence Plan*, which was launched in 2017. This plan sets out a vision for the country to be the world's centre of AI innovation by 2030 (Government of the People's Republic of China, 2017). Education and training play a huge part in the realisation of this plan, with the government aiming to accelerate the cultivation of top-tier talent in the field of AI (Government of the People's Republic of China, 2017). The government intends to achieve this by developing AI majors in university, increasing enrolment in master's and doctorate programmes in AI, and integrating AI content in the study of other disciplines such as mathematics, biology, psychology, sociology and law, among others (Government of the People's Republic of China, 2017). In line with the objectives of this plan, the country launched an International AI Training Programme for Chinese Universities, which began operating at Peking University in 2018 (China Daily, 2018). Through this programme, China aims to train at least 500 teachers and 5,000 students in AI in the country's top universities over the next five years (China Daily, 2018). The government has also invested in vocational training with the Ministry of Education collaborating with three robotics enterprises to co-establish 10 public vocational training hubs and 90 vocational training centres within Chinese vocational schools by 2020 (He, 2017). Towards this end, the Ministry of Education has allocated 5 million RMB (≈726,427 USD) to each training hub and 3 million RMB (≈435,856 USD) to each training centre, as well as supplementary resources for training teachers and procuring equipment (He, 2017).

Technical and Vocational Education and Training (TVET)

TVET institutions should also be capable of offering programmes that incorporate AI-related competencies, especially if they intend to produce graduates whose skills are attuned to changes in the labour market. In some countries, lifelong learning is understood as referring to basic skills education and adult literacy programmes (Chakroun & Daelman, 2018). However, while lifelong learning certainly includes these aforesaid initiatives, it encompasses a broader spectrum. The International Labour Organisation (ILO) defines lifelong learning as including "all learning activities undertaken throughout life for the development of competencies and qualifications" (ILO, 2004). The ILO argues that "the renewed interest in lifelong learning is partly due to the interest by industry which considers lifelong learning as the appropriate skill formation strategy for the 'new economy" (ILO, 2004).

Germany and **Singapore** have similar individual training account schemes. In the former, eligible individuals, either unemployed or employed workers in specific circumstances, can receive education vouchers from their respective employment agency or job centre to pursue relevant training; these vouchers are redeemed at educational institutions that have been accredited to provide continued training and education (Federal Ministry of Labour and Social Affairs, 2012). Similarly, the latter launched its SkillsFuture initiative in 2016 to provide 500 SGD worth of credits (topped up periodically) to every citizen aged 25 and up to pay for courses at any of the 500 government-sponsored training providers (Skills Future, n/d). Data analytics is one of eight training streams that Singaporeans can follow.

The UNESCO Education Sector is also developing initiatives that harness AI to achieve SDG 4, with a particular focus on TVET. For instance, in partnership with Ericsson, UNESCO's ICT in Education Unit is launching the initiative 'Artificial Intelligence for Youth' that focuses on scaling up AI skill development for young people. This project aims to support and foster the capacities of master trainers to empower youth in developing innovative AI applications. It will also create a repository of curated AI-related training courses, and mobilise AI hub centres and hackathons to cascade training for youth across a broader scale.

The examples herein emphasise the importance of collaborating with industry in bolstering the effectiveness of TVET when it comes to filling in AI competency gaps. Constant coordination with industry is needed to ensure that the instructional content of TVET programmes are aligned with the needs of the labour market. Since AI technologies evolve very quickly, this coordination must be regular and systematic; it should not be surprising that instructional programmes might need to be constantly rethought and revisited, given the rapid pace of development in AI technologies.

However, coordination is not the only way by which TVET institutions can collaborate with industry. Ministries of education and labour can partner with industry players to share the training 'burden' of bridging the AI skills gap. Since industry stands to benefit from a larger AI-capable talent pool, it should also invest in training and upskilling, recognising that bridging the AI skills gap is not the education sector's sole responsibility.

Governments indeed recognise the important role of TVET in bridging the AI skills gap, with some even installing welfare mechanisms to support the upskilling and retooling of individuals holding jobs that are vulnerable to automation such as the cases of Singapore and Germany. However, bridging the AI skills gap should not be confined to reforms in formal education.

Non-formal and informal learning

'Schooling' must be distinguished from 'learning': While schooling happens within structured learning environments contained within a fixed time and place, learning occurs in a continual fashion, regardless of time and place. With the existence of mobile technologies, for instance, it has even become more apparent that learning can occur well outside the bounds of traditional, brick-and-mortar educational institutions (Woolf et al., 2013). **Massively open online courses (MOOCs)** and online learning platforms such as **Khan Academy** are alternative channels by which individuals can access training on AI-related skills, with various universities offering online courses on programming, data science and machine learning, for instance. There have also been grassroots initiatives such as *Code.org* and *EU Code Week*, whose outreach only continues to grow over time (European Commission, 2016).

MOOC platforms are in fact good examples of learning systems that contribute to bringing training on AI-related skills and use AI techniques to make the most of themselves. This is because of their inherent digital character. Coursera, edX, iversity, Future Learn, Udacity, CognitiveClass.ai, etc. are examples of such platforms which, in some cases, say that they are applying NLP (Natural Language Processing) and Machine Learning in combination with Crowdsourcing, for example, to grade short answers, coding exercises, vocabulary and even automatically generate 'wh' (who/what/when/where/why) questions.

The impact of these kind of platforms lies in the virtuous circle that they can generate among four factors: (i) Global Reach, which produces a big amount of usage data as they reach the whole World, (ii) they can combine Synchronous and Asynchronous learning, which means flexibility for students, (iii) they offer an opportunity for "career changers" for lifelong learners, and (iv) they let the owners and teachers research and experiment.

It must be noted, though, that given the relatively recent appearance of these informal learning platforms, data and research on their overall effectiveness still have a long way to go insofar as they must be well measured and contrasted. When it comes to measuring the effectiveness of these platforms, in fact for any learning system at scale, the definition of relevant key performance indicators is of course a very complex task. It is easy to start using simple indicators like participation, persistence, completion, satisfaction and activity. But more sophisticated metrics should arise, ranging from correlations between different measures of activity to non-trivial successful/unsuccessful patterns that can be discovered using the power of AI.

