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**Sustainable
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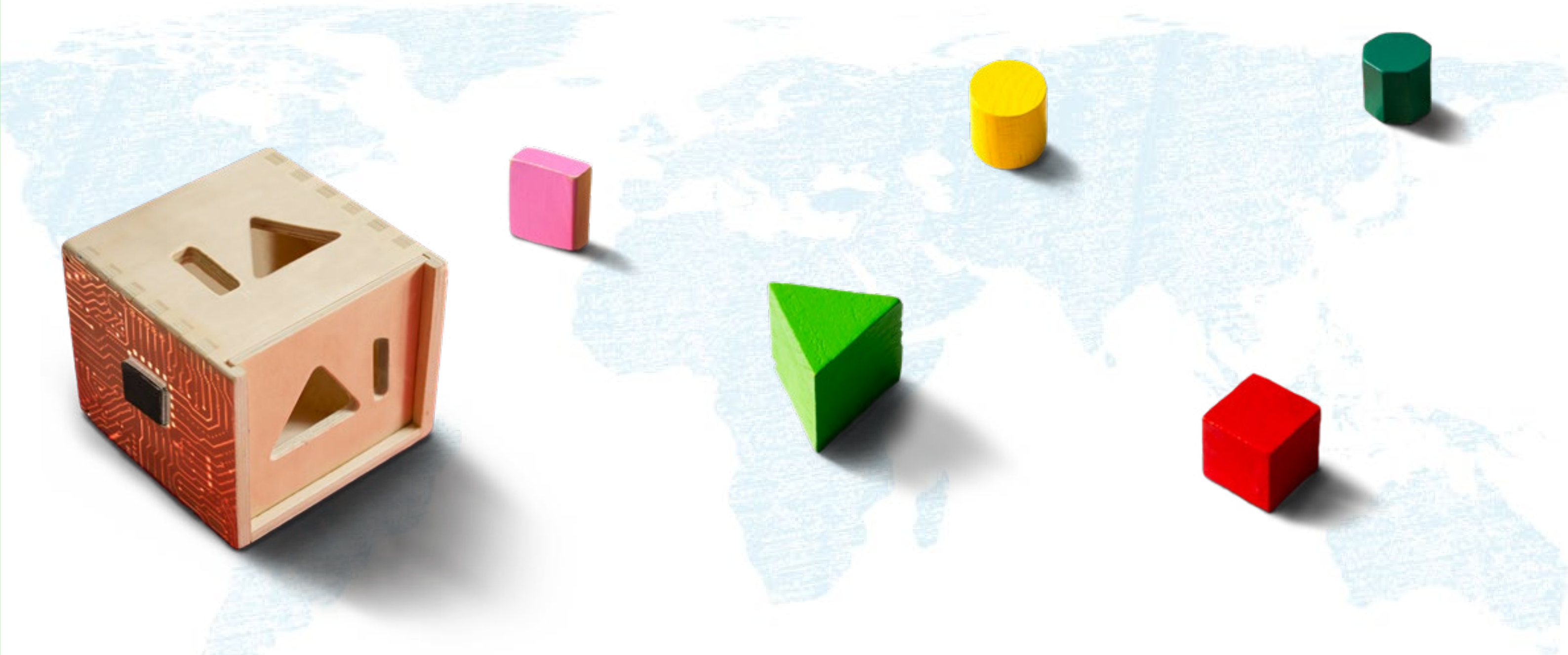
Principles for
ARTIFICIAL INTELLIGENCE
Towards a Humanistic Approach ?



ARTIFICIAL INTELLIGENCE FOR SUSTAINABLE DEVELOPMENT:

challenges and opportunities for UNESCO's science and engineering programmes

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Working paper

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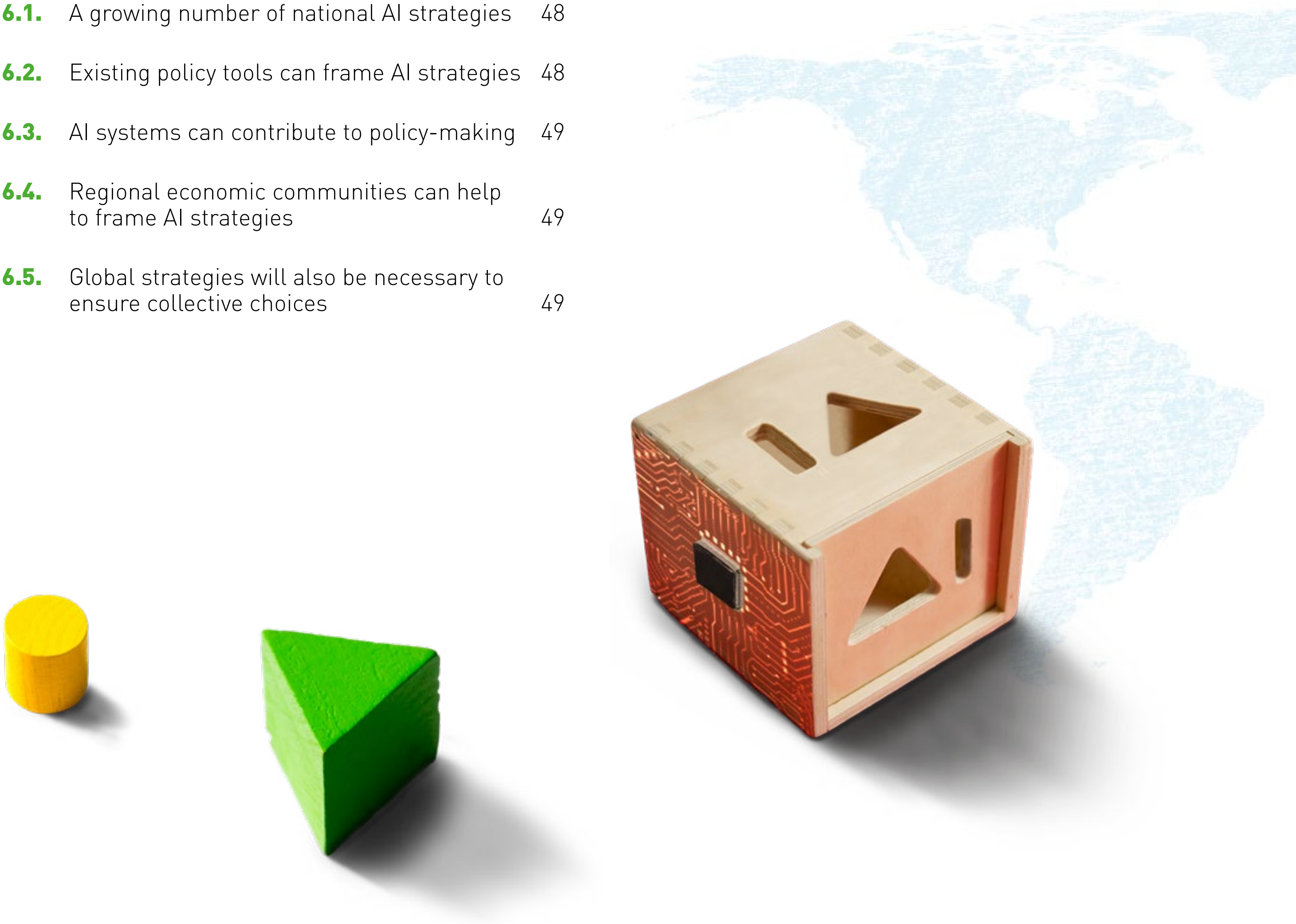
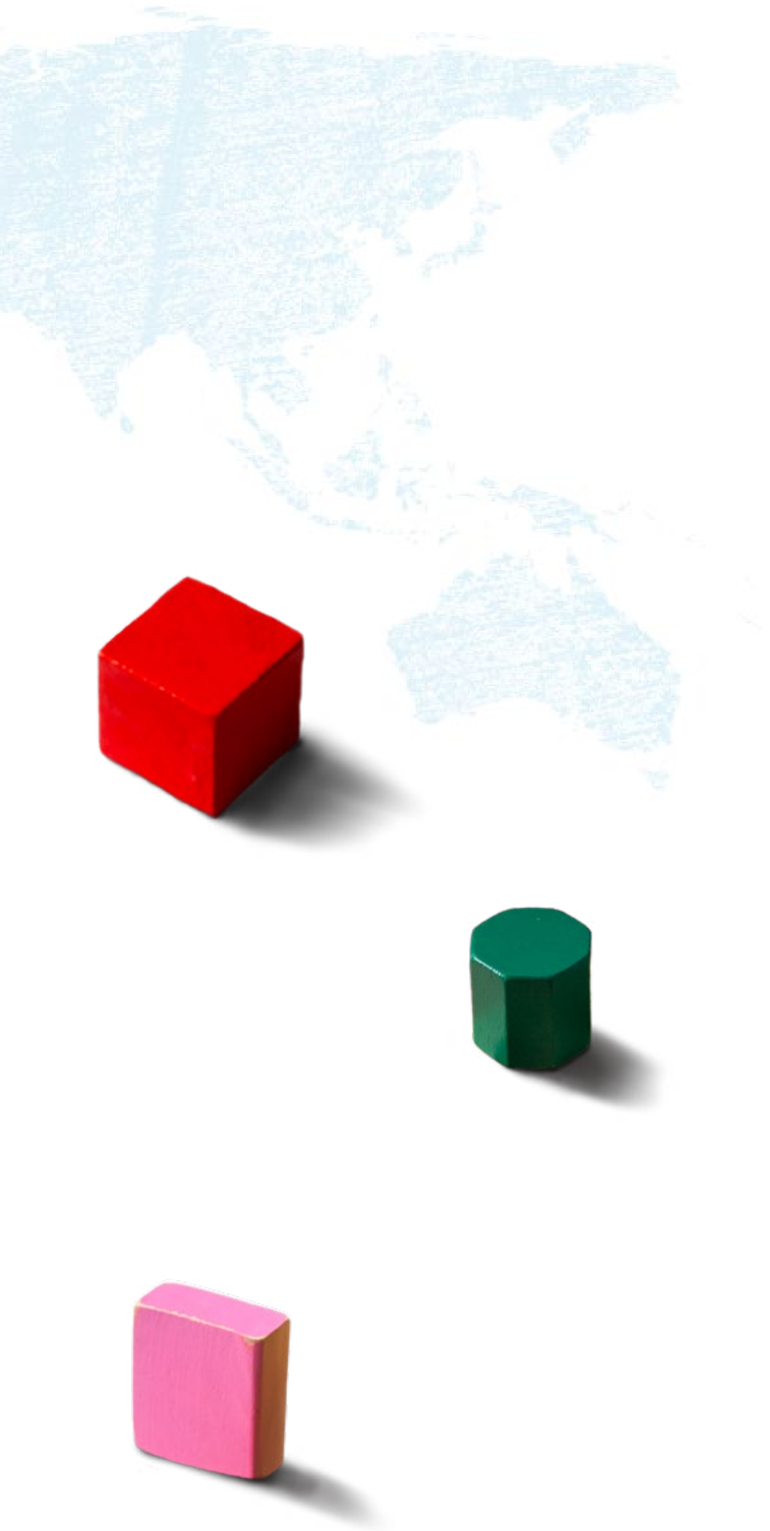




1. Introduction

We are living through what has been termed the Fourth Industrial Revolution, a fast-paced socio-economic transformation driven by rapid technological progress that is disrupting entire industries and governance systems. Also termed Industry 4.0, it follows on the First Industrial Revolution in the 18th century (mechanization), driven by the invention of the steam engine; the Second Industrial Revolution (mass production) in the 19th century, driven by the invention of electricity; and the Third Industrial Revolution (automation) in the 20th century, driven by the invention of electronics and information technology.

Since the second half of the 20th century, biotechnology, nanotechnology, cognitive science and information technology have converged, blurring the frontier between the physical, the digital and the biological as they spawned new research fields such as nanobiotechnology informatics. The advent of the World Wide Web in 1993 heralded the dawn of the digital economy, which has revolutionized commercial transactions and business models in fields ranging from media and entertainment to retail and healthcare.

Digital technologies include big data and analytics, robots and other cyberphysical systems, the Internet of Things, Blockchain technology and artificial intelligence. The term 'artificial intelligence' was actually coined back in 1956, at a workshop at Dartmouth College, New Hampshire, in the USA, three years before the first microchip was patented.

Progress in artificial intelligence was initially slow, hampered by an insufficient volume of data and computer power. Artificial intelligence first caught the public eye in 1997, when IBM's Deep Blue became the first computer to beat the grandmaster of chess, Russian legend Garry Kasparov. Twenty years on, Sophia, a humanoid robot developed by Hanson Robotics, gave her first interview to CNBC television's Andrew Ross Sorkina at the Future Investment Institute in Saudi Arabia in October 2017, prompting the host country to grant 'her' Saudi citizenship[1].

UNESCO's own International Hydrological Programme began developing an application of artificial intelligence in 2005, in partnership with a team at the University of California, Irvine (USA). The UNESCO G-WADI Geoserver application uses an artificial neural network algorithm to estimate real-time

1 See: https://www.youtube.com/watch?v=S5t6K9iwcdw

precipitation worldwide. The application is being used to inform emergency planning and management of hydrological risks, such as floods, droughts and storms. It tracked the Haiyan Super Typhoon as it approached the Philippines in 2013, for example. The Namibian Drought Hydrological Services use the geoserver to prepare daily bulletins with up-to-date information on flood and drought conditions for local communities.

Sophia and friend

Scientists working with UNESCO use a variety of digital tools to analyse vast quantities of data in fields ranging from theoretical physics to ecological research, water management and climate change assessments. Scientists are using the Internet of Things for instance, to improve urban water management (smart water systems) and, in biosphere reserves, to monitor biodiversity with drones and motion sensors. AI components can be incorporated in these and other connected objects.

Artificial intelligence is now evolving at breakneck speed, thanks to increasingly powerful supercomputers. The Apple iPad2 tablet computer is more powerful than the Cray-2 supercomputer, which was the fastest on the planet at the time the Human Genome Project got under way in 1990. The new research frontier is quantum computing, a field which promises a future of unprecedented computing speed. Scientists from the Abdus Salam International Centre for Theoretical Physics are participating in this adventure and training their peers from developing countries through the new Trieste Institute for the Theory of Quantum Technologies.

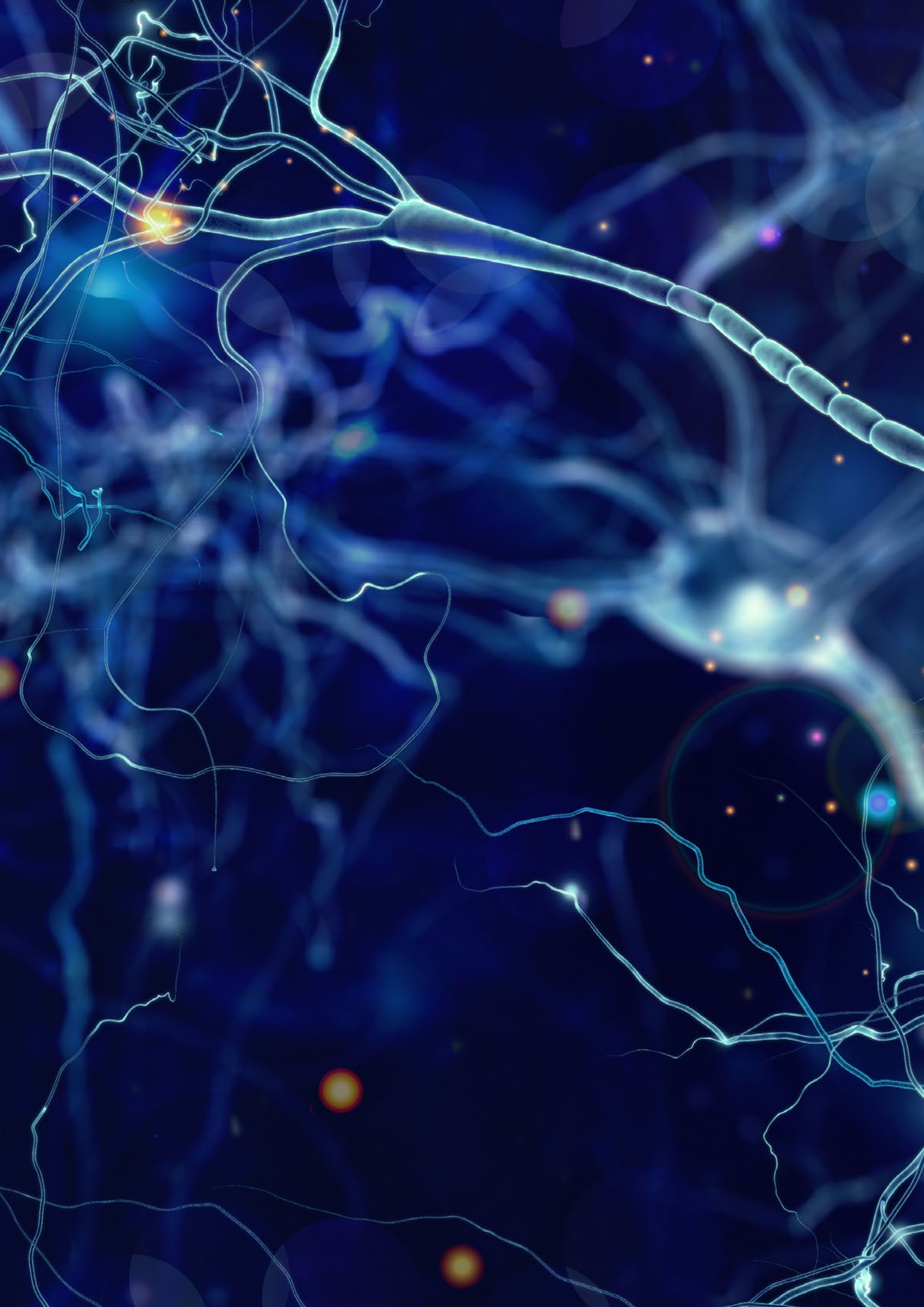
Given the speed with which artificial intelligence is evolving and its potential to disrupt the economy – and, thus, peoples' livelihoods –, it is imperative that UNESCO position itself rapidly to ensure that it can provide all of its Member States with the necessary foresight to take advantage of this technological revolution while ensuring respect for human dignity and security. Artificial intelligence holds great promise for building inclusive knowledge societies and helping countries reach their targets under the *2030 Agenda for Sustainable Development* but it also poses acute ethical challenges.