MOOCs may be considered to fall within a wider category of "Large-scale Learning Environments". Apart from the examples of formal MOOC platforms given above, other less formal systems, usually based on communities, have a relevant impact in how many people learn: citizen science communities, YouTube channels by volunteer teachers, collaborative programming communities (Scratch, GitHub), community tutorial and forums systems (StackOverflow), shared critique communities (DeviantArt), informal communities of learners ("Explain It Like I'm Five" sub-Reddit), etc.

It remains important to invest in such non-formal and information learning programmes. The aforementioned case of the national Finnish strategy to make 1% of the total population AI literate provides a good example of how informal and non-formal capacity development initiatives can also be fostered through ICT-based platforms. Given the rapid pace at which AI technologies are evolving, constant and continuous upskilling will always be needed. Moving forward, however, when there is more data available regarding the results of these lifelong learning initiatives, governments can begin to monitor and evaluate and therefore make the necessary adjustments to render those initiatives more effective.

Section III:

AI in education - challenges and policy implications

AI-powered services have already become prevalent in human lives in many places, including the least developed countries. For instance, bots in **Kenya** now give answers to questions about reproductive health in a safe and confidential way, thus dispensing with a visit to the doctor's office. The bots rely on AI technology to process and reply to questions concerning sexual and reproductive health securely and confidentially. Several AI applications have also emerged in the agriculture sector across several African countries. In **Kenya**, Vital Signs collects and integrates data on Agriculture, Ecosystems and Human Well-Being. It uses satellite imagery data to estimate rainfall and drought patterns. In **Nigeria**, Zenvus is a data-driven platform that provides farmers with insights based on data collected from sensors and other means. Their mission is to eliminate poverty in developing countries by improving overall farming productivity.

Financial and public transportation sectors are further examples of where AI-powered technologies are changing people's lives. Tala is Kenya's number one finance application. It provides credit with low fees and easy repayment schedules. Their target customers have no credit history. Through the application, the company can assess excluded customers by analysing Facebook and SMS data to determine the customer's risk of failure to pay. Another example in **Nigeria** is Kudi.ai, a system that lets users improve the use of money transfers by using natural languages and AI to make peer-to-peer payments easier using a chatbot that works on popular messaging apps.

These examples prove that radical innovation is possible under extreme conditions. Some authors have developed a framework to analyse frugal innovations as solutions conceived through needs under difficult conditions (Leadbeater & Wong, 2010). New discussions both in the field of international aid and within national policies are starting to unfold. Is education a field in which technology can help leapfrog inequalities (Winthrop, Barton & McGivney, 2018)? How can developing countries with severe social problems address the complex ecosystem needed to develop AI solutions in education? How can public policies empower teachers so they are key actors in this process and not mere spectators?

Recent systematic reviews show that AI in Education has been a field of research concentrated in developed countries (Roll & Wylie, 2016). As part of an advance technological discussion that builds upon firmly developed infrastructure and knowledge ecosystems, AI in Education is a neglected topic in the developing world. This document intends to bring the discussion to the least developed and developing countries, recognising the multiple limitations these countries face while uncovering the need for structural innovation to leapfrog education as a human right using technological opportunities to advance at a large scale in new learning scenarios.

This final section presents the six main future challenges regarding the incorporation of AI in education as a way to improve the equity and quality of learning and to promote the realisation of SDG 4. It combines the two main topics of this document, namely the new opportunities of AI to improve learning and the way education should prepare students and future workers in an AI-powered world.

First challenge: a comprehensive public policy on AI for sustainable development

The education sector is both customer and actor in the face of sweeping developments in AI-powered technology. In this regard, the education component becomes key when countries develop national AI strategies, as we've seen in the cases of Australia, China, Estonia, France, Singapore, South Korea and, albeit more recently, the United States.

On one hand, AI holds great potential for improving education systems: How can AI help learners, teachers, administrators and policymakers? On the other hand, education systems are expected to form learners who possess the skills needed to thrive in a society surrounded by AI. Currently, most of the AI developments in education come from the private sector. Companies such as Pearson, McGraw-Hill, IBM, Knewton, Cerego, Smart Parrow, Dreambox, LightSide or Coursera are advancing in the introduction of adaptive learning through intelligent algorithms that use Big Data to personalise learning. Most governments are struggling to manage this serge in private sector engagement with AI in education.

Recent studies show that the digital education market will increase 5% annually until 2021 (Docebo, 2016). Experts forecast a 50% growth in the artificial intelligence market between 2017 and 2021 (HTF Market Intelligence, 2018). What is the role of the state in this context? Can it cope with the velocity of technological change driven by private markets?

The best way to approach these initial questions for developing countries is through a comprehensive perspective on the topic. AI works within complex ecosystems of knowledge, innovation, business and new regulations. State policies should be capable of simultaneously addressing multiple questions to generate solutions and regulations, and create or support innovation ecosystems to bring the opportunities of AI to the field of education.

The development of public policies regarding AI in education is still in its infancy, but it is a field that will most likely grow exponentially in the next ten years. It is difficult to find some common components at such an early stage, but some issues are starting to emerge as key factors shown by the study cases:

- Public policies will not be able to cope with the speed of innovation in the field of AI with its traditional institutions. New agencies and institutions within the public sector are key to creating the AI intellectual and material context of sustainable development.
- As part of this strategy, countries are developing labs and incubators with public funds to unfold initiatives in AI that promote public goods.
- The state must create partnerships with the private sector to enlarge the AI ecosystem because the public sector will not be able to innovate at such a complex technological level alone.
- To address ethical issues, it´s essential to consult experts and form teams to create blueprints and roadmaps in the uncertainty of the near future development of AI.
- As part of the ecosystem, it´s essential to create new funding opportunities to develop academic and research facilities for the formation and training of AI specialists.
- The initiatives from these countries are unleashing the potential of AI in education with experiments of adaptive learning platforms, online assessments, automatic essay correction, specially design in context of large-scale technological penetration.
- Some of these countries are also concerned with the ethical consequences of AI in education. Therefore, new regulations are being introduced to secure the use of AI by private companies in terms of data uses, privacy and the transparency of the ways in which algorithms are designed.
- As part of the commitment to develop a complex ecosystem of AI as a common good, some governments are starting to enlarge the public understanding and public debate regarding these issues within the context of a new democratic ideal.

As presented in this paper, many countries have programmed significant budgetary commitments towards the creation of AI research centres and the recruitment and training of AI professionals. Indeed, strengthening AI training and research through higher education is seen as critical for building national expertise in AI. Governments are investing in research and advanced training in AI, which primarily occur at higher education institutions, through the establishment of academic centres of excellence in AI, university and research institute networks and scholarships to attract more talent into the field of AI.

Public-private partnership is another important aspect of strengthening AI training and research. Countries cited in this paper have forged partnerships between industry and academia not only to share material and financial resources but also to ensure that educational programmes are well-aligned with labour market needs. Partnerships should not be limited to industry and academia, though; intra-sector partnerships prove just as important as academia-industry partnerships. Partnerships between universities and research institutes foster collaborative research, which can accelerate the development of expertise in AI.

For these efforts to be effective, however, they must be aligned with a broader national strategy for AI, with a clear vision and clearly defined objectives. This is the case for all three examples described above. The elaboration of such strategies can be seen as anticipatory responses to AI: Rather than passively responding to developments in AI, the cited countries have chosen to build national expertise so they can lead the development and dialogue in this regard. An effective education sector response to AI should not be merely 'palliative'. The education sector is well-placed to shape a country's vision for AI since it is, after all, the cradle of future expertise in the field.

At this point, we promote the creation of an AI Observatory to look at relevant initiatives of AI in education and inform on national and international AI strategy plans (see Conclusions).

To understand the potential of these initiatives and the situation of other countries, attention needs be shifted towards benchmarking parameters. This will allow initiatives to compare themselves and identify where they stand in the journey. This could even allow countries to compare themselves on becoming AI ready. For instance, the Automation Readiness Index: Who is ready for the coming wave of automation? Government AI Readiness (Stirling, Miller & Martinho-Truswell, n/d).

With this comprehensive view in mind, what are the possibilities for introducing AI in education in developing countries? Technology has open new opportunities for countries facing large social challenges. In Africa, access to mobile phones has grown exponentially in the last 15 years, driving economic growth (Aker & Mbiti, 2010). New discussions are emerging in developing countries to use the power of AI to promote social equality (BID, 2018).

Second challenge: Ensuring inclusion and equity in AI in education

While AI can open numerous possibilities as presented in this paper, it can also be a disruptive technology and may deepen the existing inequalities and divides as the marginalised and disadvantaged population are more likely to be excluded from AI-powered education. The result is a new kind of digital divide: a divide in the use of data-based knowledge to inform intelligent decision-making (Hilbert, 2015).

Equity and inclusion should be core values when designing policies for AI in education. Policy makers should thus ask several inclusion and equity questions when developing their policies. For instance, what infrastructure conditions are urgent in developing countries to make AI in education possible? What have we learned from previous experiences to build sustainable and equitable conditions to digital rights in terms of internet access? How can AI serve the education provided to disadvantaged groups and populations? How can digital education and AI grow faster in developing countries to close the educational gap between rich and poor students of the world? What are the good practices on AI for women and girls to close gender gaps?

Recent studies have mapped the obstacles for introducing AI in education in developing countries. The main ones include 1-ICT hardware availability, 2-Electrical availability, 3-Internet reliability, 4-Data costs, 5-Students´basic ICT skills, 6-Language and 7-Lack of culturally appropriate content (Nye, 2015). Further reviews on the introduction of Big Data in developing countries show that the lack of basic infrastructures creates a new digital divide in the use of data-based knowledge for informed intelligent decision-making (Hilbert, 2015). To remove these obstacles, multiple policies must be put in place. It is essential to start by defining the internet as a human right and creating multiple international alliances to build infrastructure in the poorest sectors of the developing world (Mutoni, 2017). The work carried out by the United Nations Broadband Commission is one clear example of this.

Third challenge: Preparing teachers for AI-powered education and preparing AI to understand education

There are no indications of a system-wide adoption of AI-based applications for teaching and learning or system management, even though the educational technology industry has yet to cease production on new developments. Their fundamental flaw is that, rather than addressing the existing problems and issues that teachers face, they promote new ways of organising teaching that collide with mainstream traditional practices, often without rigorous evaluations supporting the claimed benefits of new solutions. Not surprisingly, teachers hear what vendors have to say, but do not necessarily buy into it. Against this context, some countries have already designed policies that support the national EdTech industry’s efforts to promote innovation, intensify efforts and modalities of qualifying and empowering the demand (teachers and schools), while supporting their innovative practices and, finally, exploring how AI can contribute to a richer, more evidence-informed policy and planning environment in education.

The examples presented herein show how learning analytics platforms can use predictive algorithms to help teachers diagnose and anticipate learning difficulties faced by learners and thus implement personalised interventions to respond to those difficulties. However, while predictive algorithms certainly facilitate data analysis and interpretation, these algorithms are not what make learning analytics systems powerful. The effectiveness of learning analytics systems lies in their usefulness and relevance to learners and educators. Real-time data processing should translate into real-time feedback, quicker intervention and individualised instruction. As such, educators continue to play the primary role. Teachers and head teachers should be given sufficient autonomy to manage their respective classrooms and schools, founded on the notion that they are most familiar with the needs of their learners. Automated analyses only serve that autonomy if teachers and head teachers are empowered to manage learning provision in their respective schools. If not, the implementation of any AI-powered tool can only do so much.

Teachers will therefore remain at the frontline of education; it is misinformed to say that AI can replace teachers. Arguments to the contrary reduce the teaching profession to the performance of solely cognitive and routine tasks, ignore the research that stresses the importance of a human mentor to support the learning process and neglect the creative and socio-emotional aspects of teaching, which go beyond mere knowledge transmission (Bali, 2017). Furthermore, teachers will decide how and when it would be appropriate to use AI-enabled tools. As such, the development of these AI-enabled tools and their integration into the delivery of educational programmes must be a participatory process, designed to "deliver the support that educators need – not the support that technologists or designers *think* they need" (Luckin et al., 2016). That said, AI-enabled technologies do provide opportunities to automate certain routine and administrative tasks such as grading and recordkeeping, which teachers are currently performing. Automating such tasks can free up teachers' time, effectively allowing teachers to devote more energy to the creative, empathetic and inspirational aspects of their profession.