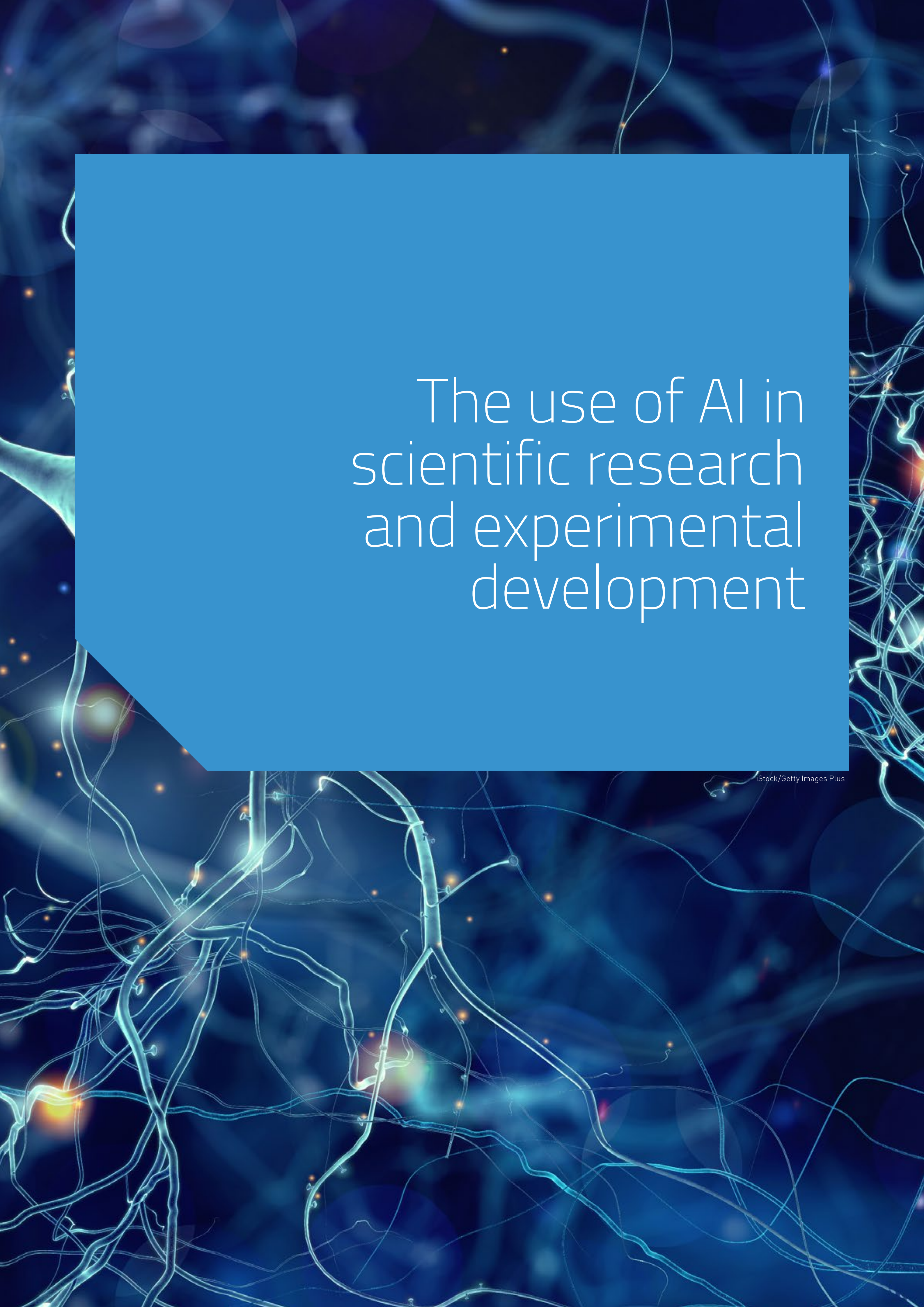
Developing countries will only be able to reap the benefits of the Fourth Industrial Revolution, if they can overcome the skills shortage that hamstrings their national innovation systems. They will need to introduce new, out-of-the box teaching and training techniques that value cross-disciplinary skills and creative thinking, in order to produce a technically savvy, innovative workforce. They will also need to adopt policies and programmes which nurture quality basic research and an innovation culture.

The current paper sets out to identify emerging opportunities and challenges arising from the rapid development of artificial intelligence and their implications for UNESCO's programmes in natural sciences. As part of this foresight exercise, the Natural Sciences Sector surveyed relevant staff and UNESCO chairholders and centres. Respondents were asked to identify opportunities and challenges for UNESCO's work in the following areas:

- Scientific research and experimental development
- Ecosystem and environmental management
- Science governance and foresight

The findings of this survey have informed the current paper. It is one of several working papers prepared by UNESCO's programme sectors in 2018–2019.





The use of AI in scientific research and experimental development

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2. The use of AI in scientific research and experimental development

2.1. The contribution of AI to scientific discovery

Today, researchers produce massive quantities of information and data. In the USA, researchers produced 321,846 papers in international journals in 2014 alone, according to the Thomson Reuters Web of Science, Science Citation Index Expanded (UNESCO, 2015). Researchers must wade through numerous papers to keep abreast of developments in their field, including papers published by their peers abroad. Researchers are also confronted with a deluge of experimental data that is growing at a mindboggling pace. No researcher can digest such an avalanche of information and data – but today's machines can.

> Today's machines can self-learn and self-correct

Today's machines not only feed on big data. They can also self-learn and self-correct. Through a process known as deep learning, AI systems learn from processing large training data sets until they can' see' patterns and spot anomalies in large, complex datasets. In an interview last year, Intel Vice President Gadi Singer said he considered using AI to reshape scientific exploration to be his most important challenge (Singer, 2018).

Using deep learning, a machine can identify very faint patterns within a large, multidimensional dataset. A typical example is the researcher who knows what they are looking for but cannot define the exact mathematical equation. The dataset is too large for trial and error and there are not enough known features to justify using big-data analytical techniques to search for a pattern. The researcher has tagged several examples. He or she feeds them into the deep learning system then leaves it to learn what to look for, until it ultimately identifies a pattern (Singer, 2018).

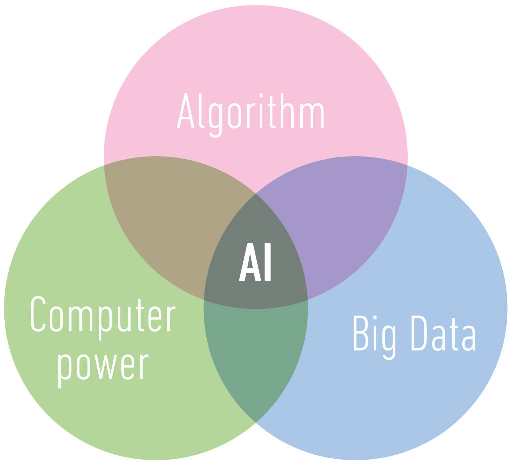
Even when a person has a mathematical model, such as a set of accurate equations, they can use AI to achieve comparable results 10,000 times faster. 'Say you have a new molecular structure and you want to know how it's going to behave in some environment for pharma exploration', says Singer. 'There are very good predictive models on how it will behave [that do not use AI]. The problem is that those models take a tremendous amount of computation and time – it might take you weeks to try just one combination' (Singer, 2018).

The predictive capabilities of AI are being used to predict outbreaks of disease in various countries. The start-up Artificial Intelligence in Medical Epidemiology (AIME) analyses local government datasets in combination with satellite image recognition systems. AIME has teamed up with the Brazilian NGO Viva Rio to provide low-cost predictions of where to expect a greater incidence of disease in the coming three-month period. The project has proved so successful that AIME has since been deployed in the Dominican Republic (WWWF, 2017).

In the past couple of years, explains Singer, 'new machine learning methods have emerged for learning how to learn. These technologies are tackling an almost endless realm of options, like all the possible mutations in human DNA, and are using exploration and meta-learning techniques to identify the most relevant options to evaluate' (Singer, 2018).

A popular AI method in life science research provides a powerful tool for surveying and classifying biological data. Deep-learning algorithms take raw features from an extremely large, annotated dataset, such as a collection of images or genomes, and use them to create a predictive tool based on patterns buried inside. Once trained, the algorithms can apply that training to analyse other data, sometimes from vastly different sources (Nature, 2018). In medical diagnostics, a machine can learn to identify bone fractures if it is fed a sufficient number of x-ray images, a skill which could help to compensate for the shortage of radiologists in many countries.

Figure 1.
Key components of artificial intelligence



Source: design by S. Schneegans/UNESCO

AI is already playing an important role in research in data-intensive fields such as medicine, genetics, cell and systems biology and neuroscience. For instance, IBM's Watson computer achieved what may be a world first at the University of Tokyo in 2015. It diagnosed a Japanese patient with a rare type of leukemia and identified a life-saving therapy much faster than if doctors had examined the genetic data manually. The computer compared 25,000 clinical tests, 1.2 million patient files and two million scientific articles (Otake, 2016).

> The private sector is driving much of research in AI

The private sector is driving much of research in AI. For instance, Cognetivity Neurosciences Ltd in the UK is developing the Integrated Cognitive Assessment (ICA), a platform which uses AI and machine learning techniques to test cognitive function, potentially allowing early diagnosis of dementia. ICA eliminates learning bias, since it tests cognitive function rather than memory. A person can take the test repeatedly over time, including on their Ipad[2].

One impediment to the use of AI in medical diagnostics is the difficulty encountered by developers in obtaining the reams of data necessary to establish effective algorithms. Data privacy rules governing patient–doctor confidentiality may prohibit hospitals from sharing medical images, for instance, such as patient scans and x-rays, with a company interested in developing a diagnostic tool.

2 See the video at: https://www.cognetivity.com/

> The accuracy of machine learning techniques has been called into question… An AI algorithm will always produce an answer but not always the same answer to the same question

The accuracy of machine learning techniques has also been called into question. Statistician Dr Genevera Allen has observed that these techniques have no way of saying 'I don't know' or 'it's not clear'. This means that an AI algorithm will always produce an answer but not always the same answer to the same question. She told BBC news that 'there is general recognition of a reproducibility crisis in science right now' and urged researchers in the field of machine learning to develop systems which can assess the accuracy of their own findings (Torbert, 2019). Dr Antonello Scardicchio from UNESCO's Abdus Salam International Centre for Theoretical Physics (ICTP) concurs. 'This is, indeed, a problem for reproducibility in science and an even bigger problem when it comes to decisions regarding health, legal and financial issues, etc., as there are times when nobody can tell how an AI algorithm has arrived at a given decision'.

Innovation in medicine, genetics, cell and systems biology and neuroscience is increasingly being coupled with information technology. This convergence raises profound philosophical questions, such as: what does it mean to be human? Should AI be used only to correct a medical condition or handicap (such as paralysis), or should it be used to enhance human beings? There are start-ups which are already striving to create human hybrids or 'cyborgs'. Elon Musk, for instance, believes that human beings must merge with AI to become hybrids, lest we become the equivalent of pets to AI systems, or even irrelevant. His start-up, Neuralink, is striving to integrate AI with the human brain using a 'neural interface'. The latter is a mesh which would serve as a wireless brain–computer interface, circulating through the host's veins and arteries (Hinchcliffe, 2018).

AI brain implants raise a host of ethical issues. What if a brain implant became capable of programming a person's thoughts and, thereby, of controlling them? Up until now, it has been possible to limit a person's freedom of movement and freedom of speech. Brain implants could extend this power to controlling the mind. Potentially, a person's thoughts could even be controlled by a machine, rather than by a human being (Hinchcliffe, 2018).

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2.2. What might the future hold?

2.2.1. Could major scientific discoveries come from AI systems?

In a mid- to long-term perspective, AI could fundamentally alter the way in which research is conducted, structured and understood. This evolution will require scientists and engineers to learn new skills to keep up and could eventually result in AI outcompeting research organized by, and for, humans.

> AI is already mimicking the scientific method

AI is already mimicking the scientific method by generating hypotheses and verifying them through simple experiments. A decade ago, Ross King and his colleagues developed a systematic robot scientist that can infer possible biological hypotheses and design simple experiments using a defined protocol automated system to analyse orphan genes in budding yeast. 'While this brought only a moderate level of discovery within the defined context of budding yeast genes, the study represented an integration of bioinformatics-driven hypothesis generation and automated experimental processes' (Kitano, 2016).

Could AI systems be designed to ask the 'right' questions that may lead to major scientific discoveries? Kitano (2016) questions the importance of this step in basic research. He argues that budget, competition and resource constraints such as the length of a person's active research career already limit efficiency in basic research. When time and resources are abundant, he suggests, asking the right questions is of lesser importance. He also recalls the role played by chance in scientific discovery, suggesting that 'the critical aspect of scientific discovery is how many hypotheses can be generated and tested, including examples that may seem highly unlikely'.

Kitano (2016) speculates that AI systems could be placed at the centre of a network of intelligent agents comprising both other AI systems and humans to coordinate large-scale biomedical research. He takes this hypothesis a step further, suggesting that scientific discovery could not only combine AI and qualified researchers but also involve citizen scientists who would undertake distinct tasks to produce a collaborative form of intelligence, or crowd intelligence. He cites the example of Patientslikeme, a patient-powered research network. 'Whether this path would ultimately make our civilization more robust (by facilitating a series of major scientific discoveries) or more fragile (due to extensive and excessive dependence on AI systems) is yet to be seen' (Kitano, 2016).

2.2.2. Quantum computing may be the next frontier

Researchers in computer science and physics see quantum computing as being the next frontier. Quantum computing promises a future of unprecedented computing speed. This is slowly becoming a reality, with IBM and Google already producing quantum computing chips that will someday drive a quantum machine. The creation of the first quantum computer will certainly have an impact on AI by enabling us to solve more complex problems.

> Quantum computing promises a future of unprecedented computing speed

To streamline its research and training activities on this topic, the ICTP inaugurated the Trieste Institute for the Theory of Quantum Technologies (TQT) in March 2019. The institute has been established in partnership with the University of Trieste and the International School for Advanced Studies (SISSA) in Italy, with support from IBM and Google.

The TQT provides a hub for the study of the future of AI on quantum devices, offering in parallel a convenient link to private actors (Google and IBM to begin with). The TQT's first conferences on quantum technology in 2019 were the Advanced School and Workshop on Ubiquitous Quantum Physics: the New Quantum Revolution from 18 to 22 February and the School on Advances in Condensed Matter Physics: New Trends and Materials in Quantum Technologies, from 7 to 15 May.

In November 2018, a researcher from the ICTP's Condensed Matter and Statistical Physics Section was among the recipients of a €1 billion European Commission initiative called the Quantum Flagship that is funding the development of quantum technology over the next 10 years.

For the first three-year phase of the Flagship, ICTP's Marcello Dalmonte will be acting as co-principal investigator of a research project that will focus on quantum simulation, one of five of the Quantum Flagship's research themes. Quantum simulators study quantum systems, such as the atomic make-up of materials or chemical reactions, performing tasks that are too complex for even the most powerful, transistor-based classical computers[3].

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3 https://en.unesco.org/news/international-centre-theoretical-physics-contributes-second-quantum-revolution

The use of AI for environmental management and disaster risk reduction

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3. The use of AI for environmental management and disaster risk reduction

3.1. The implications of AI for ecosystem and environmental management

AI and related technologies such as the Internet of Things are expected to foster progress in most, if not all, areas of ecological and biodiversity research, together with environmental and ecosystem management, in general.