Given the eventual widespread use of AI in the classroom, teacher training is therefore a critical aspect of empowering teachers to use educational data to improve pedagogy. To be able to use AI-enabled technologies effectively, teachers would also need assimilate new competencies, specifically (Luckin et al., 2016):

- A clear understanding of how AI-enabled systems can facilitate learning provision, so that they can make sound value judgments on new AI-enabled educational products;
- Research and data analytical skills, so that they can interpret data provided by AI-enabled systems, ask useful questions about the data and provide students with feedback based on insights that arise from the data; and
- New management skills, so that they can effectively manage both human and AI resources at their disposal.
- A critical perspective on the ways Ai and digital technologies affect human lives and new frameworks of computational thinking and digital skills can increment students´ capacities to understand the power, the dangers and the possibilities of AI.
- Enable teachers to take advantage of AI taking over repetitive tasks to bring in more human capabilities they may not have had time for before: mentorship, emotional support, interpersonal skills, etc.
- Help learners acquire those skills and competencies that are likely not to be replaced by machines.

Teacher training programmes should therefore account for these new competencies, both at the in-service and pre-service level.

Not only teachers have to prepare to understand and grasp the new technological possibilities digital and AI-powered education are developing. The history of innovations in education is full of lost promises that fail to understand how teachers work and the culture of schools. To create new educational possibilities, AI developers have to participate in a new dialogues with educators, content designers and cross-disciplinary specialists.

At present, two distinct communities have evolved, namely learning analytics (LA) and Educational Data Mining (EDM). These two communities significantly overlap in terms of objectives and techniques, but they differ in that EDM researchers, originating from the community of intelligent tutoring systems, work on very small-scale cognition. EDM methods are drawn from a variety of disciplines, including data mining, machine learning, psychometrics of statistics, information visualisation and computational modelling. The field of learning analytics is more focused on learning content management systems and large-scale test results. To do so, they combine institutional data, statistical analysis and predictive modelling to identify which learners need help and how instructors can change academic behaviour.

Future developments in AI-powered software in education must build strong bridges between cognition, classrooms and large-scale test scores. The challenge is to create new pedagogical dialogues at micro and macro levels of understanding education. For instance, we should analyse systems thinking, critical thinking, self-regulation and active listening. Data analysis should move across individual tutoring systems and evaluate students' skills for the 21st Century (Woolf et al. 2013).

Fourth challenge: Developing quality and inclusive data systems

Given that data fuel AI, complete, reliable and timely data constitute an important prerequisite for installing AI-enhanced data analytics systems. A fully functional data analytics system with comprehensive and up-to-date data opens possibilities for AI-enabled predictive and machine learning algorithms. Data enable intelligent systems. Without the needed data, no sort of algorithm, no matter how sophisticated, can function properly. As such, a data-rich environment is a prerequisite to AI-enabled systems. However, data availability is a necessary yet insufficient condition. It follows that any AI-enabled system is only as good as the data it contains. After all, inaccurate data are likely to make machine learning algorithms generate incorrect outputs. Indeed, predictive algorithms can only make complete and accurate predictions if the data they are handling are itself complete and accurate.

However, many countries still struggle with collecting basic yet critical educational data. The UNESCO Institute for Statistics (UIS) cites the many hindrances to the efficient and effective collection and use of educational data (UIS, 2018b). Educational data should be open and usable at the school level. An EMIS should be able to generate analyses that are granular enough to help teachers and education administrators understand the key challenges while also being able to aggregate data to reveal trends that can inform policy development.

Furthermore, data must also account for inequities, providing insights, for example, on learning outcomes disaggregated according to demographic factors such as age, gender and socio-economic background (UNESCO, 2018). The ability to generate such analyses allows education systems to determine the educational disadvantage experienced by specific marginalised or vulnerable populations. However, data on disadvantaged groups still currently tend to be incomplete and even absent. For instance, a 2016 study by UNICEF showed that, out of 40 countries surveyed, 19 had no data at all on children with disabilities; for many countries that did have data, it was only specified that the child was on a special-needs programme but failed to indicate the disability (UNICEF, 2016). Data on refugees and internally displaced populations (IDPs) also remain limited, with most of those data coming from camps and camp-like settings (UNESCO & UNHCR, 2016). Refugees studying in national schools are also frequently not identified as refugees in national education statistics, thus making it more difficult to monitor and evaluate their learning outcomes. Furthermore, since the collection and analysis of education data usually happens on a once-a-year basis, the data are often unable to convey accurate information on transient populations.

It is also important to note that the education system itself is not the only source of data relevant to learning provision. Household data, as specifically mentioned by the UIS, can also provide insights on exogenous factors that might account for learning difficulties at school. The same can be said of data coming from other ministries, e.g. the ministry of health. Data on nutrition can be used to report on, for instance, the design of school meal programmes. This speaks to the importance of data integration: When government systems are integrated, more data become shared and available across all sectors. This data sharing means that more data can be used by the education sector to run AI algorithms and consequently, more possibilities to generate analyses, models or predictions.

The understanding that data are capable of yielding direct value and are useful across all levels of the education system is critical to ensuring data quality. In fact, the extent of data use at least partly determines data quality (Orr, 1998). After all, the more useful data is to a stakeholder, the more incentive there is for that stakeholder to ensure that the data is produced in an accurate and timely manner. Open data can also be an impetus for data use. The ability to access data and metadata does not only allow intermediaries (e.g. NGOs) and community stakeholders to draw direct value and mine insights from education data, but this transparency also creates a greater sense of accountability on the part of ministries of education for the improvement of educational outcomes (UNESCO, 2018). Open data are anchored on the discourse of data 'prosumption', i.e., stakeholders do not only consume data but are also involved in data production and interpretation (Williamson, 2015). Stakeholders must have access to data analytics if they are to be involved in the improvement of the education system.

AI-powered technologies provide opportunities to make educational data more useful at each level of the education system. Learning analytics, for instance, as demonstrated in the examples provided in this paper, provide educators with real-time insights about students' individual progress and learning patterns, thus allowing the former to make real-time adjustments to their instructional approach. Furthermore, the real-time generation of data could also mean that student-level data are constantly updated, i.e., if the learning analytics systems used at the school level directly feed into a system-level EMIS. This real-time data capture also provides opportunities to expand data sets on refugees and IDPs, given how traditional annual data collection schedules have produced insufficient data on such populations. Automated analytics also make it easier to disaggregate data according to various demographic factors, thus also making it relatively easier to identify sources of educational inequality. Of course, having an adequate amount of data is a prerequisite to producing such analyses. As such, countries with weak or incomplete data systems should focus on strengthening their data systems and bridging their data gaps.