> Motion-sensor cameras can ... gather vast quantities of data on biodiversity

Motion-sensor cameras can be used in natural habitats to gather vast quantities of data on biodiversity inexpensively and unobtrusively. These are already being used in the World Network of Biosphere Reserves. It used to be time-consuming to analyse such images but a recent article in the *Proceedings of the National Academy of Sciences* has shown that AI can automate animal identification for 99.3% of the 3.2 million images in the Snapshot Serengeti dataset. Moreover, it can perform at the same level of accuracy (96.6%) as crowdsourced teams of human volunteers. The authors of the article affirm that 'automatically, accurately, and inexpensively collecting such data could help catalyze the transformation of many fields of ecology, wildlife biology, zoology, conservation biology, and animal behavior into "big data" sciences' (Norouzzadeh, 2018).

This is a good example of the clear benefits and power of AI but it also illustrates the possible impact on the status and employment opportunities of present ecological knowledge-holders. If field observations are performed by cameras and image recognition is undertaken by machines, field ecologists could find reduced demand for their services and, ultimately, for their knowledge. This could have profound implications for the community of researchers, who will be required to learn new skills to adapt to changes within their profession, as well as for holders of indigenous and traditional knowledge.

Another example is the use of drones equipped with AI technologies to combat deforestation or poaching. In Kenya, for instance, the World Wildlife Fund has received a US$5 million grant from Google to use an AI device with drones to track poachers in the Maasai Mara (WWWF, 2017). Although such systems can successfully detect and deter poachers, it would be naïve to assume that the illegal trade in wildlife will not adopt AI to its own advantage. For example, poachers could use drones to identify and possibly kill valuable wild animal species.

> Drones equipped with AI technologies [can] combat deforestation or poaching

AI can also provide tools for forecasting and analysing changes to ecosystems. Sensors are being used in agriculture, for instance, to help farmers monitor their crops and livestock. Agriculture is a key economic activity in many biosphere reserves. The tool Mcrops has been developed in Uganda to flag diseases affecting cassava plants in real time (WWWF, 2017). Another example is Sequoia, developed by Parrot, a French company. Sequoia is a multispectral sensor attached to a drone which combines a camera with a GPS sun sensor (ultraviolet and infrared rays) to analyse crop vitality by capturing the amount of light plants absorb and reflect.[4]

AI can be integrated with other technologies to amplify the spatio-temporal scales at which ecological patterns and processes can be studied. For example, remote sensing based on satellite imagery can provide an impression of habitat heterogeneity over a large area. By incorporating this information, a study can be designed to monitor biodiversity by deploying camera traps in a combination of locations representative of the entire area. One recent study combined citizen science with deep learning algorithms (artificial intelligence), and produced accurate abundance counts of

4 See: https://www.imnovation-hub.com/society/types-of-smart-sensors-applied-to-agriculture/#1

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Elephants in the United Republic of Tanzania; drones and motion-sensors can help to monitor biodiversity but could also fall into the hands of poachers.

wildebeest migration within hours, compared to weeks for traditional counting techniques (Torney *et al.,* 2019).

The Man and the Biosphere (MAB) programme has some experience of using drones in the Wudalianchi Biosphere Reserve in China. In 2015, a leading Chinese company for the manufacture of civil drones, Dji Technology Co. Ltd, demonstrated how drones could be utilized for land use planning and monitoring to biosphere reserve managers attending the sixth international training workshop of the East Asian Biosphere Reserve Network in Harbin City, Heilongjiang Province. Using field data acquired by drones, the team from Dji Technology Co. Ltd had developed 3D models of Wudalianchi Biosphere Reserve. The workshop was organized jointly by DJI Technology Co. Ltd and the International Center on Space Technology for Natural and Cultural Heritage, a UNESCO category 2 centre.

UNESCO and the International Research Centre on Space Technologies for Natural and Cultural Heritage (a category 2 centre) are organizing a capacity-building meeting in Africa in 2019 on Monitoring using New Technology, including drones. This meeting will also be an asset for the capacity-building component of the Biosphere and Heritage of the Lake Chad Basin (BIOPALT) project targeting managers of protected sites. The BIOPALT project is helping states to prepare their application for the creation of a transboundary biosphere reserve in the basin and their nomination for Lake Chad to be designated both a world heritage site and biosphere reserve.

In parallel, MAB is working with Kyoto University in the Mont Nimba Biosphere Reserve in Guinea to improve the conservation of chimpanzees in this biosphere reserve by using drones to monitor land use and change in vegetation cover. The drones are not yet equipped with AI but there is obvious potential for doing so.

MAB and colleagues from UNESCO's Global Geopark programme are planning to survey biosphere reserve managers and geopark managers jointly by 2020 to ascertain the extent to which these sites are using AI technologies, or plan to do so.

3.2. The implications of AI for geosciences

3.2.1. Reducing subjectivity in interpreting image logs

The main advantage of using AI in geology is to interpret image logs related to exploration data. Today, exploration geologists have to deal with vast quantities of collected data. AI helps manage these data. The system uses heuristic techniques (experimentation, trial and error) and has the potential to help geologists search for mineral resources and precious metals. For example, it can help geologists interpret borehole images in glaciated terrain.

> The main advantage of using AI in geology is to interpret image logs related to exploration data

Image logs hold important information about subsurface sequences and the spatial distribution and characteristics of faults/fractures and bedding (well-defined planes horizontal or parallel to the land surface in massive rock formations). Image logs can provide insights into the rock texture, textural organization and type and distribution of porosity. To reduce the subjectivity of the interpretation and cut the time it takes to interpret images, AI can provide a new semi-automatic process for image log interpretation.

AI can automatically extract rock properties information and has two advantages: it avoids subjectivity in interpretation and reduces the interpretation time. However, some level of human interaction and correction is still necessary in this process.

3.2.2. Big data, cloud computing and AI in the service of sustainable development

When it met at UNESCO headquarters in Paris from 18 to 21 February 2019, the Council of UNESCO's International Geoscience Programme (IGCP) stressed the urgency of integrating sustainability into the geosciences, to help countries reach their Sustainable Development Goals. The Council identified three priority areas for research in geosciences:

- Efficient, safe and sustainable Earth resources exploration and extraction,
- Innovative renewable energy production and CO_2 mitigation,
- Better understanding and predicting climate change and geohazards.

The IGCP Council also identified nine priority topics[5] for its 2019 call for project proposals. One of these topics is Big data, Cloud Computing and Artificial Intelligence in Geosciences, which will involve close collaboration with research institutions and the private sector. The projects selected will be sponsored jointly by the Jeju Province Development Corporation of the Republic of Korea, UNESCO and the International Union of Geological Sciences for five years.

> Several UNESCO Global Geoparks already use augmented and virtual reality to add to the visitor's experience

3.2.3. Enhancing the visitor's experience

Several UNESCO Global Geoparks already use augmented and virtual reality to add to the visitor's experience by enabling them to visualize geological and/or environmental change more easily. The integration of AI to personalize the visitor's experience even further would not be a big step forward from this point.

Through AI, the education packages provided by geoparks will be tailored to the level of education and interest of the individual. In museums, visitor centres and at sites of interest in the geopark, AI chatbots could increase the visitor's experience. Through AI-driven data mining and analysis of visitor behaviour, AI could also be used to develop customized programmes or routes matching the individual desires, habits and preferences of each tourist.

UNESCO geoscientists and MAB colleagues are planning to survey managers of UNESCO Global Geoparks and managers of biosphere reserves in 2019, to ascertain the extent to which they are using AI technologies or plan to do so in these designated sites.

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5 See here for a list of the other eight special topics: http://www.unesco.org/new/en/natural-sciences/environment/earth-sciences/international-geoscience-programme/proposal-submission/

3.3. The implications of AI for freshwater management

3.3.1. Machine-learning algorithms already in use in water science

Although AI is probably only being used in exceptional cases in the operational water sector, machine learning algorithms are increasingly being used in water science. In Serbia, for instance, the Centre for Water for Sustainable Development and Adaptation to Climate Change, which operates under the auspices of UNESCO (category 2 centre), has been using AI and statistical modelling for years to control the quality of time-series data in structural and environmental monitoring.

One of the most important techniques is deep learning, part of the so-called weak AI. Deep learning can complement modelling forecasts as a predictive tool to detect patterns, classify and correct remote sensing products, or for mitigation by anticipating the future.

Deep learning has great potential for supporting a wide range of applications, such as water demand projections, the water–food–energy nexus or climate change. For example, in Germany, the Federal Institute of Hydrology and Fraunhofer Institute for Intelligent Analysis and Information Systems applied Echo State Networks (ESN) to produce discharge forecasts and water-level simulations on the Rhine and Danube Rivers. The results of the ESN models are better than the existing traditional hydrological model, Hydrologiska Byråns Vattenbalansavdelning (HBV). Nevertheless, the HBV models provide added value if the outflows calculated by them are used as input data for an ESN model. The simulations show that ESN models are also suitable for cases in which non-physical factors (such as the operation of locks) play a major role.

The application of deep learning might also accelerate the standardization of data and metadata formats in the hydrological field. This would lead to a much improved global monitoring system of environmental systems and would directly support open data initiatives to make data Findable, Accessible, Interoperable and Reusable (FAIR). Today, there are shortcomings in this area resulting from the high cost and complexity of managing water data, combined with non-existent or outdated policies for the collection, storage, dissemination, sharing and use of water data.

Deep learning also comes with caveats. It tends to deliver 'black box' solutions that discriminate between the signal and background without providing the operator with an understanding of the relationship between hydrological input and output. This makes the interpretation of the output difficult from a physical, mechanistic point of view and can lead to unwanted bias. An example of bias are what have been termed 'filter bubbles' (or 'echo chambers'). Deep learning is also highly sensitive to overfitting. (See the Glossary for an explanation of these terms.) Blockchain approaches might be useful for detecting the manipulation of data and algorithms and, thereby, protecting the integrity of data.

3.3.2. The advantages of a three-pronged approach to urban water management

The Internet of Things, machine learning and Blockchain technology can be combined to facilitate urban water management. By combining these three technologies, UNESCO's aim is to generate and disseminate knowledge with a view to improving service provision and quality, while ensuring the sustainability of the water resource itself.

> "The Internet of Things, machine learning and Blockchain technology can be combined to facilitate urban water management

Smart water systems use an approach based on the Internet of Things. These smart systems are comprised of a network of physical devices (like a flow meter). Devices include a sensor which records data (such as the level of water quantity and quality, images etc.) and a communication device that transmits data in real time to a cloud-based server. These smart water systems are gaining momentum in urban water resources management, as they increase the efficiency and effectiveness of the system while providing cost-savings.

The following example demonstrates how the three technologies (Internet of Things, machine learning and Blockchain) work together to ensure smarter water management:

- Firstly, IoT devices collect water data through sensors and transmit the data to a Blockchain-based server. For example, while monitoring the environmental impact of fracking, water quantity and quality data can be transmitted through Internet of Things devices embedded in the water distribution system.
- The data in the Blockchain server are transparent and protected through a distributed peer to peer network. For example, the water quantity and quality data can be stored in the Blockchain registry in a tamper-proof manner.
- The machine learning algorithm then uses the data to create predictive analytics and aid decision-making capabilities. Smart contract protocols embedded in the Blockchain technology can be used to execute a decision. For example, the water quantity and quality data collected over a period of time can be used by machine learning algorithms to predict future water quality and quantity and see when they reach dangerous levels. If and when they do, smart contract protocols can be

configured to send a warning message to citizens, media personal and relevant authorities to ensure swift action.

When well integrated with the water distribution network, a combination of the Internet of Things, machine learning and Blockchain technology can be used to:

- pay water bills to reduce transaction costs;
- set up a peer to peer trading system thus incentivizing consumers to use less water;
- account for water transfers in water markets and, thus, help to avoid bureaucratic turf battles and overlapping jurisdictions; and
- track assets in supply chain management, thus helping to determine the carbon footprint better.

3.4. The implications of AI for disaster risk reduction

3.4.1. Extending AI beyond disaster response to prevention

Many ideas and prototypes have already been tested in disaster risk reduction. So far, they have tended to focus on the response and rescue phase. For example, Sendai city in Japan has tested a prototype with private companies for a tsunami alert using AI and Blockchain technology, whereby the AI system automatically launched a drone, sending an alert through mobile phones and radios and using facial recognition software to identify victims, such as people being swept away in a car by a tsunami wave.

UNESCO is a part of a consortium participating in a project funded by the European Union. I-REACT is using a kit of new technological tools to reduce risks linked to natural disasters, including drones to improve mapping, wearables to improve geographical positioning and glasses with augmented reality to facilitate reporting and information visualization by first responders. The kit comes with a mobile app and a social media analysis tool to account for real-time crowdsourced information. The automatic analysis of social media tweets by means of machine learning algorithms and advanced semantic techniques makes it possible to pinpoint ongoing floods and provide real-time data to enhance situational awareness; such information can be useful to both citizens and first responders faced with a natural hazard.

It is expected that future applications of AI will focus not only on disaster response but also on the prevention phase. In the field of earthquake risk reduction, there are sensors available which can provide about 10 seconds' advance warning of an impending earthquake. However, seismology is not yet capable of predicting an earthquake hours, days or weeks in advance. A panel set up by the Government of Japan to discuss the contours of an AI strategy stated in its final report in 2017 that 'no methods have been established, so far, to predict earthquakes using AI'. This is because the field of seismology has not yet determined which type of data can best follow the processes signaling a build-up to an earthquake. Without the right kind of data, machine-learning algorithms will be unable to develop an appropriate model for predicting earthquakes.

3.4.2. AI already being used to manage water-related hazards

AI can be useful for producing hydrological runoff time series, which are essential for reservoir management, environmental protection and hydropower management.

A number of new modelling systems are being tested for their ability to forecast drought events with precision: Artificial Neural Networks (ANN), Adaptive Neural-based Fuzzy Inference Systems (ANFIS), Genetic Programming (GP) and Support Vector Machines (Wang *et al.*, 2009; Jalalkamali and Moradi, 2015). The current drawback in using AI for drought management is the lack of 'big data' necessary to produce models that can provide accurate forecasting. The G-Wadi Geoserver tackles this problem (see Box 1).

3.4.3. AI can improve climate change assessments

Climate scientists have to juggle huge amounts of observational (Earth and satellite) and simulated data to monitor the current climate, make future projections and detect high-risk zones.

> “By improving the accuracy of global climate models and climate forecasts, AI and machine learning algorithms will help to mitigate and manage climate change-related risk

Clouds are the single biggest source of uncertainty in global climate models. New studies (e.g. Rasp *et al.*, 2018) suggest that AI and artificial neural networks can successfully resolve more complicated and smaller-scale atmospheric processes like the ones involved in convective cloud formation and, thus, reduce the uncertainties inherent to current climate models.

By improving the accuracy of global climate models and climate forecasts, AI and machine learning algorithms will help to mitigate and manage climate change-related risk, including catastrophic weather events such as tornadoes, hurricanes and thunderstorms, which are projected to become both more frequent and more severe (McGovern *et al.*, 2017); AI and machine learning algorithms will also help to increase preparedness and response to environmental risk, fields where fast, smart solutions are of vital importance.

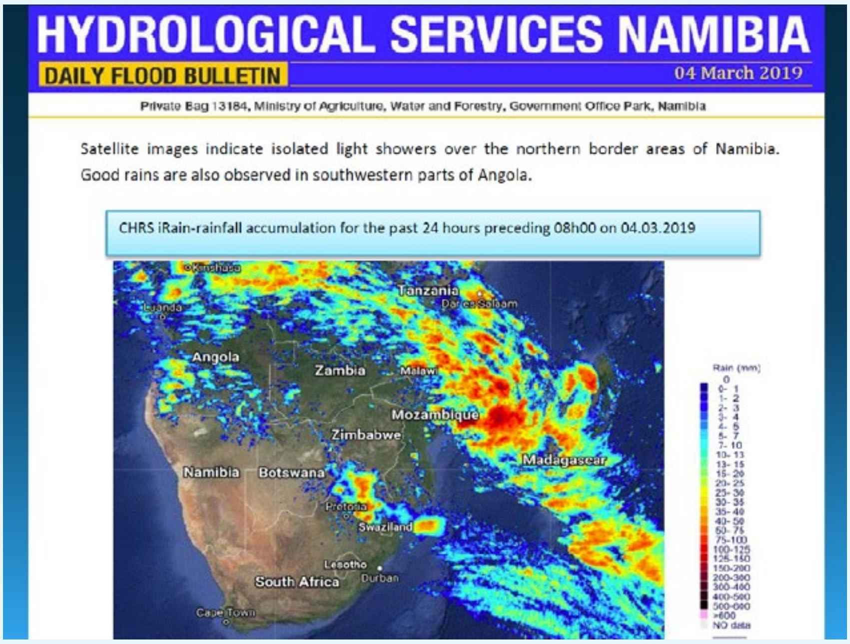
Box 1.

Using AI to manage drought and other hydrological risks

UNESCO's G-WADI Geoserver application (Water and Development Information for Arid Lands – a Global Network) uses an artificial neural network (ANN) algorithm to estimate real-time precipitation worldwide. This product is called the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks – Cloud Classification System (G-WADI PERSIANN-CCS[6]).

The G-WADI PERSIANN-CCS GeoServer has been under development since 2005, through collaboration between the Center for Hydrometeorology and Remote Sensing at the University of California, Irvine, and UNESCO's International Hydrological Programme. The core algorithm of this system, supported by NASA and NOAA, extracts local and regional cloud features (coldness, geometric structure and texture) from the international constellation of GEO satellites capturing infrared imagery and estimates rainfall at 0.04° × 0.04° spatial resolution (roughly 4 km²) every 30 minutes. Information from LEO satellites is then used to adjust the initial precipitation estimation from the ANN algorithm.

The G-WADI PERSIANN-CCS Geoserver is being used to inform emergency planning and management of hydrological risks, such as floods, droughts and extreme weather events. For example, the Namibian Drought Hydrological Services uses it to prepare daily bulletins with up-to-date information on flood and drought conditions for local communities (*see image*). It is being widely used globally to track storms, such as in the case of the Haiyan Super Typhoon, where the Geoserver captured the maximum precipitation intensity of approximately 361 mm per day on 7 November 2013, while the storm was approaching the Philippines.



Daily Flood Bulletin prepared by the Namibian Hydrological Services using the G-WADI PERSIANN-CCS Geoserver; slide shown by Dr Will Logan at an awareness-building workshop organized by UNESCO in March 2019, see Box 5.

The system is now available through the iRain mobile application, devoted to facilitating citizen involvement in collecting local data for global precipitation monitoring.[7] iRain allows users to visualize real-time global satellite precipitation observations, track extreme precipitation events worldwide and report local rainfall information using a crowd-sourcing functionality to supplement the data. This provides an opportunity to improve remotely sensed estimations of precipitation. Moreover, the use of a crowdsourcing functionality in iRain to supplement the data opens up opportunities for engaging citizen scientists.

6 It can be accessed at http://hydis.eng.uci.edu.

7 See: http://en.unesco.org/news/irain-new-mobile-app-promote-citizen-science-and-support-water-management

Fostering quality data for optimum research

iStock/Getty Images Plus

4. Fostering quality data for optimum research

4.1. Ensuring quality data and data management

The Natural Sciences Sector supports scientific research and experimental development (R&D) as a means of advancing human knowledge and sustainable development. Since R&D are largely data driven, these UNESCO programmes can benefit greatly from the predictive and prescriptive capabilities of AI to find innovative solutions in fields ranging from health to the environment and industry.

Despite the increasing gathering and availability of data in many parts of the world, the use of information (i.e. processed data) to inform policies and decisions remains limited. Reasons include a shortage of financial and human resources, a lack of commitment and investment from political leadership, gaps in technical skills and an absence of clearly defined strategies and mechanisms to support the sharing and use of data and information. Since the quality of the data fed into the AI system will be critical to determining the success of research, it is imperative that UNESCO pursue its support of member states in ensuring quality data and data management.

In freshwater management, for instance, standards need to be adopted for water data and metadata, to foster a decision-making process informed by science and ensure sound management and governance of water. Countries also need to embrace an open data approach to water data access and licensing and a quality system needs putting in place to manage data products derived from AI.

The data generated and shared through UNESCO online platforms must be of the highest quality to safeguard the credibility of UNESCO as an intellectual organization. These platforms currently include the Global Observatory of Science, Technology and Innovation Policy Instruments (GO-SPIN), managed by the Section for Science Policy and Partnerships, the Water Information Network System, managed by the International Hydrological Programme (see Box 2), and the indicators and statistics in science and education platform, managed by the UNESCO Institute for Statistics.

Box 2.
UNESCO's Water Information Network System

The International Hydrological Programme's Water Information Network System (WINS) was launched in January 2017. It is an open-access, participatory platform for sharing, accessing and visualizing water-related information, as well as for connecting water stakeholders.

Based on a tool equipped with a geographical information system, WINS allows people to store, access and create tailored maps on water at all levels.

Its online library offers a wide range of additional information, in the form of reports, policy briefs, graphs, charts, videos, etc.

Contributors are empowered to share information by the system's transparency and respect for authorship: indeed, all information shared on the platform benefits from standardized metadata and from a Digital Object Identifier (DOI), which accurately identifies and credits the contribution, thereby facilitating sharing down the line.

Cooperation is also fostered between service providers: standardized protocols allow WINS to display information from external platforms and vice versa. This helps to create a one-stop-shop online catalogue of information, as recommended by the UN Administrative Committee on Coordination in its report ACC/2000/18.

In this sense, the platform is helping to bridge the gap between North and South in terms of access to, and sharing of, knowledge, while fostering proactive cooperation in this area. So far, 40 UNESCO member states have joined the platform, as well as five centres operating under the auspices of UNESCO (category 2 centres), and seven water-related Chairs. Overall, 340 contributors are sharing information.

For details, see: https://en.unesco.org/ihp-wins

> More data are needed to map the global research effort

More data are needed to map the global research effort. Could AI help to develop better indicators in science, technology and innovation (STI), to ensure that policy-makers have better information at their disposal? UNESCO's project in STEM and Gender Advancement (SAGA) has identified the need for better indicators to improve monitoring of gender trends in research and innovation, for instance. Could AI eventually do away with the need for data surveys?

> Could AI help to develop better indicators and ensure that policy-makers have better information at their disposal?

As early as 2010, UNESCO's Abdus Salam International Centre for Theoretical Physics (ICTP) identified AI and data science as critical areas for its new strategic plan. ICTP is strategically placed not only because of its connections with the scientific community worldwide but also because the theoretical basis of AI is, in many cases, familiar to theoretical physicists. In addition, theoretical physicists are playing a leading role in the development of AI for quantum computers.

Last but not least, AI is already playing an important role in research, especially in data-intensive fields such as medicine, genetics, cell and systems biology and neuroscience, as we saw earlier.

ICTP is fostering excellence in research by its in-house team of scientists and is currently recruiting a staff scientist in AI and data science.

4.2. The Internet of Things can help bridge the scientific divide

AI helps to organize and make sense of huge amounts of data. In the near future, the Internet of Things will be one of the sources of real-time data. There may even come a day when the Internet of things will not exist without AI components. These components can be incorporated in connected objects such as drones, sensors and robots. Imagine an AI algorithm capable of collecting data from sensors in a factory and performing predictive maintenance; such a system would save time and money by preventing unplanned shutdowns.

Applications based on the Internet of Things exist in many fields. Drones and sensors can be used to monitor water quantity and quality, soil moisture and air quality, to track animals and map disease. Given the wide range of potential applications that can benefit communities (Biggs *et al*., 2015). UNESCO has been advocating the use of the Internet of Things for development. Between 2010 and 2018, ICTP organized 26 training activities on the Internet of Things in 20 developing countries stretching from Nepal to Benin.

> UNESCO has been advocating the use of the Internet of Things for development

The Internet of Things can help scientists from developing countries to bridge the so-called scientific divide. If we define the digital divide as being the gap between those with access to digital technologies and those without, the scientific divide can be defined as the gap between those with access to scientific data and those without. The collection of empirical data has enabled advances in science and contributed to improvements in the quality of life.

> The Internet of Things is a low-cost, low-power technology [that] can be deployed in remote areas

Until recently, data collection has been based mainly on a limited range of expensive equipment that uses wired infrastructure, particularly when it comes to environmental applications. Data collection has been a costly, difficult task restricted to a relatively small number of fixed, sparsely distributed locations and maintained by organizations with large budgets. As a result, the data gathered are often incomplete, especially in developing countries and remote areas.

The Internet of Things could radically change that; this low-cost, low-power technology does not require any pre-existing infrastructure and can be deployed in most remote areas. The vast range of sensors that can be connected to the nodes support many different scientific applications, including those outlined above.

Issues at the science–policy nexus

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5. Issues at the science–policy nexus

5.1. Smart solutions are already here

The revolution in artificial intelligence is already under way. How prepared is society for this revolution and in what ways can public policies ensure that this disruptive technology has a beneficial effect on human societies and the environment and does not widen the technological divide?

> Economists predict that AI products will account for up to 15% of the total production of goods within a decade
> *Yoshua Bengio*

In July 2018, Yoshua Bengio, an expert in deep learning, told the *UNESCO Courier* that 'economists predict that AI products will account for up to 15% of the total production of goods within a decade' (UNESCO, 2018a).

Applications of AI are already offering consumers 'smart solutions'. These solutions may target the individual (smart heart stimulators like pacemakers, robotic house-cleaners, smart washing machines and refrigerators, drone deliveries, *see photo*), the group (smart ventilation, lighting and heating systems for buildings) or urban populations (traffic light control). The systems tend to be situation-specific, so it may not be straightforward to transfer the technology elsewhere.

The Fourth Industrial Revolution (Industry 4.0) currently under way will see much practical engineering work shift to the Internet and the Internet of things. In the near future, home refrigerators will be able to communicate with individual stores to place orders for food then inspect the delivered goods before accepting them. Over the next ten years, we shall use many AI applications without even realizing that the task was accomplished by a computer rather than by a human being. The human being will still be needed to define the parameters and interpret the results, though, since AI systems are, after all, algorithms.

'Smart solutions' will make urban life more pleasant, such as by reducing traffic jams and pollution, but they will come at a price. People will also have to accept the omnipresence of surveillance cameras and the inherent invasion of privacy. Motion sensors could control the movements of employees, such as by monitoring the amount of time they are absent from their workstation or the time they spend on a specific task. There is, thus, a risk that machines will become our masters. Today's smart phones already automatically count the number of steps a person takes in a day. Were a person to remain beneath what is considered a healthy threshold, machines could hypothetically apply pressure for the person to walk more that day, such as by emitting shrill sounds or by repeating instructions at regular intervals. Today's cars already emit a shrill sound if an occupant forgets to attach their safety belt.

5.2. How neutral is technology?

Over time, technology may come to be used in ways that its creator never imagined. The Global Positioning System (GPS), for instance, was originally designed by the US Department of Defense for military use and only later adapted to civil use, in recognition of the technology's potential for commercial spin-offs.

AI systems already include dual-use technologies, such as sensors, drones and robots. The myriad possibilities offered by AI systems begs the question: which applications are desirable and which are not? For instance, robots can be used to improve human safety, such as by defusing bombs and identifying the location of anti-personnel mines. They can also be turned into killers. In July this year, the Belgian parliament voted to ban killer robots. The resolution calls on the Belgian government to forbid the Belgian military from using lethal autonomous weapons and to work towards an international ban (Pax, 2018).

Is technology neutral? Opinion is divided on the question. For American historian Melvin Kranzberg, 'technology is neither good nor bad; nor is it neutral'[8].

8 See: https://en.wikipedia.org/wiki/Melvin_Kranzberg

Getty Images / Baranozdemir Delivery by drone

If technology is not neutral, is it a reflection of its creator's mind? And if so, can the creator of a technology be held responsible for applications of the technology that he or she never imagined? For example, machines trained through deep learning can interpret 360° camera views, making it possible for them to identify a face in the crowd by connecting the image to a database – although they have been known to make mistakes. This face recognition software could be used to identify missing children on city streets but also to ensure surveillance of the general population. To take another example, imagine a machine connected to a large database of genetic syndromes which has learned to analyse cases of human malformation when presented with images of patients. This knowledge could help doctors reach a rapid diagnosis but could also be used by insurance companies to discriminate against certain customers.

Both national and international public policies are needed to establish the parameters of AI and avoid abuses of this technology which could have far-reaching consequences for human society.

5.3. AI may widen the technological divide

There is concern that the potential commercial rewards of AI could lead to a monopolization of research in this burgeoning field. Yoshua Bengio, a Canadian expert in deep learning, has raised this concern. For him, by broadening their customer base, AI companies 'will increase the amount of data they have access to – and that data is a goldmine that makes the system even more powerful. Such a concentration of power can have a negative impact on both democracy and the economy. He warns that 'it favours large companies and slows down the ability of small new companies to enter the market, even if they have better products to offer' (UNESCO, 2018a).

> There is concern that the potential commercial rewards of AI could lead to a monopolization of research

Cockburn *et al.* (2017) have raised similar concerns. They argue that the potential commercial reward from AI-related research is likely to give individual companies powerful incentives to acquire and control critical large datasets and application-specific algorithms. They suggest that the adoption of policies encouraging transparency and sharing of core datasets across both public and private actors could stimulate innovation-oriented competition and enhance research productivity.

> Policies encouraging transparency and sharing of core datasets across both public and private actors could stimulate innovation-oriented competition and enhance research productivity

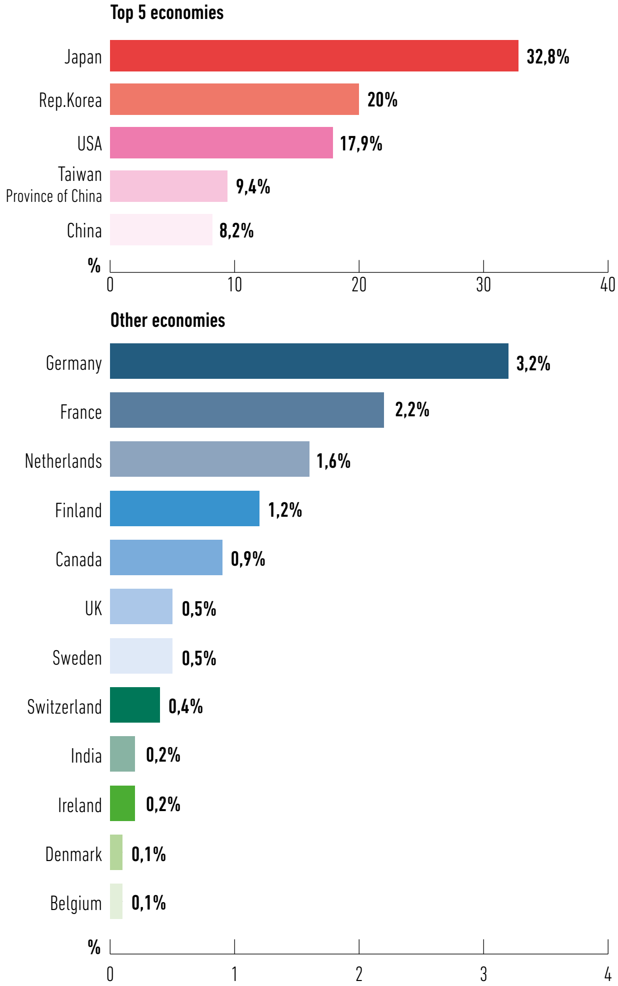
5.3.1. The genie is already out of the bottle

UNCTAD observes that 'digitalization will affect all countries, irrespective of whether they actively pursue it. Developing countries, and especially least developed countries, may risk increasing dependency on a few global digital multinational corporations, or further marginalization from the global economy' (UNCTAD, 2017).

AI may already be widening the technological divide, even among industrial countries. AI patents are currently largely concentrated in multinational corporations headquartered in just seven economies, according to the Organisation for Economic Co-operation and Development (OECD, 2017), which studied the patenting behaviour of the top 2,000 companies for R&D between 2012 and 2014. Corporations headquartered in just seven economies accounted for 93% of AI patents registered with the top five patent offices[9]: Japan (33%), the Republic of Korea (20%), USA (18%), the Taiwan Province of China (9%), China (8%), Germany (3%) and France (2%). See Figure 2.

The current concentration in AI is part of a wider trend. Over the past decade, there has been a dizzying number of mergers and acquisitions which have created powerful multinational corporations with a bigger GDP than some national economies. The figures speak for themselves. 'In the USA, 12,249 companies concluded mergers and acquisitions in the twelve months to 30 June 2015'. Of these deals, 315 represented an investment of more than US$ 1 billion (UNESCO, 2015).

Figure 2.
Patents in artificial intelligence held by top R&D companies, by headquarters' location, 2012–2014



Source: OECD (2017), Figure 1.25

'There are emerging concerns in Europe about the erosion of its science base through takeover bids from competitors' (UNESCO, 2015). In August 2018, the German government vetoed the purchase of the domestic firm Leifeld by the Chinese Yantai Taihai Group, citing security reasons. The German company manufactures specialized machines and equipment for the automobile, gas, nuclear and aerospace industries, among others (Deutsche Welle, 2018).

Not all multinational corporations are investing heavily in AI but the OECD (2017) found patenting among the top 2,000 companies for R&D to be more dynamic in AI than any other technology. According to this study, the number of AI inventions is increasing by 6% per year on average, twice the average annual growth rate observed for all patents.

9 Patents registered with the top five patent families: European Patent Office, Japanese Patent Office, Korean Intellectual Property Office, State Intellectual Property Office of the People's Republic of China and the US Patent and Trademark Office.