It must be acknowledged, however, that while technologies for capturing data are indeed becoming more and more powerful, their costs could be prohibitively high, particularly for low- and middle-income countries. As such, the costs of such data systems need to be carefully examined and weighed against the potential benefits. While numerous governments are able to produce large amounts of education data to inform decision-making, many countries are still unable to do so (Custer et al., 2018). Many efforts to remedy this problem have fallen short since they focused on the procurement of more sophisticated data reporting technologies, even when the issue lay in weak institutional processes that would result in faulty, incomplete and unused data. This harks back to strong institutional and organisational processes being a prerequisite to the installation of any data-dependent system, including AI technology. As such, institutional capacity-building becomes a crucial investment, particularly for countries whose data processes remain ad hoc and thus unable to produce consistent, relevant and timely data.

Fifth challenge: making research on AI in education significant

While we can reasonably expect increased research on AI in education in the coming years, it is also worth recalling the difficulties that the education sector has in taking stock of educational research in a significant way for practice and policy-making. The particular domain of research on educational technology clearly demonstrates that what researchers state as key research questions are quite often unrelated to teachers' needs.

Technology's potential to transform education has often been stated, though it is widely accepted that, for various reasons, this potential has yet to be harnessed as expected in developed countries (Conlon & Simpson, 2003; Cuban, 2001; OECD, 2015; Sandholtz, 2001) or developing countries (Power, Gater, Grant, & Winters, 2014). When reviewing how decisions about technology use in education are made, it is striking how little is known about the effects of using technology on the quality of school education, and, more specifically, which particular uses of technology can result in better learning. Current developments regarding AI in education seem to be yet another instance of this well-known phenomenon. This is a far from optimal state of affairs in poorer, resource-constrained developing contexts, where technology-based reforms are being pushed as the remedy for poor economic and social conditions. As the emphasis of many national initiatives in this context is usually put on granting access to technology as an intrinsic added-value, not much research has been conducted on the actual effects on learning.

There is a great need to sustain AI applications in education in ways that contribute to making schools better suited to the needs and activities of an AI-empowered society. To do so effectively is not just a matter of financing, but also of monitoring and assessing what works in education, disseminating it in ways that are meaningful for teachers and suitable for scaling up. The pending issue of how AI use relates to educational performance can be explored through correlations and will be done even more in the future, but accompanying empirical research and experiments will have to be carried out so as to build a useful knowledge base. Rather than claiming that more research must be done, the conclusion is that research must be oriented differently.

It is well known that the adoption of an innovation essentially depends on end users perceptions of the advantages of applying a new strategy in relation to what they are currently using (Rogers, 2003). Applying this principle to the concrete example of technology in education, it might be expected that AI can support the design of new strategies to achieve the following:

- learn better, e.g. in a more personalised manner
- learn more, i.e. achieve better outcomes from learning
- learn different things, i.e. achieve learning goals that only technology can enable

Research should ascertain the strategies that will make this possible, the conditions in which they would be feasible and, ultimately, capable of being applied widely. The feasibility issue is extremely important for school learning because there may be many strategies that could prove to be incompatible with the current configuration of schools and even the teaching profession.

Education research, relating to technology and also in general, is complicated by the very nature of its subject matter and because contextual conditions limit its capacity to provide results from which generalisations can be drawn, thereby affecting its ability to contribute to the creation of universally valid theories.

In education, there is an omnipresent problem of these so-called "ubiquitous interactions", i.e. the sheer number of variables that increase the difficulty of isolating impacts or combining the results of different studies (Lederman, 2003). As it is very difficult to isolate the influence of instructional strategies, any example relating to strategies to improve learning would serve student skills and abilities, socioeconomic status, motivation and the interaction between all these variables.

Finally, there is also a need for a localised and decentralised examination of what is taking place in classrooms, particularly in the context of developing countries. Despite that the international agenda for education seems to suggest that AI may bring only benefits, there is an understanding of "local needs in local contexts" in order to find more broad strategies that could be supported by AI, replicated and also capable of being scaled up. There is no such thing as a universal technology-based solution for the current educational challenges of small developing states, which will not be the case with AI either. Well-oriented, local research can help recognise teachers as actors and not mere beneficiaries or users of well-packed technology solutions. No doubt, research has a role to play in investigating further into the role that technology solutions play in improving the quality of education, including developing countries. However, the right research questions must be asked. Given that educational phenomena are quite complex and multi-faceted, the right questions are not about whether or not to use AI in education at all, but about which AI solutions can best suit the evolving learning requirements that each individual teacher has to manage in the classroom considering the reality of teaching conditions and opportunities. AI may shine and speak by itself, but unless it is properly embedded into sound teacher practices no educational effects will ever be seen.

Sixth challenge: ethics and transparency in data collection, use and dissemination

The ethical quandaries that come with the large-scale collection, production, analysis and dissemination of data about persons are another important consideration in the development of any concerted policy framework for AI. It must be noted, though, that seeking to understand the ethical implications of new technologies is by no means a new pursuit. Over the past 30 years, scholars and practitioners have sought to define some form of computer or information ethics that can be summarised as a question "What does the ethical use of technology look like?" (Floridi & Taddeo, 2016). However, the emergence of data science as the "latest phase of the information revolution" has shifted the discourse from *information* ethics to *data* ethics. Experts have forwarded the notion that "it is not the hardware that causes ethical problems… [I]t is what the hardware does with the software and the data that represents the source of our new difficulties" (Floridi & Taddeo, 2016).

While AI has many positive applications, there are also societal and ethical concerns that should be addressed. Most people have at least read something about AI systems discriminating unfairly (ProPublica, 2016; Mic, 2016; Reuters, 2018), taking life-impacting decisions in a non-transparent way (Cathy O'Neil, 2016), ready to take all our jobs (McKinsey Global Institute, 2017) and set to wrest control from humans (The Register, 2018). While there is no need to panic, all those concerns should nevertheless be considered when AI becomes massively applied in our societies and especially because the technology is improving quickly insofar as what is impossible today could be possible tomorrow. There is much work going on today that tries to come up with answers to such concerns (The European Commission, 2018; Dillon, 2018; Future of Humanity, 2018; Nuffield 2018).