> Patenting among the top 2,000 companies for R&D is more dynamic in AI than any other technology

What are the implications for start-ups in AI of the dominance of multinational corporations around the world? At a forum on AI in Africa organized by UNESCO in Benguerir, Morocco, in December 2018, one participant suggested that multinationals stifled the growth of disruptive start-ups through acquisitions. Speaker Dr Tapiwa Chiwewe from IBM Research Africa responded that his corporation was actually helping start-ups in South Africa thrive by providing them with access to information and equipment via the cloud that would not have been available to them in the past (see Box 3).

Dr Chiwewe was one of three panelists at the breakout session in Benguerir on the theme of Building Capacity in AI: from basic research to applications. The other panelists were Dr Alessandro Scardicchio, a researcher at the ICTP, and Dr Fernando Vega Redondo from the University of Bocconi in Italy.

The following recommendations emerged from the session:

- The teaching of ethics should be embedded in AI training courses, including at the ICTP.
- Computer science departments in Africa need to engage in curricular reform to ensure that they are able to do research on AI and develop related skills.
- The ICTP should develop cooperation with African governments which have manifested interest in funding research chairs or centres in AI at national universities to foster quality education and both basic and applied research in AI.
- Stakeholders should develop open access online learning platforms to facilitate skills development in AI, one possible model being IBM's Digital Nation Africa platform.
- African governments should invest in basic and applied research in AI and related technologies, ideally in partnership with the African private sector, to ensure an endogenous research capacity in AI and endow African scientists with the capacity to identify the undesirable effects of some AI algorithms, such as gender and racial biases;
- African stakeholders should invest in the Internet of Things, given that the quality of the data fed into the AI system will be critical to determining the success of research conducted in Africa, that this low-cost, low-power technology does not require any pre-existing infrastructure and can be deployed in most remote areas and that the wide range of potential applications of this technology can benefit rural communities, in particular; moreover, AI components can be incorporated in connected objects such as drones, sensors and robots;
- Governments should engage with multinational corporations to find common ground on how these corporations can best contribute to achieving the national agenda in a rules-based environment that includes the adoption of policies and laws that safeguard the national interest while allowing the multinationals to meet their own objectives;
- Multinational corporations should embrace the open source movement, such as by donating some of their intellectual property to open source initiatives or creating open access platforms like IBM's Digital Nation Africa to provide people with equipment (via the cloud) and the means to develop their skills.

UNESCO is participating in a 'bottom-up' project led by the Knowledge for All platform which is mapping players in AI in the Global South. This multipartner project involves UNESCO's Communication and Information Sector and the newly established UNESCO Chair in Artificial Intelligence, John Shawe-Taylor, Professor of Computational Statistics and Machine Learning at University College London. As of April 2019, the project had identified 286 start-ups in Asia (excluding China), 29 in sub-Saharan Africa and 22 in the Middle East and North Africa. The project is also mapping AI players in the Global South in academia, accelerators and investors, corporate entities and the social sector[10].

10 See: https://www.k4all.org/project/aiecosystem/

Box 3.
The social compact between IBM and the Government of South Africa

The Government of South Africa has passed legislation to ensure that companies behave as responsible corporate citizens. Codes of Practice require all entities operating in the South African economy to contribute to the objectives of Broad-based Black Economic Empowerment (B-BBEE). Since multinationals may have global practices preventing them from complying with the ownership element of B-BBEE through the traditional sale of shares to black South Africans, the Codes of Practice have made provision for the recognition of Equity Equivalent contributions, as an alternative contribution to the economy.

Equity Equivalent programmes are expected to contribute towards the achievement of:

- enterprise creation and development;
- foreign direct investment ;
- accelerated empowerment of black rural women and youth;
- sustainable growth and development.
- human development with focus on education and skills development;
- infrastructure investment with emphasis on developing the country's research and development infrastructure.

When IBM decided to set up a research lab in South Africa in 2016, it first had to convince the government that the company's research focus would reflect national priorities. One outcome of the negotiations was an agreement under which IBM set up an Equity Equivalence Investment Programme.

Dr Tapiwa Chiwewe from IBM Research in South Africa described how the multinational corporation was fulfilling its social obligations, at a session on capacity-building in basic and applied research organized on 13 December 2018 as part of UNESCO's Forum on AI for Africa.

He explained that IBM was focusing on healthcare, education, agriculture and financial services in South Africa, as these were major challenges for the country. 'Before IBM takes on a new project', he said, 'it first checks that there is a pressing problem needing to be solved. It then brings an external partner on board to understand the context of the problem better and ensure that the solution developed is fit for purpose. IBM may obtain private data (or publicly available data) from that partner and use that to solve a given problem… To ensure that AI solutions are fair, IBM analyses the source of data, the output of the AI models and the underlying algorithms to check for bias'.

Dr Chiwewe gave examples of the type of research work being done by IBM. 'For instance, there is a four-year lag in reporting cancer statistics in South Africa', he said. 'AI can correct this by automating the process of studying pathology reports, meaning that this analysis can now be done in near-real time. To take another example, in the financial sector, access to credit is a problem. An AI application can create a credit score that will reduce the default rate on repaying loans'.

The IBM research lab in South Africa is located in the Tshimologong digital innovation precinct, an innovation hub close to Wits University. In parallel to the research lab, IBM has set up an academic programme offering internships and scholarships to South African students. IBM has also awarded faculty awards to professors doing work in key technology areas.

Dr Chiwewe and his colleagues spend time giving talks at universities to share their knowledge of AI. They also organize student competitions on related themes. From his visits to computer science departments across South Africa, he has noticed that few of them are doing research on AI. 'There is a need for curricular reform in these departments to develop skills'.

IBM also has an enterprise development programme that mentors young inventors. One participant asked whether the growing concentration of AI in the hands of a few multinationals was not having a detrimental effect on South African start-ups, which could easily be swallowed up by these tech giants.

In reply, Dr Chiwewe cited examples of South African start-ups in AI that had become viable businesses. JUMO, for instance, has launched an AI-powered platform to assess lending risk and tailor financial products to those living in developing countries where credit information is scarce; it has received an investment of US$52 million from several investors, including Goldman Sachs.

Another start-up, NMRQL, has launched an AI-powered unit trust fund.

'Today's start-ups have the advantage of being able to access equipment via the cloud from companies such as IBM', he said, 'where the start-ups could even open free accounts. There is a freer flow of information and knowledge nowadays which gives start-ups an advantage'.

Dr Chiwewe assured participants that 'IBM believes in the open source movement and donates some of its patents to open source initiatives. To empower African youth with digital skills and tools to improve their daily lives and provide access to a wide range of opportunities, anyone can log onto IBM's Digital Nation Africa to learn about technologies such as AI and obtain a certificate. For more advanced technologies like quantum computing, people can access a 16-qubit quantum computer via the cloud through IBM's Q Experience'.

For details of the Equity Equivalence programme, see: https://www-05.ibm.com/za/aic/programme.html

5.3.2. Open source and open science movements can make a difference

The open source and open science movements are striving to level the playing field in AI. Thanks to the lower cost, free open source software can improve access to technologies in the developing world, in particular, and provide a sustainable basis for scientific decision-making.

According to the World Information Technology and Services Alliance and Information Handling Services Global Insight Inc., global spending on computer software and services (excluding software embedded in devices) amounted to an estimated US$1.2 trillion in 2011 (see Figure 3), or almost one-third of global spending on information and communication technologies (ICTs) the same year, which is equal to about 2% of GDP (UNCTAD, 2012).

An estimated 10 million people were employed in the global computer software and services sector in 2011. National shares of this sector ranged from 0.1% to 2.2% of total employment. The developing countries with the highest proportion of employment in this sector, according to available data, were Costa Rica (0.8%), South Africa (0.7%) and India (0.6%) (UNCTAD, 2012).

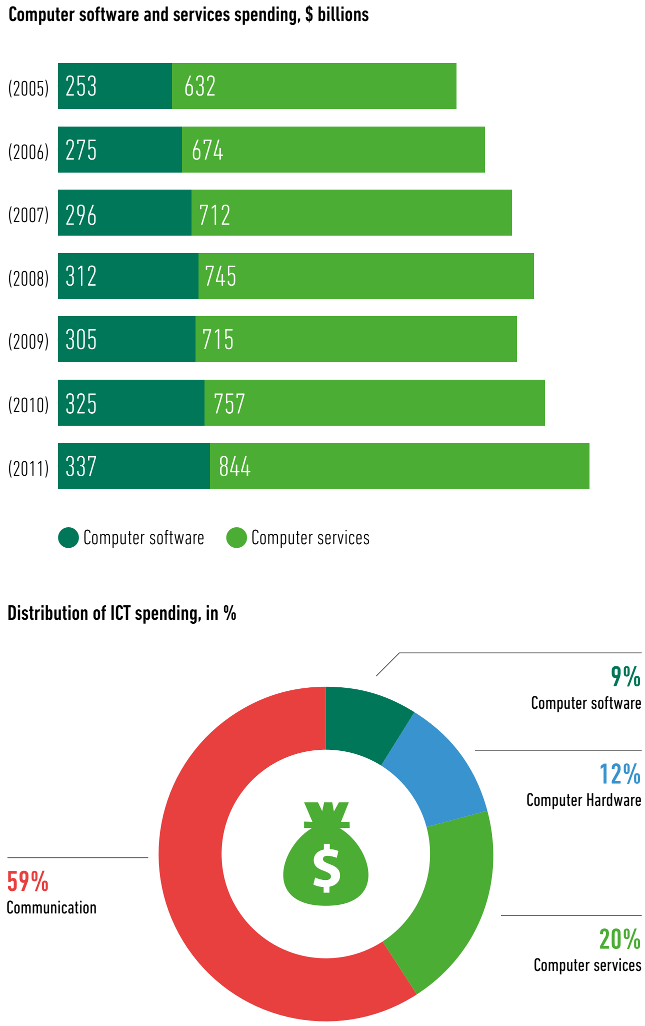
There is considerable regional variation in the intensity of policy initiatives related to free open source software, according to global surveys conducted by the Center for Strategic and International Studies (CSIS, 2010). Europe is the most active region, accounting for close to half (46%) of all initiatives, with a high approval rate (see Table overleaf). Among developing regions, Asia is the frontrunner with more than 80 initiatives, followed by Latin America (57) and Africa (9).

However, many buyers still attach importance to the reputation of the brand names of proprietary software vendors and it is not uncommon for software users in both the public and private sectors to associate price with importance, thereby discouraging lower-cost solutions. At the same time, there is a dire need in low-income and middle-income economies for affordable and accessible specialized software in engineering.

Hydrologists are constantly creating innovative mathematical models to manage water in an effective way, to solve local problems. For these models to be effective, however, they should be easy to use and capable of handling massive data sets. This last step requires sophisticated software infrastructure, which is expensive and may take years to build.

In 2013, UNESCO launched the Hydro Free and (or) Open-source Platform of Experts (HOPE[11]) initiative. HOPE brings experts together for capacity-building and training using free open source software. HOPE has also been designed to stimulate cooperation in R&D and enhance the dissemination of free open source software. Since education is becoming increasingly linked to technology, it is essential to promote and foster equal access to ICTs, in order to improve the quality of education in the water sector. HOPE contributes to this by providing youth and young professionals in the water sector with training in how to use free open source software (*see also p. 40*).

Figure 3.
Global expenditure on computer software and services in 2011



Source: graphic by UNESCO, using data from UNCTAD, 2011

There are a number of independent initiatives in ecological monitoring that permit open-source information-sharing, significantly reducing costs. The following are some examples. Open databases supporting *in situ* activity sensors include the Tropical Ecology Assessment and Monitoring (TEAM) Network Education portal, the TRY plant trait database and the Bio acoustica online repository and analysis platform. DNA sequences are shared as reference sources for DNA barcoding. GEO BON, meanwhile, supports open datasets for Exceptional Biodiversity Variables through its own portal (Mulatu *et al.*, 2017). A vast array of types of open source software are available for remote sensing and data analyses.

11 https://en.unesco.org/hope

There are also initiatives in the private sector. Open AI is a non-profit firm whose 60 full-time researchers and engineers focus on problems that require the team to make fundamental advances in AI capabilities. They publish their research at machine learning conferences and use open-source software tools. Their website states that 'we will not keep information private for private benefit but, in the long term, we expect to create formal processes for keeping technologies private when there are safety concerns'[12].

Table.
Open source policy initiatives by region, 2000–2009

	Approved	Proposed	Failed	Total
Europe	126	27	10	163
Asia	59	20	2	81
Latin America and the Caribbean	31	15	11	57
North America	16	11	10	37
Africa	8	1	–	9
Middle East	5	2	–	7

Source: CSIS, 2010

> " Open-source platforms enable anyone with a computer and an Internet connection to modify... the code anonymously and legitimately

These safety concerns are very real. AI software and hardware are vulnerable to the usual security breaches in cyberspace. However, open-source AI development projects also enable anyone with a computer and an Internet connection to modify open-source machine learning libraries or the code anonymously and legitimately. This makes it hard to attribute ownership to a given AI system, and thus accountability, should something go wrong. In light of the growing number of open-source AI development projects, Jayshree Pandya, Founder of Risk Group, deems it urgent to define a security risk governance framework for AI. 'How will we regulate AI when humans will likely lose control of its development?' she wonders. She observes that 'there may also come a day when AI systems are capable of changing their own code or self-replicating' (Pandya, 2019).

12 See: https://openai.com/about/

5.4. AI: the new space race?

It has been suggested that AI may be the new space race. The Centre for a New American Security, a think tank based in Washington DC, has stated that 'falling behind in AI development and implementation would present a risk for US global economic and military leadership. The United States may very well be in a new space race' (Horowitz *et al.*, 2018).

The President of the Russian Federation stated in 2017 that 'artificial intelligence is the future, not only for Russia, but for all humankind. It comes with colossal opportunities but also threats that are difficult to predict. Whoever becomes the leader in this sphere will become the ruler of the world' (*Russia Today*, 2017).

China's *Next Generation Artificial Intelligence Development Plan* (2017) fixes the targets of attaining the same level in AI as the USA by 2020 and of becoming the world leader in AI by 2030 (Asgard and Roland Berger, 2018).

Chinese start-ups in AI already numbered 383 by 2017. This places China well behind the world leader, the USA (1 393), but ahead of Israel (362), the UK (245), Canada (131), Japan (113), France (109), Germany (106) and India (82). The Republic of Korea ranks 12th and the Russian Federation 20th (Asgard and Roland Berger, 2018).

5.5. What will greater automation mean for low-skilled jobs?

The same economies dominate both AI patents and industrial robots. Although most industrial robots are not yet equipped with AI, robots and other cyberphysical systems are now being designed to monitor production and make independent decisions on the factory floor.

Five economies accounted for 74% of global sales in industrial robots in 2016: China (excluding the Taiwan Province of China, which is the sixth-biggest market), the Republic of Korea, Japan, USA and Germany. The most automated countries in the world are the Republic of Korea, Singapore, Germany and Japan. However, China has become the world's biggest market for industrial robots: between 2013 and 2016, Chinese robot suppliers expanded their global market share from 25% to 31% (IFR, 2017).

In China's Guangdong Province, the Midea manufacturing company has reduced its workforce by half since it introduced robots onto the factory floor in 2011. These robots were bought from Kuka, Germany's biggest and most advanced manufacturer of robots. In 2016, Midea purchased Kuka (Tsang, 2016). As of 2013, Midea had about 100,000 employees in China and abroad.

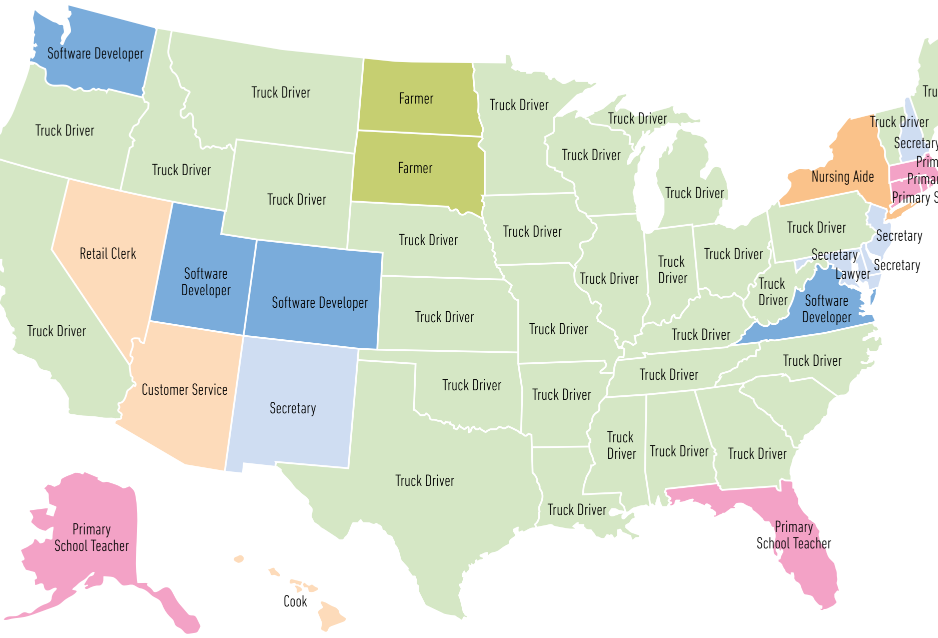

Ju1978 / Shutterstock.com

Between 2011 and 2016, the supply of industrial robots worldwide increased by about 31% per year. By 2016, there were about 1.8 million operational robots and their number is expected to top 3 million by 2020. Most robots are employed in the automotive industry (35%) but, thanks to strong growth in Asian demand, the electronics and electrical industry took 31% of the market in 2016, including in China, Japan and the Republic of Korea (IFR, 2017).

> Automation driven by AI will see many industries replaced by new ones.

Automation driven by AI will see many industries replaced by new ones. 'Up to 47% of US jobs in 2010 were rated as highly likely to become computerized in the next 10–20 years' (WEF, 2016). According to a study by the University of Minnesota that drew on US census data, truck-driving was the most common job in 29 out of 50 US states in 2014 (Quoctrung, 2015; see Figure 4). These jobs would be threatened by self-driving trucks, as would the secondary economy built around them, such as the roadside cafés and motels that rely on the custom of truck-drivers.

Figure 4.
Most common jobs in the USA by state, 2014

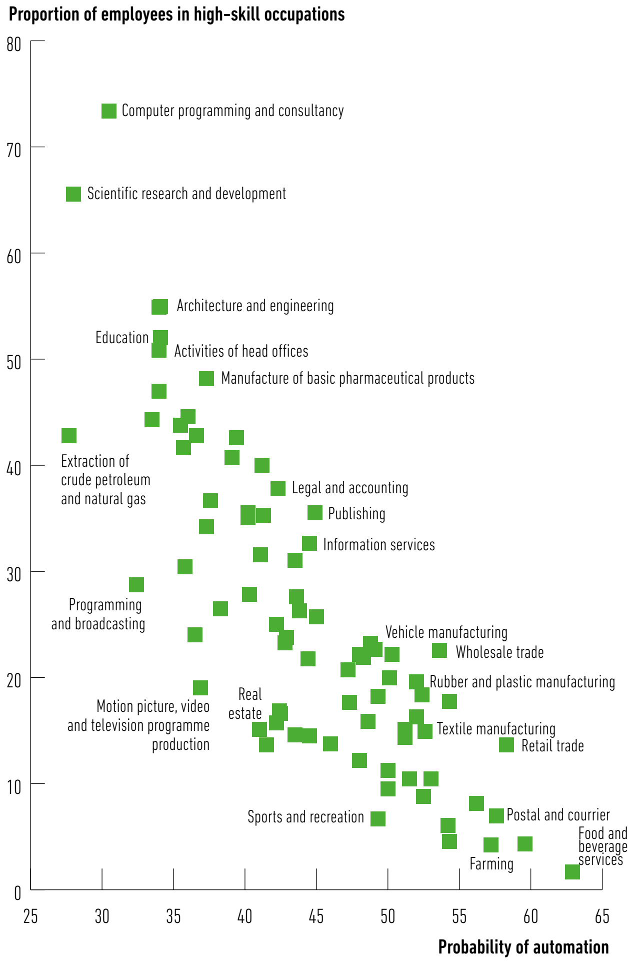


Source: IPUMS-CPS/University of Minnesota, credit Quoctrung Bui/National Public Radio, USA, Reproduced with permission

Jobs are poised to disappear from places such as the factory floor, fast food and retail outlets, call centres and trucking companies but certain skilled professions will also be affected by greater automation, such as accounting or publishing. The media and entertainment industry has become the top digital industry, followed by retail and high technology (UNCTAD, 2017). Product digitization has had a sweeping impact on jobs in cultural industries: trade in recorded music declined by 27% and that in movies by 88% between 2004 and 2013, even as audio-visual services as a whole have gained ground (UNESCO, 2016).

According to a study of employment trends tied to automation in England between 2011 and 2017 by the UK Office for National Statistics (ONS, 2019), 'as the proportion of employees in high-skill occupations increases, the probability of automation decreases. For those industries where half of the workforce or more are highly skilled, their probability of automation is at least 35%' (see Figure 5). Women in England account for 70.2% of employees in jobs with a high risk of automation but only 42.6% of employees in jobs with a low risk of automation. Over the six years to 2017, retail outlets in England installed additional automatic check-outs, resulting in the loss of one in four (25.3%) supermarket cashier jobs. Most of the cashiers were women. At least 15% of laundry workers, farm hands and tyre-fitters in England also lost their jobs to automation over this period, the study found. It estimated that about 1.5 million of the country's workers were at a high risk of losing their jobs to automation (ONS, 2019).

Figure 5.
Probability of automation in England in 2017, by the proportion of employees in high-skilled jobs for different industries (%)



Source: ONS (2019) Annual Survey Population, UK Survey of Adult Skills, Figure 8 (open access)

What impact will demographic growth have on the labour market in countries where agriculture, manufacturing and services are increasingly automated? Could widespread automation be a boon for countries like Japan that are confronted with depopulation?

The drive for automation could have the biggest impact on employment in low- and middle-income countries, since most of the lower-skilled jobs requiring automation in high-income countries have already gone through this transformation. Progress in developing AI systems with voice recognition and speech capabilities may do away with the need for call centres, for instance, which are often situated in developing countries. The drop in the availability of lower-skilled jobs could also exacerbate gender inequality, as more men compete with women for the same jobs (WWWF, 2017).

Is the digital economy creating fewer jobs than traditional industries?

There is also a risk that value produced in low- and middle-income countries could revert to high-income countries, creating a form of cybercolonialization, such as in the case of Uber drivers who would no longer share company profits if the multinational corporation replaced them with self-driving cars (WWWF, 2017).

More broadly, is the digital economy creating fewer jobs than traditional industries? Frey and Rahbari (2016) argue that, 'while today's technology sectors produce fewer jobs than the ones that preceded them, their indirect impacts on job creation are far greater.... The fate of workers thus depends less on job opportunities created by biotech companies or computer firms [than] on the demand for local services created by those companies'.

Notwithstanding this, in 2010, only 0.5% of the US labour force was employed in industries that didn't exist in 2000, such as online social media networks or video and audio streaming. Compared to the major corporations behind the early development of computer technology, such as IBM or Dell, companies leading the digital revolution have relatively few employees. In 2013, Facebook counted only 7,185 employees, compared to 431,212 and 108,800 respectively for IBM and Dell (Berger and Frey, 2015). Berger and Frey (2015) conclude that 'because digital businesses require only limited capital investment, employment opportunities created by technological change may continue to stagnate as the US economy is becoming increasingly digitized'.

The digital economy is certainly undermining job security. According to Muntaner (2018), 'most digital economy workers are exposed to the health-damaging precarious employment conditions characteristic of the contemporary working class in high-income countries'. Online digital platforms in these countries are seizing on the opportunities offered by the gig economy to limit the cost of labour. They treat their delivery staff like freelancers, rather than employees. In France, a cyclist paid by a digital platform like Deliveroo or Take Eat Easy to deliver meals or a chauffeur hired by Uber to collect the platform's customers must provide their own means of transport. They have no employment contract with the platform and, thus, no job security, no right to an unemployment benefit, no statutory holidays, no sick leave. Once their costs have been deducted, they earn less than the hourly minimum wage in France, according to Amellal (2018), for whom these digital platforms are eroding more than a century of social gains in France.

The courts are beginning to regulate these platforms. In November 2018, the French supreme court, the Cour de Cassation, awarded a cyclist working for Take Eat Easy the status of company employee. In January 2019, the Court of Appeal of Paris rendered a judgment affirming that a chauffeur working for Uber was entitled to an employment contract (Collas, 2019).

5.6. Growing competition for skills

According to a 2018 survey of nearly 1,400 CEOs in 91 countries, many companies face 'a shortage of skilled talent to clean, integrate and extract value from big data and move beyond baby steps toward AI'... It's not only a matter of hiring or developing AI specialists and data scientists. It is equally important to cultivate a workforce ready to use AI-based systems'. In Asia-Pacific and Africa, as many as 35% and 45% of company CEOs respectively express 'extreme concern' about the availability of necessary skills (PwC, 2019).

The current skills gap is preventing companies from embracing AI. Although 85% of company CEOs surveyed feel that AI will significantly change the way they do business in the next five years, nearly one-quarter of them have no plans to pursue AI 'at the moment'. A further 35%'have plans do so in the next three years (PwC, 2019).

> The current skills gap is preventing companies from embracing AI

According to the survey, globally, CEOs see retraining and upskilling as the best answer but it will take 'time and money'. More than one-quarter of Middle East CEOs see 'hiring from outside their industry' as a potential solution, as do one in five CEOs in Western Europe (PwC, 2019).

The survey suggests that 'governments and businesses need to work together to help their people adjust to the disruptive impact of new technologies. A culture of adaptability and lifelong learning will be crucial to spreading the benefits of AI and related technologies widely through society' (PwC, 2019).

> The skills shortage is fostering growing competition [in] both the domestic and international labour markets

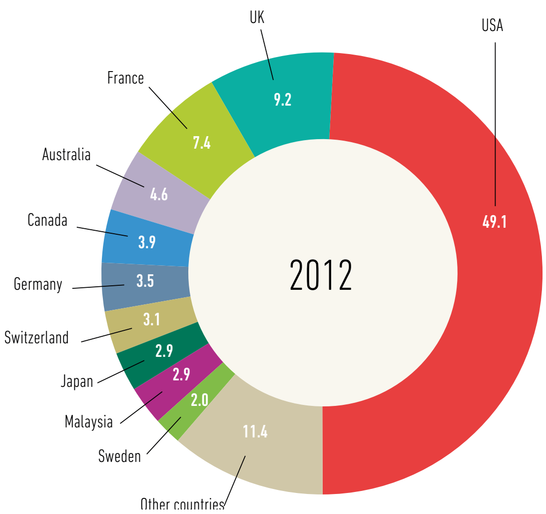
The skills shortage is fostering growing competition, as companies and institutions vie to attract and retain talent. This trend is affecting both the domestic and international labour markets. The Japanese government's selection criteria for most large university grants now take into account the proportion of foreigners among teaching staff and researchers[13] (UNESCO, 2015, p.35).

Employers increasingly consider mobility among skilled employees to be an asset. 'Studies conducted across Europe have shown that a high level of mobility by qualified personnel across countries and between the public and private sectors contributes to the overall professionalism of the labour force, as well as to the innovative performance of the economy' (UNESCO, 2015, p.81).

The European Union now requires public-funded bodies to advertise vacancies internationally and has introduced a 'scientific visa' to slash the red tape for non-EU nationals submitting job applications. These policies have been inspired by the need to augment the number of researchers in the EU, a significant share of whom will have to come from third countries (UNESCO, 2015, p.242).

Countries of all income levels are striving to attract foreign talent – but not necessarily for the same reasons (see Figure 6). Malaysia's general population is not shrinking[14] but it does suffer from a shortage of skilled personnel, a situation which also poses a dilemma to the numerous multinational electronics firms it hosts. Brain drain is a problem, with Singapore alone absorbing 57% of the diaspora. Malaysia plans to become the sixth-biggest destination for international students by 2020; by 2012, it already tied with Japan for eighth place, with 2.9% of all international PhD students in science and engineering enrolling in Malaysian universities (see Figure 6).

Figure 6.
Distribution of international doctoral students enrolled in science and engineering programmes by host country, 2012 (%)



Source: UNESCO Science Report: towards 2030 (2015), Figure 2.12

13 By 2013, 15.5% of graduate students in Japan were of foreign origin (UNESCO, 2015).

14 Malaysia's population grew by 1.6% in 2014 (UNESCO, 2015).

Around the world, regional economic communities are taking inspiration from the EU model by twinning scientific integration with economic integration. Scientific mobility is a key element of this strategy. The Association of South East Asian Nations (ASEAN), for instance, plans to remove restrictions to the cross-border movement of people and services, as part of the ASEAN Economic Community's drive to create a common market and production base. In parallel, ASEAN's *Plan of Action on Science, Technology and Innovation 2016–2025* 'aims to strengthen scientific capacity in member states by fostering exchanges among researchers both within the region and beyond' (UNESCO, 2015, p.76).

> Scientists have never been so mobile

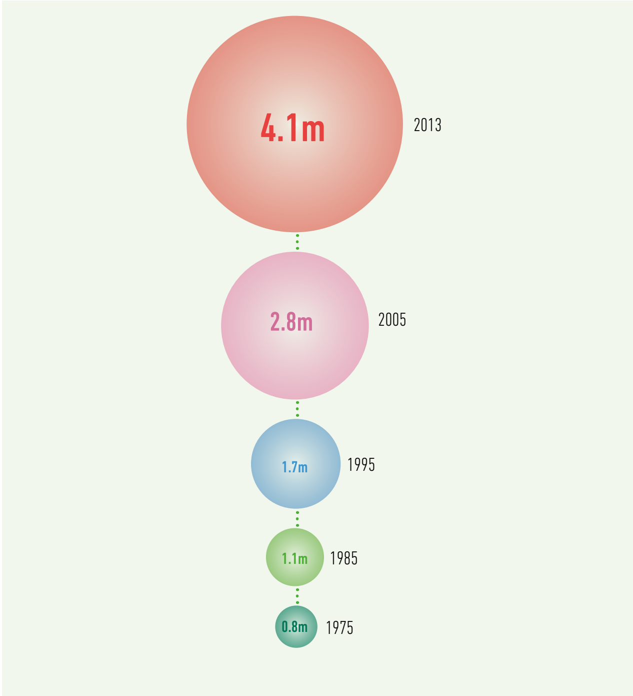
Scientists have never been so mobile, particularly when it comes to university students and the private sector. The number of those opting to study abroad grew by almost 50% between 2005 and 2013 (see Figure 7). In parallel, 'increasingly, firms are relocating their research laboratories abroad. Universities, by and large, remain much more immobile, with only a small minority setting up campuses abroad' (UNESCO, 2015, p.57).

> One in four scientific articles was cosigned by a foreign collaborator in 2014

The desire to attract foreign talent is driving not only physical mobility but also virtual mobility, thanks to the development of digital technologies. In research, there has been a global move towards open science through online international collaboration and open access to scientific publications and underlying data. One in four scientific articles produced around the world was cosigned by a foreign collaborator in 2014, compared to one in five a decade earlier (UNESCO, 2015).

With 60% of people now living in countries with a stagnant or shrinking workforce, companies 'that can't find the talent they need in one country use remote working to employ people elsewhere' (WEF, 2016).

Figure 7.
Long-term growth of tertiary-level international students, 1975–2013



Source: *UNESCO Science Report: towards 2030* (2015), Figure 1.4

5.7. The need for skills to keep pace with technology

5.7.1. A trend towards greater investment in R&D

For countries to reap the benefits of the Fourth Industrial Revolution, they will need to invest in research infrastructure and equipment and to train a critical mass of scientists and engineers.

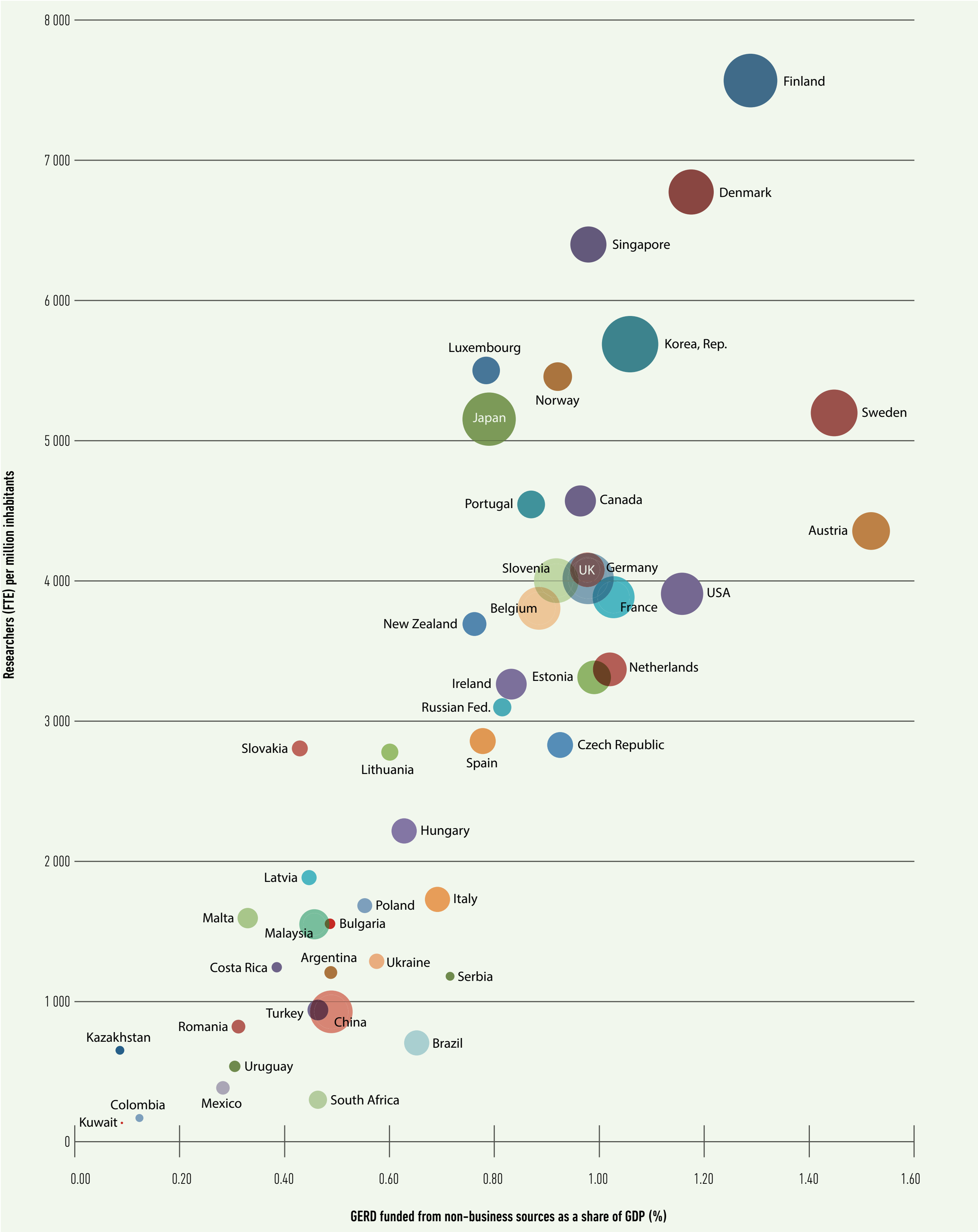
The good news for developing countries is that the availability of cloud computing infrastructure and the increasing processing power of common computers are lowering the cost of AI research infrastructure.