How are those AI concerns impacting education and especially digital education?

The following is an explanation on how these concerns may arise from an educational perspective.

- Access to educational systems. Increasingly more educational institutions are using Machine Learning algorithms to accept or reject students. Two potential problems with this approach include:
  - Lack of explainability. Some ML techniques (e.g. Deep Learning) cannot easily explain why certain students are accepted while others are rejected. Should a rejected student have the right to understand those reasons?
  - Unfair discrimination. When Machine Learning algorithms are trained on a certain data set (let's say with students from a Western European country), then the result might not be directly applicable to students from other parts of the world. The training data set might be biased towards a certain group and therefore might discriminate unfairly when used on a different group.
- Recommendations to individual students. Like the previous point, if recommendations are "machine-learned" based on a large set of previous data, the resulting recommendation might not be adequate for students from a different target group. Of course, if the recommendations are based on the individual learning history of the student, then this problem does not exist.
- Personal data concentration. In the case that -like in the digital world- educational platforms will be owned by a few major players in the world, two concerns arise
  - The concentration of personal (student and teacher) information, which might create a privacy risk. Large concentrations of personal data are an attractive target for cyber criminals.
  - Dominating platforms could forge data monopolies cornering the market on the ability to develop the best algorithms. This would give them a great degree of power and also increase the "explainability" concern when those "best" algorithms take the majority of educational decisions for student learning paths.
- Liability. What happens if the automated decisions that guide students in their learning process turn out to be wrong? Who or what is responsible and accountable? The platform owner? The assigned teacher? The algorithm?
- Impact on work. If AI systems automate increasingly more tasks that are normally performed by teachers, what happens to their jobs? AI systems can assess the student's initial level, guide the student through the course based on collective intelligence combined with individual experience, automatically evaluate test results and even automate the student-teacher interaction using chatbots and NLP techniques.

While those concerns need to be dealt with, we should not forget that without using AI for education, the outcome might be much worse. For one thing, AI can automate many mechanical, repetitive and boring tasks and this gives human teachers more time for more complex cases, leveraging the human interaction and make sure that more students become successful. Another positive aspect is that AI in Education can help scale up upskilling the workforce to become AI-ready. The workers whose jobs will be mostly affected by AI automation have an opportunity to get trained in skills needed to work alongside AI systems.

Data privacy and security almost immediately come up in discussions regarding data ethics. The main challenge lies in being able to use personal data while ensuring that personally identifiable information and individual privacy preferences are protected. Installing necessary safeguards to prevent data theft is also critical. In education, this becomes even more challenging in the context of young learners, who, in legal terms, cannot yet provide express consent regarding the collection and use of their personal data.

Despite these important concerns, however, less than 30% of countries across all regions, excluding Europe, have comprehensive data protection laws in place (UNCTAD, 2016). This is at least partly due to a lack of understanding of legal issues in data privacy among policymakers and law enforcement entities (UNCTAD, 2016). While the increase in global, regional and national frameworks concerning the protection of personal data certainly marks a growing understanding of how urgent the issue is, many of these frameworks still do not offer adequate protection to citizens, both in policy and practice – particularly in developing countries (World Wide Web Foundation, 2017).

A 2016 study by the United Nations Conference on Trade and Development (UNCTAD) reveals growing public distrust in systems that use and collect personal data. People are often uncertain about how their data will be used after giving their consent (UNCTAD, 2016). Governments should be particularly concerned about this growing distrust, especially given the generally increasing amount of data being collected by the public sector with the rise, for instance, of digital identification systems (World Wide Web Foundation, 2017). While it may be true that these digitisation efforts contribute to improved service delivery, concerns about potential data breaches and expanded government surveillance are nonetheless abound – and reasonably so. Given these concerns, legal frameworks therefore need to not only ensure that personal data are strongly protected against cyber-attacks; they must also reassure citizens that their data will not be used for unwarranted surveillance (World Wide Web Foundation, 2017).

Governments must clearly communicate the scope and purpose of any data collection exercise: what sort of data will be collected, for what end the data will be used, and what consequences, intended or unintended, might occur within the data model. This not only increases citizen willingness to participate in the exercise, but it also allows citizens to weigh its benefits against its potential risks, thus allowing them to make more informed decisions about consenting to the use of their data. This is yet again grounded on the notion of data 'prosumption'. As sources of data, citizens must know why their data are being collected and be able to provide their consent in an informed manner. Furthermore, data collection should be anchored on the minimisation principle, i.e. to use the minimum amount of data required to achieve public benefit (World Wide Web Foundation, 2017).

The ethical issues discussed above convey a clear need for policy frameworks for the use of AI in education to incorporate an ethical orientation. The collection and use of individual data, even when used for improving learning, should always be anchored on express and informed consent, transparency, equity and fairness.

Conclusions

To date, non-State actors, particularly the private sector, have principally led the response to AI in most countries. Tech giants, concentrated largely in the United States and China, for instance, are dominating the development of AI-enabled technologies. The rise of tech startups has also played a significant role in accelerating AI penetration. The rapid expansion of the EdTech industry is particularly notable, with AI-enabled learning technologies seeing increasing use in the classroom.

Nonetheless, given the increasing ubiquity of AI in all aspects of human activity, more and more governments are beginning to actively implement concrete responses to AI. Some countries such as France, Australia, Estonia, South Korea, China and the United States have even released national AI strategies. In all such responses, education is an comprehensive element. However, in developing countries, these discussions are far off and limited by structural obstacles (basic technological infrastructure, high profile trained human resources in the field of AI, etc.). What are the possible paths to unfurling comprehensive strategies in developing countries to integrate AI in education? What is the international community's role in helping bridge the digital gap between countries that is increasing their social divide?

This paper discussed these questions using examples and reflections on two main axes through which the education sector can leverage and adapt to AI: (1) using AI to generate real-time insights towards improving educational outcomes; and (2) rethinking and redeveloping educational programmes to make them more responsive to changes brought about by AI.

Some countries are taking advantage of the abundance of educational data that came with the advent of the Information Age. These countries and their respective educational institutions have begun harvesting insights from large masses of data to provide more personalised learning experiences. Of course, the elephant in the room begs noticing, i.e. the ethical implications of collecting and mining data from learners. As such, any concerted policy framework regarding the use of AI in education needs to address this issue; education systems must clearly delimit how learner data are used and be expressly based on learners' consent to their data being used.