However, as we have seen in section 5.3, much of the current investment in AI is being driven by the private sector, which has less access to financial support in developing countries. There is a correlation between government support for R&D and business investment in the same. 'Once countries are prepared to invest more in research personnel and in publicly funded research, the propensity of businesses to invest in R&D also grows' (UNESCO, 2015, see Figure 8).

Figure 8.

Mutually reinforcing effect of strong government investment in R&D, 2010–2011

The size of the bubbles is proportionate to business sector funding of R&D as a share of GDP (%)



Source: UNESCO, 2015, Figure 1.3

As of 2015, the G20 still accounted for a disproportionate share of both human and financial investment in R&D: two-thirds (64%) of the global population but 91% of research expenditure and 86% of the world's researchers, according to the UNESCO Institute for Statistics.

Investment in R&D is, nevertheless, growing in developing countries. Between 2007 and 2013, investment in R&D among low-income countries even doubled to PPP$3.9 billion, equivalent to PPP$38 000 per researcher[15] (UNESCO, 2015, Table 1.2).

> Once countries are prepared to invest more in research personnel and in publicly funded research, the propensity of businesses to invest in R&D also grows

Despite the global economic and financial crisis, global expenditure on R&D grew from PPP$1,132 billion to $PPP1,478 billion between 2007 and 2013. Even as governments in high-income countries reacted to the crisis with austerity budgets, the business enterprise sector in many countries maintained or even augmented its own investment in R&D as a buffer against the crisis (UNESCO, 2015, p.30).

Many developing countries, meanwhile, used the global commodities boom to raise their own investment in R&D, including Argentina, Brazil, Ethiopia, Malaysia, Mexico and Turkey. China invested massively in R&D, doubling its global share of expenditure to 20% in the six years to 2013 (UNESCO, 2015, p.30).

Between 2007 and 2013, the number of researchers worldwide grew by 21% to 7.8 million. Researcher density grew in countries of all income levels. Among low-income countries, the number of researchers rose from 99 to 121 per million inhabitants (in full-time equivalents) between 2007 and 2013. Growth in some upper middle-income countries has been spectacular, such as in Argentina (from 984 to 1,256 per million); China (853 in 2009 to 1,071); Malaysia (368 in 2006 to 1,780 in 2012); and Turkey (715 to 1,189 per million). The global average rose to 1,083 per million (UNESCO, 2015, Table 1.3).

In November 2017, UNESCO adopted the *Recommendation on Science and Scientific Researchers*, following broad consultations. This normative instrument provides countries with guidelines on how to nurture endogenous research and development.

UNESCO is currently developing a series of indicators to monitor countries' implementation of the Recommendation, including those that track progress toward Sustainable Development Goal (SDG) 9.5, namely to *Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending.*

The UNESCO Institute for Statistics, which is the United Nations' custodian for indicators SDG 9.5.1 and 9.5.2, already surveys UNESCO member states regularly to collect data on research expenditure and research personnel. The Recommendation goes a step further by making it a legal obligation for all Member States to supply national data regularly. It also provides a package intended to build up every country's community of scientists, which is the specific sense of SDG 9.5.

5.7.2. An underexploited pool of talent

Only three out of ten researchers in the world are women (2013), meaning that most countries are underexploiting their talent pool, including in the developed world. The notable exceptions are Latin America and the Caribbean, as well as states in Europe and Central Asia which formed part of the Communist bloc at the time of the Union of Soviet Socialist Republics (UNESCO, 2015, Figure 3.2).

In the great majority of countries, women researchers work mainly in the public sector. This phenomenon is uncorrelated with a country's level of development. For instance, women make up one-third of researchers in the business enterprise sector in Botswana, Kenya, Namibia, Portugal, the Russian Federation, South Africa, Thailand and Vietnam, compared to 26% in Belgium, Chile, Colombia, Singapore, Slovenia and Sweden, 20% in Slovakia, France and Poland, 14% in Germany and the Republic of Korea, 15% in Ethiopia, 11% in India and 8% in Japan. In the Arab world, 37% of researchers are women but, for half of the Arab countries reporting data, barely any women at all work in the business sector (UNESCO, 2015). These trends have implications for domestic innovation, insofar as the private sector is the main driver of the Fourth Industrial Revolution.

Women graduates dominate life sciences in many countries but are still a minority in mathematics, physics, engineering and computer sciences, fields that play a vital role in the digital economy (UNESCO, 2015).

15 Dollar amounts are calculated in purchasing power parities to facilitate international comparisons. According to this approach, a given sum of money, when converted into US dollars at the purchasing power parity rate (PPP$), will buy the same basket of goods and services in all countries.

Box 4.

Overcoming the physical limits to miniaturization of brain implants

Dr Nazek El-Ateb in her lab

Most electronic components have been shrinking in recent decades, including those found in cellular telephones, laptop computers, cameras and medical devices. The problem is that traditional miniaturization techniques have reached their physical limits. Below a certain size, the capacity for memorization of these tiny devices degrades.

In 2017, Dr Nazek El-Atab won the L'Oréal-UNESCO For Women in Science International Rising Talent award for her research into the fabrication of atomic-scale devices. Thanks to the 'quantum-confinement effect', these devices can tune electronic and optical properties of materials with more precision than conventional devices, saving time and money. Using a technique known as Atomic Layer Deposition (ALD), the device can construct the active layer of nanoscale transistors and memory cards in a single step.

Dr El-Atab's current research focuses on the fabrication of 3D nanotube-based nano-electronics that will potentially overcome the decade-long challenge of developing electronics for implantation in the brain. Brain implants could enable the deaf to hear, the blind to see and the paralyzed to control robotic arms and legs.

Dr El-Atab is a Postdoctoral Research Fellow at the MMH labs of the Computer Electrical Mathematical Science and Engineering Division of the King Abdullah University of Science and Technology in Saudi Arabia.

She is one of a growing number of L'Oréal-UNESCO For Women in Science laureates and fellows whose research is nurturing the Fourth Industrial Revolution.

For details, see: https://en.unesco.org/science-sustainable-future/women-in-science

Since the establishment of the three most prestigious international prizes for mathematics (Fields, Wolf and Abel), only two women mathematicians have been recognized, out of a total of 142 laureates.

> Women are still a minority in mathematics, physics, engineering and computer sciences, fields that play a vital role in the digital economy

The L'Oréal–UNESCO Programme for Women in Science has been raising the profile of exceptional women researchers for the past two decades through a system of annual prizes and research fellowships, in order to change attitudes towards women researchers and provide young girls with positive role models (see Box 4). The programme's slogan is 'The world needs science. Science needs women'.

In 2019, the L'Oréal Foundation and UNESCO extended the international awards dedicated to materials science to mathematics and computer science. Two mathematicians figure among the five laureates of the 2019 edition of the Women in Science programme, Claire Voisin (France) and Ingrid Daubechies (USA).

5.7.3. The case for investing in cross-disciplinary education and new knowledge creation

AI and machine learning, together with a host of other innovative technologies that include robotics, nanotechnology, 3D printing and additive manufacturing, genetics and biotechnology, are forming the bedrock of new markets for products and processes that will shape the way people live and do business in the decades to come.

This trend offers opportunities for developing countries to tap into these markets. Many of the aforementioned fields possess a set of both softcore and hardcore applications, the former being much cheaper than the latter to produce. For example, softcore applications in nanotechnology utilize locally available chemicals and chemical reactions to produce new nano-materials in a bottom-up approach that is much more cost-effective than the top-down alternative, which focuses more on manufacturing solid-state components that require costly clean rooms. Nanotechnology has been dubbed the 'technology of the poor' on account of these softcore applications.

Many products developed using nanotechnology, biotechnology and nano-biotechnology are gradually replacing more expensive alternatives as demand for them grows. This is the case for nano-based pesticides and insecticides, for instance. New low-cost fabrics designed using biotechnology, meanwhile, are expected to replace current non-sustainable petrochemical fabrics, which also come with a big price-tag.

> It is from [the basic research laboratories of universities] that the next wave of high technologies will come, in intimate synergy with digital technologies

Disciplines such as molecular biology, biotechnology, nanotechnology and materials science are rooted in the basic research laboratories of universities. It is, thus, from these laboratories that the next wave of high technologies will come, in intimate synergy with digital technologies (UNESCO, 2015, p.427). This is why it is so vital for a country to invest in basic research, if it wishes to be an active player in the Fourth Industrial Revolution.

> The use of ready-made solutions has tended to be favoured over spending valuable time on developing a bespoke solution or product.

However, value creation nowadays often depends on using existing knowledge better rather than generating new knowledge (basic research), whether process technologies are developed domestically or not. Ever since the 1990s, the use of ready-made solutions has tended to be favoured over spending valuable time on developing a bespoke solution or product. During the heady years of high oil prices in the first years of the 21st century, Russian companies preferred to import advanced technologies, rather than use the boon to develop their own, even though this led to a growing dependence on developed countries in certain areas, such as pharmaceuticals and high-tech medical equipment (UNESCO, 2015, p.343).

In the software industry, ready-made solutions have been extremely effective in reducing the time and cost of software development but this has created a form of dependence. Buying a software off the shelf may work well when the end-user lacks the knowledge and skills to tailor a solution to their specific needs but it does mean that the company utilizes the existing technology without taking part in developing any of its components. This creates a lost opportunity for the company to hone the skills of its employees while creating value.

The same goes for AI. Many AI solutions and algorithms are purchased off the shelf by customers who played no part in their development. The extent to which companies in developing countries can draw on technical knowledge will largely determine their ability to generate dynamic, environmentally sustainable productive capacities. These companies will only be able to leapfrog over costly investment in infrastructure by ensuring they possess a sufficient absorptive capacity to build on the backlog of unexploited technologies and benefit from the associated lower risks.

At the government level, it will be of utmost importance for developing countries to set up innovative practical policies and programmes that can successfully deliver food security and robust rural development, in order to promote the desired pro-poor economic growth, whereby the income of the poor grows at a faster rate than that of the rest of the population.

> Scientists and engineers will also need to be retrained

Given the ways in which AI is already changing the conduct of research, scientists and engineers will also need to be retrained. A risk for developing countries is that some of their best researchers in AI may be attracted to multinational corporations by lucrative salary packages and other benefits. On 13 June 2018, Google announced the creation of the first centre for AI in Accra, the capital of Ghana. A month later, Google began recruiting researchers specializing in machine learning.

How can local employers compete effectively to retain the skills they need? It will be important to raise awareness among policy- and decision-makers in developing countries of the policy options at their disposal to tackle internal and external brain drain, among other challenges.

As we have seen, the world of work is changing radically, as automation becomes more widespread. For a policy to succeed, it will need to extend to the general population. In order to ensure the broad application of AI and proper quality control of output and recommendations, AI technologies must be disseminated and the general population must be trained to use them, including through the use of open access systems.

This is being done through UNESCO's HOPE initiative (*see p. 31*), for instance. Over the past two years, HOPE has brought together 18 universities, centres and other bodies around the FREE and open source tools for WATer resource management (FREEWAT[16]) project, a Horizon 2020 project financed by the European Commission. FREEWAT takes an innovative participatory approach, bringing together technical staff and relevant stakeholders, including policy- and decision-makers, to design scenarii for the application of conjunctive water policies. The HOPE consortium has also organized capacity-building workshops and seminars and trained 700 participants.

FREEWAT is part of the ICT4WATER cluster, which combines ICT and water management projects, all of which are co-funded by the European Commission. Their common goal is to increase efficiency in water management and enable greater cooperation among water regulators, operators and users by deploying technical solutions. The FREEWAT approach is being used for 14 case studies within the European Union, three case studies in neighbouring countries (Switzerland, Turkey and Ukraine) and is being applied to a large transboundary aquifer in Africa (UNESCO's Groundwater Resources Governance of Transboundary Aquifers project). Training courses have been run in 53 countries spread across all five continents.

5.7.4. An integrated approach to science teaching

The trends outlined above imply that developing countries will need to take a cross-disciplinary approach to education, in order to equip the workforce, in general, and new university graduates, in particular, with the requisite skills to reap the benefits of the Fourth Industrial Revolution. The integrated approach to science teaching has become a priority for UNESCO's International Basic Sciences Programme.

> Developing countries will need to take a cross-disciplinary approach to education

The development of an innovation ecosystem should also include:

- innovative programmes and projects related to the Sustainable Development Goals to tackle infrastructure problems in the spheres of water, health, energy, agriculture and, most importantly, ICT networks to ensure Internet connectivity everywhere;
- a creative set of educational programmes that include well-designed science and engineering fairs (competitions) and well-established science clubs in all schools, as well as science parks within regional knowledge hubs that could be associated with these schools;
- entrepreneurship programmes for secondary schools and universities, including robust pre-incubation and incubation programmes, as well as programmes that build leadership skills among university graduates.

The integrated science teaching approach fluidifies the boundaries between biology, chemistry, mathematics and physics. Current education systems produce graduates who lack a combination of skills. The integrated science teaching approach is striving to overcome this relative disciplinary isolation by establishing internal, external and historical connections between science (such as biology), mathematics and technology (such as nanotechnology or robotics).

It is important to start with school curricula and to ensure continuity through the secondary and tertiary levels of education to overcome the relative disciplinary isolation of scientists in the traditional (fragmented) approach to science teaching. School curricular need to emphasize three dimensions: blurring the boundaries between traditional scientific disciplines; fostering original ideas and creative thinking and; reducing the amount of rote learning (memorization of detail).

A good example of a creative educational programme is enquiry-based (hands-on) science education for the first 12 years of schooling. Enquiry-based (hands-on) learning teaches children the scientific method, which hinges on observation, measurement and experimentation. Pupils learn to formulate hypotheses that they then test and adjust, in light of the results of their experiment. Criticism is a basic tenet of the scientific method. As Sir Peter Medawar put it in his *Advice to a Young Scientist* (1979), 'all experimentation is criticism. If an experiment does not hold out the possibility of causing one to revise one's views, it is hard to see why it should be done at all'.

> Enquiry-based (hands-on) learning teaches children the scientific method

Enquiry-based science education promotes both conceptual understanding and the development of capabilities widely recognized as being vital for everyone in the twenty-first century, such as critical thinking, team work, consideration of alternatives and effective communication. Children are motivated by the satisfaction of having made sense of something they did not previously understand. Enquiry is only one of a range of ways of learning but it is a particularly important one, being based on research and modern views of how pupils learn, as well as the importance of progressively developing a child's understanding of phenomena in the world around them, as their experience grows.

16 See: www.freewat.eu

Currently, it is difficult to add new courses such as nanosciences, robotics, etc. early on in a child's education, as this overloads the curriculum, even though students will encounter this cross-disciplinary approach at a later stage in their education. For instance, advanced computer skills, quantitative thinking and mathematics all are prerequisites for any undergraduate studying microbiology today.

Scientists educated in an integrated manner, regardless of their ultimate professional specialty, will share a common scientific language, facilitating both cross-disciplinary understanding and collaboration by enabling interdisciplinary communication and nurturing the type of researcher who is well-equipped to cope with the rapid and far-reaching advances of the Fourth Industrial Revolution in terms of understanding, experimental techniques and computational analysis.