Education systems have also been actively reforming themselves to ensure that learners are acquiring the skills required by an AI-enabled future workplace. These reforms are happening across all educational sub-sectors, from the early years to continuing education. This lifelong learning orientation is of course appropriate in light of how fast AI technologies evolve. As such, this process of rethinking and redeveloping educational programmes in response to AI might need to become a regular and continuous process.

Since these reforms are taking place in light of an AI skills gap, there also needs to be more dialogue and collaboration between industry and the education sector. Bridging this skills gap is not the sole responsibility of the education sector; if educational institutions are to produce a workforce that satisfies the needs of industry, it would be in the best interests of industry to be more involved in the development and delivery of learning programmes.

UNESCO, given its leadership role in the SDG 4-Education 2030 Agenda, has the mandate to coordinate with national governments and mobilise non-State actors, including NGOs and private enterprises. Furthermore, UNESCO's extensive network of businesses, policymakers and practitioners working within the education sector, allows the Organisation to broker partnerships between learning solution providers. Moreover, the Organisation's normative function allows it to define fundamental criteria and standards for the selection of appropriate AI technologies, in light of SDG 4 objectives. Moreover, UNESCO's mandate makes the Organisation competent to provide technical assistance to countries seeking to move towards AI-enabled education systems.

Inevitably, AI is a field that spurs innovation and, by doing so, increases countries' competitiveness. Countries will continue competing in such a rich and rapidly evolving arena. Yet, at least when it comes to education, there is also room for cooperation, whose basis is knowledge sharing. To promote the discussion and the relevance of adopting comprehensive perspectives of AI in education there is a need of more information about how countries are moving forward in this uncertain and constantly changing territory. The creation of an **Observatory of AI in education** to look at relevant initiatives of AI in education and to inform on national and international AI strategy plans may be seen as a platform for knowledge sharing and peer learning. This observatory (with strong emphasis on developing countries) will help increase the evidence-based dialogue among decision makers.

Indeed, there have been multiple responses to the changes accompanying the rise of AI in various areas of human activity as shown by the examples provided in this paper. However, these responses remain independent of a holistic and concerted policy framework for AI in education. Nonetheless, it is important to note that the initiatives presented are worthwhile starting measures that can guide the creation of a coherent policy framework. It is of course critical to engage different sectors in the development of such a framework, since the impact of AI sweeps across sectors.

ANNEX

AI definition and related concepts

A reference book on the AI domain: Russell, Stuart J. & Peter Norvig called **Artificial Intelligence: A Modern Approach** (2010). Refer to the figure below for definitions based on different dimensions.

The definitions in the top quadrants address thought processes and reasoning while the ones in the bottom quadrants address behaviour. The definitions on the left measure success in terms of fidelity to human performance while the ones on the right measure success against an ideal performance measure, referred to as rationality. A system is rational if it does the "right thing", given what it knows. A human-centred approach must be, at least partly, an empirical science, involving observations and hypotheses about human behaviour. A rationalist approach involves a combination of mathematics and engineering.

The full references in the image are:

- Haugeland, John. **Artificial intelligence: The very idea**. MIT press, 1989.
- Bellman, Richard. **An introduction to artificial intelligence: Can computers think?** Thomson Course Technology, 1978.
- Charniak, Eugene. **Introduction to artificial intelligence**. Pearson Education India, 1985.
- Winston Patrick. Henry. **Artificial Intelligence (Third edition)**. Addison-Wesley Publishing Company, 1992.
- Kurzweil, Ray, et al. **The age of intelligent machines**. Vol. 579. Cambridge, MA: MIT press, 1990.
- Rich, Elaine, and Kevin Knight. **Artificial intelligence**. Tata McGraw-Hill, 1991.
- Poole, David Lynton, Alan K. Mackworth, and Randy Goebel. **Computational intelligence: a logical approach**. Vol. 1. New York: Oxford University Press, 1998.
- Nilsson, Nils J., and Nils Johan Nilsson. **Artificial intelligence: a new synthesis**. Morgan Kaufmann, 1998.

Different proposed definitions for:

Machine Learning

i) The field of Machine Learning seeks to answer the question "How can we build computer systems that automatically improve with experience, and what are the fundamental laws that govern all learning processes?

- Mitchell, Tom Michael. The discipline of machine learning. Vol. 9. Pittsburgh, PA: Carnegie Mellon University, School of Computer Science, Machine Learning Department, 2006.

ii) Machine learning algorithms can figure out how to perform important tasks by generalising from examples.

Thinking Humanly

'The exciting new effort to make computers think… machines with minds, in the full and literal sense.' (Haugeland, 1985)

'[The automation of] activities that we associate with human thinking, activities such as decision-making, problem-solving, learning…' (Bellman, 1978)

Thinking Rationally

'The study of mental faculties through the use of computational models.' (Charniak & McDermott, 1985)

'The study of the computations that make it possible to perceive, reason, and act.' (Winston, 1992)

Acting Humanly

'The art of creating machines that perform functions that require intelligence when performed by people.' (Kurzweil, 1990)

'The study of how to make computers do things at which, at the moment, people are better.' (Rich & Knight, 1991)

Acting Rationally

'Computational Intelligence is the study of the design of intelligent agents.' (Poole, et al., 1998)

'AI… is concerned with intelligent behavior in artifacts.' (Nilsson, 1998)

– Domingos, Pedro. A few useful things to know about machine learning. Communications of the ACM 55.10 (2012): 78-87.

iii) Machine Learning is the science (and art) of programming computers so they can learn from data.

– Géron, Aurélien. **Hands-on machine learning with Scikit-Learn and TensorFlow: concepts, tools, and techniques to build intelligent systems**. O'Reilly Media, Inc., 2017.

iv) Machine learning tools are concerned with endowing programs with the ability to "learn" and adapt.

– Shalev-Shwartz, Shai, and Shai Ben-David. **Understanding machine learning: From theory to algorithms**. Cambridge university press, 2014.

Deep Learning

i) Deep learning is a specific subfield of machine learning: a new take on learning representations from data that puts an emphasis on learning successive layers of increasingly meaningful representations. The "deep" in deep learning isn't a reference to any kind of deeper understanding achieved by the approach; rather, it stands for this idea of successive layers of representations. The depth of the model is the amount of layers contributing to a data model. Perhaps more suitable names for the field could have been layered representations learning and hierarchical representations learning. Modern deep learning often involves tens or even hundreds of successive layers of representations, which are all learned automatically from exposure to training data. Meanwhile, other approaches to machine learning tend to focus on learning only one or two layers of representations of the data and sometimes referred to as shallow learning.

In deep learning, these layered representations are (nearly always) learned via models called neural networks, structured in literal layers stacked on top of each other.

– Chollet, Francois. **Deep learning with python**. Manning Publications Co., 2017.

ii) The true challenge to artificial intelligence proved to be solving tasks that are easy for people to perform but hard for people to describe formally, e.g. problems that we solve intuitively and feel automatic like recognising spoken words or faces in images.

Deep learning allows computers to learn from experience and understand the world in terms of a hierarchy of concepts, with each concept defined in terms of its relation to simpler concepts. By gathering knowledge from experience, this approach avoids the need for human operators to formally specify all the knowledge that a computer needs. The hierarchy of concepts allows computers to learn complicated concepts by building them out of simpler ones. A graph showing how these concepts are built on top of each other would be deep (with many layers). For this reason, this approach to AI is referred to as sdeep learning.

– Goodfellow, Ian, et al. **Deep learning**. Vol. 1. Cambridge: MIT press, 2016.

Big Data

i) Big data is a combination of data-management technologies that have evolved over time. Big data lets organisations store, manage and process vast amounts of data at the right speed and at the right time to gain the right insights. The key to understanding big data is that data should be managed so that they can meet the business requirement that a given solution is designed to support.

– Hurwitz, Judith S., et al. **Big data for dummies**. John Wiley & Sons, 2013.

ii) Big data is a blanket term for any collection of data sets so large or complex that it becomes difficult to process them using traditional data management techniques such as, for example, the RDBMS (relational database management systems).

The characteristics of big data are often referred to as the three Vs:

- Volume — How much data are there?
- Variety — How diverse are different types of data?
- Velocity — At what speed are new data generated?

Often these characteristics are complemented with a fourth V, Veracity: How accurate are the data? These four properties make big data different from the data found in traditional data management tools.

– Cielen, Davy, Arno Meysman, and Mohamed Ali. **Introducing data science: big data, machine learning, and more, using Python tools**. Manning Publications Co., 2016.

Data Mining

i) Data mining is the process of discovering interesting patterns and knowledge from large amounts of data. The data sources can include databases, data warehouses, the Web, other information repositories or data dynamically streamed into the system.

– Han, Jiawei, Jian Pei, and Micheline Kamber. **Data mining: concepts and techniques**. Elsevier, 2011.

ii) Data mining is the process of discovering insightful, interesting and novel patterns, and descriptive, understandable and predictive models from large-scale data

– Zaki, Mohammed J., Wagner Meira Jr, and Wagner Meira. **Data mining and analysis: fundamental concepts and algorithms**. Cambridge University Press, 2014.

iii) Data mining is the analysis of (often large) observational data sets to find unsuspected relationships and summarise the data in novel ways that are both understandable and useful to the data owner

– Hand, David J., Heikki Mannila, and Padhraic Smyth. **Principles of Data Mining**. MIT press, 2001.

Data Analytics

i) Big Data Analytics is a way of extracting value from these huge volumes of information, and it drives new market opportunities and maximises customer retention.

– Zakir, Jasmine, Tom Seymour, and Kristi Berg. **Big Data Analytics**. Issues in Information Systems 16.2 (2015).

ii) Data analytics is the science of drawing insights from raw information sources. https://www.investopedia.com/terms/d/data-analytics.asp

iii) Data analytics is the pursuit of extracting meaning from raw data using specialised computer systems. These systems transform, organise and model the data to draw conclusions and identify patterns. https://www.informatica.com/ca/services-and-training/glossary-of-terms/data-analytics-definition.html#fbid=ETHvIPIs4QM

iv) Data Analytics (DA) is the method of examining and analysing raw data so that conclusions can be drawn. Data analytics is a valuable part of science-centred industries in verifying or disproving current theories or models. The purpose of DA is to sort through data to arrive at a conclusion. https://study.com/academy/lesson/what-is-data-analytics-definition-tools.html

Learning Analytics

In this context, learning Analytics (LA) is an emerging discipline that pursues improvement in teaching and learning by a critical evaluation of raw data and the generation of patterns that characterise learner habits, predict learner responses and provide timely feedback. Moreover, LA supports decision-making, tailors readable content, simplifies realistic assessments and provides personal supervision of learners' progress. The goal is to scale the real-time exploitation of LA by learners, teachers/academics and educational computer-based systems to enhance learners' accomplishments at course and individual levels.

– Peña-Ayala, Alejandro, **Learning Analytics: Fundaments, Applications, and Trends: A View of the Current State of the Art to Enhance e-Learning**. Vol. 94. Springer, 2017.

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Artificial Intelligence in Education: Challenges and Opportunities for Sustainable Development

Artificial Intelligence is a booming technological domain capable of altering every aspect of our social interactions. In education, AI has begun producing new teaching and learning solutions that are now undergoing testing in different contexts. This working paper, written for education policymakers, anticipates the extent to which AI affects the education sector to allow for informed and appropriate policy responses. This paper gathers examples of the introduction of AI in education worldwide, particularly in developing countries, discussions in the context of the 2019 Mobile Learning Week and beyond, as part of the multiple ways to accomplish Sustainable Development Goal 4, which strives for equitable, quality education for all.

First, this paper analyses how AI can be used to improve learning outcomes, presenting examples of how AI technology can help education systems use data to improve educational equity and quality in the developing world. Next, the paper explores the different means by which governments and educational institutions are rethinking and reworking educational programmes to prepare learners for the increasing presence of AI in all aspects of human activity. The paper then addresses the challenges and policy implications that should be part of the global and local conversations regarding the possibilities and risks of introducing AI in education and preparing students for an AI-powered context.

Finally, this paper reflects on future directions for AI in education, ending with an open invitation to create new discussions around the uses, possibilities and risks of AI in education for sustainable development.

4 QUALITY EDUCATION

Sustainable Development Goals