A growing number of least developed countries are putting cross-disciplinary programmes in place to stimulate a vocation for science among the young and give graduates the skills they need to devise innovative solutions for key development challenges in priority fields such as agriculture, industry, civil engineering, security and health. Digital technologies are being introduced into schools to facilitate this strategic transformation.

> A growing number of least developed countries are putting cross-disciplinary programmes in place

Active learning workshop at RobotsMali

©UNESCO Bamako Office, active learning workshop at RobotsMali

Mali is one such example. The country's *Strategic Framework for Economic and Sustainable Development (2016-2018)* deems 'it particularly timely to use ICTs to develop the teaching of science and technology at secondary level and to encourage girls to opt for scientific careers'[17]. In 2016, the government created an annual Science Fair (*Fête de la science*) and Miss Science contest.

On 19 March 2018, the government inaugurated the National Centre for Collaborative Education in Robotics (*Centre national collaboratif de l'éducation en robotique*, RobotsMali) in the new Cité universitaire of Kabala south of Bamako. In addition to teaching robotics and coding, RobotsMali provides training in AI, electronics and the Internet of Things, as well as in entrepreneurship, marketing, design and project management.

> In addition to teaching robotics and coding, RobotsMali provides training in AI, electronics, the Internet of Things,..., entrepreneurship, marketing, design and project management

As part of its Youth Capacity-building Programme in STI, UNESCO's Bamako office provided RobotsMali with educational material and equipment in 2018, in coordination with UNESCO's Africa Department and with the financial support of China. This material included 40 laptop computers and kits of robots and drones for different age groups: children up to 13 years, teenagers and university students.

The project was implemented in partnership with the Ministry of Education and the Ministry of Innovation and Scientific Research, along with the Malian Association of Women Engineers. UNESCO's Youth Capacity-building Programme in STI also plans to train teachers in primary and secondary schools across Mali in how to teach robotics and to support schools wishing to create their own robotics clubs.

> UNESCO plans to organize short courses on robotics in 2019 in Africa and beyond

17 « Il parait particulièrement opportun de développer l'enseignement des sciences et techniques par l'introduction de TIC au secondaire en favorisant l'accès des filles aux séries et filières scientifiques. » *Cadre stratégique pour la relance économique et le développement durable (2016-2018)*

Through its engineering programme, meanwhile, UNESCO plans to organize short courses on robotics in 2019 in Africa and beyond in partnership with companies working on AI like Quanser. The aim is to demonstrate how secondary schools can incorporate AI into teaching using the hands-on learning approach. The programme is using the same approach to incorporate ethical issues into AI teaching.

5.7.5. Building awareness of AI and critical thinking

In spite of the indubitable promise of AI, the use and deployment of AI as black boxes without a proper understanding of how AI works and the consequences of these technologies is problematic.

> Specific efforts need to be devoted to training researchers from the developing world in basic research related to AI

This is why research and education in AI are a key factor in curbing effects that may not only limit access to AI potential but also damage our societies. These effects include biases in AI, privacy issues and the proliferation of misleading or false information. Moustapha Cissé from Facebook AI Research cites the examples of facial recognition systems which work better with European faces than with African ones and AI systems that can identify skin cancers better in white patients than in black ones (UNESCO, 2018b).

There will be no way to address these issues unless education and basic research in AI expand at the same rate as technological advances in AI. The developing world is particularly vulnerable in this regard. With AI having been developed in Western societies, the detrimental effect of biases are expected to be particularly acute in developing countries, which means that specific efforts need to be devoted to training researchers from the developing world in basic research related to AI (Zou and Schiebinger, 2018).

The ICTP is in the process of establishing a diploma course in Quantitative Life Sciences that includes a strong component on AI and data science.

In parallel, the ICTP has been raising awareness and fostering critical thinking about AI in the scientific community through a series of training workshops and research activities. For instance, the ICTP hosted a school on Large-Scale Problems in Machine Learning in August 2002.

The ICTP– International Centre for Theoretical Sciences Winter School in November 2018 focused on the theme of Learning and AI.

ICTP is working with centres of excellence in Africa, such as the network of the East African Institute for Fundamental Research (a category II centre) in Kigali, Rwanda, to integrate AI into tertiary education curricular and basic research programmes. The ICTP has also been reaching out to the wider public through conferences and a series of video clips for Raiscuola[18].

During Mobile Learning Week in March 2019,UNESCO also reminded a young audience that popular environmental applications (apps) bring many benefits but also demand sacrifices on the part of the user (see Box 5).

Mobile apps can help people to identify a particular animal species.

© Getty Images/FTiarei

18 See, for example (in Italian): http://www.raiscuola.rai.it/speciale-unita/antonio-celani-intelligenza-artificiale-dalleorigini-ad-oggi/286/41405/default.aspx

Box 5.

Building awareness of the pros and cons of common apps

In 2019, the theme of Mobile Learning Week at UNESCO headquarters was artificial intelligence and sustainable development.

At a workshop organized jointly by UNESCO's Natural Sciences Sector and Social and Human Sciences Sector on 5 March during Mobile Learning Week, the public was reminded that popular environmental applications (apps) bring many benefits but also demand sacrifices. These sacrifices might be obvious, such as the amount of time a person spent using the app or their decision to relinquish their right to privacy by giving the app their geographical location.

Other sacrifices were more insidious, the public heard. Clients tended to develop a relationship of dependency on the satellites and cloud used by apps by accepting the information retrieved from them as the ultimate truth, explained Dr Vanessa Nurock, Associate Professor in Political Theory and Ethics at Paris 8 University. In this way, apps had become the modern equivalent of the Gods or oracles worshipped in the past, she said.

The session focused on whether environmental apps were effective educational tools that could also foster citizen science – or just another consumer product.

Dr Will Logan, who heads the International Center for Integrated Water Resources Management in the USA, a 'category 2' centre of UNESCO, presented iRain, a free app that can be used by individuals, schools, local governments and national hydrological services alike to estimate rainfall (see also Box 1).

Dr Logan demonstrated how the apps could be used to anticipate water-related hazards such as flooding, droughts and storms but also to track rainfall over the past 35 years, for instance, to see whether climate change had affected precipitation over a given area, such as the Sahara. He mentioned that people were tailoring the app to their own needs and finding uses for them that the developer had never imagined, a trend applauded by Dr Nurock.

Dr Régine Vigne-Lebbe explained that the apps developed by her university in collaboration with the Museum national d'histoire naturelle (National Museum of Natural History) had been designed to broaden the public's environmental awareness. These apps help people to identify a particular plant or animal species.

Professor of Biodiversity Informatics at the Sorbonne University in Paris, Dr Vigne-Lebbe underscored the difference between apps that were simply connected objects and those that incorporated AI components to enable an automatic identification process.

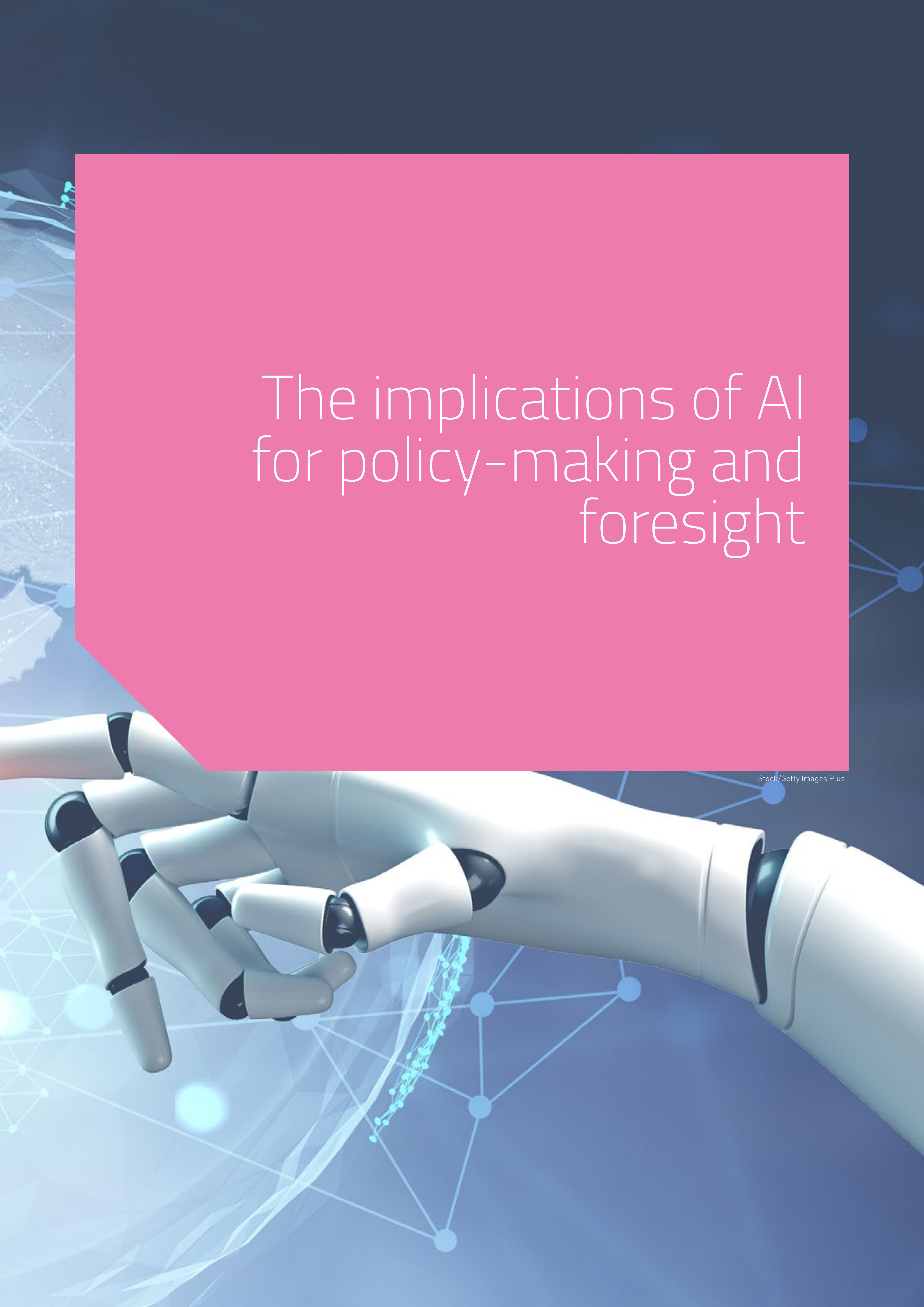
She cautioned budding citizen scientists to remain vigilant when using apps equipped with AI. Machines excelled at data processing and at compiling statistical records, she said, but deep learning worked like a black box. The machine did not explain how it arrived at a certain conclusion, so the user did not learn how to recognize future specimens.

Apps which were simply connected objects, on the other hand, and thus incapable of providing an automatic identification process, could communicate verbally to offer advice and an explanation of how they arrived at their findings, enabling the user to learn the right terminology for describing a plant or animal. Armed with this knowledge, the user would be better equipped in future to identify a species and read relevant literature.

Dr Vigne-Lebbe predicted that future apps would combine human active observation with automatic recognition for optimal results.

For details, see: https://en.unesco.org/news/experts-debate-whether-environmental-apps-are-fostering-citizen-science

The implications of AI for policy-making and foresight



iStock/Getty Images Plus

6. The implications of AI for policy-making and foresight

6.1. A growing number of national AI strategies

The first national AI strategies were adopted by Canada and Japan in March and April 2017. Since then, the list has lengthened. Policy researcher Tim Dutton is regularly updating a list[19] of countries which have adopted AI strategies, or are contemplating doing so. In addition to Canada and Japan, it includes Australia, China, Denmark, Finland, France, Germany, India, Kenya, Republic of Korea, Singapore, United Arab Emirates, United Kingdom and USA.

> How can UNESCO ensure that developing countries are more than simply providers and users of data, more than just clients of AI?

Dutton has observed that 'no two strategies are alike, with each focusing on different aspects of AI policy: scientific research, talent development, skills and education, public and private sector adoption, ethics and inclusion, standards and regulations, and data and digital infrastructure'.

The *UNESCO Science Report* 2020 will be monitoring the development of national and regional AI strategies since 2017 as part of its mandate for tracking global trends in science governance.

Should STI policies promote AI research in developing countries? Currently, much of the developing world tends to be a testing ground for technologies developed elsewhere. How can UNESCO ensure that developing countries are more than simply providers and users of data, more than just clients of AI?

19 See https://medium.com/politics-ai/an-overview-of-national-ai-strategies-2a70ec6edfd

The Natural Sciences Sector has a number of tools at its disposal. It already provides Member States with policy advice to strengthen the governance of national innovation systems. For example, UNESCO's Global Observatory of Science, Technology and Innovation Policy Instruments (GO-SPIN) maps national innovation systems to inform policy-making.

The issues outlined in the preceding section with regard to the growing concentration of AI-related research in the hands of a minority also underscore the need to incorporate issues related to AI in the policy advice provided by UNESCO, in much the same way governments were advised to mainstream the concept of sustainable development in planning processes after publication of the Brundtland Report, *Our Common Future*, 30 years ago. There are plans to launch a series of occasional papers and policy briefs on emerging issues in STI policy, within the *UNESCO Science Report* library. One of the first papers will be looking at policy implications of AI.

UNESCO will also be examining the possibility of mapping global trends in AI implementation and research, to detect hotspots and coldspots and provide evidence for capacity-building strategies and policies.

6.2. Existing policy tools can frame AI strategies

AI is not the first disruptive technology with which policy-makers have been confronted. There have been precedents, such as the emergence of biotechnology and gene editing. In developing a national strategy for AI, governments can draw on earlier approaches to emergent technologies.

Existing policy tools can frame national strategies for AI. This mix includes legislation and other forms of regulation, technology foresight exercises, research priority-setting exercises, participatory approaches to policy formulation and recourse to ethics committees.

It will be important to carry out analytical studies of the socio-economic impact of AI and to devise policies which ensure accountability and transparency, data privacy, respect for civil rights and so on. The development of AI will need to be regulated at both the national and international levels to ensure that, in our globalized world, AI does not become an agent of human and environmental exploitation or neglect.

6.3. AI systems can contribute to policy-making

Policy-makers should complement the focus on AI governance by using AI to extend existing statistical and econometric models for better decision-making.

Together with big data, AI can provide keen insights into trends or answer 'black box' type questions where there is not a clear relationship between input and output. For example, topic modelling can be used to characterize the evolving, dynamic policy environment and thereby identify priority areas. Similarly, clustering algorithms can help to identify non-trivial taxonomies, in order to develop tailored policy instruments.

> Could AI produce models that provide an evidence-based justification for why countries should invest in science, technology and innovation?

Could AI even serve as an advocacy tool? For instance, could AI produce models that provide an evidence-based justification for why countries should invest in science, technology and innovation?

6.4. Regional economic communities can help to frame AI strategies

Regional economic communities may yet prove to be a fertile breeding ground for national and regional AI strategies. Increasingly, communities see regional scientific integration as an integral part of regional economic integration. Many are taking inspiration from the European model of integration. The European Commission adopted the Digital Single Market in 2015 and is currently working with member states to develop a coordinated strategy for AI. The European Union's General Data Protection Regulation (GDPR), meanwhile, imposes stricter data privacy rules on all entities doing business in the European Union (Bradsher and Bennhold, 2019).

In Africa, the *Policy on Science and Technology* adopted in 2011 by the Economic Community of West African States' (ECOWAS) 'is an integral part of *Vision 2020*', the subregion's development blueprint to 2020 (UNESCO, 2015, p.476). The East African Community's Common Market Protocol (2010) makes provision for market-led research, the promotion of industrial research and the transfer, acquisition, adaptation and development of modern technology. States are encouraged to collaborate with the East African Science and Technology Commission and to establish a fund for R&D for the purpose of implementing the provisions in the protocol (UNESCO, 2015). In 2017, the Southern African Development Community ratified its *Protocol on Science and Technology*.

Even though the focus of the Association of South East Asian Nations (ASEAN) has always been on the creation of a single market along the lines of the European model, 'leaders have long acknowledged that successful economic integration will hinge on how well member states manage to assimilate science and technology'. *ASEAN's Plan of Action on Science, Technology and Innovation 2016–2025* 'aims to strengthen scientific capacity in member states by fostering exchanges among researchers both within the region and beyond'. Established in 2015, the ASEAN Economic Community is expected to spur scientific cooperation among member countries, while enhancing the role of the ASEAN University Network, which counts 30 members (UNESCO, 2015, p.76[20]).

6.5. Global strategies will also be necessary to ensure collective choices

Given the ethical issues raised by AI and the fact that multinational companies are driving much of the research in AI, global strategies and guidelines will also be necessary. In the USA, the University of Stanford has set up a Global Digital Policy Incubator[21] to provide 'a vehicle for global multistakeholder collaboration between technologists, governments, private sector companies, diplomats, international organizations, academics and civil society in developing norms and policies that enhance security, promote economic development and reinforce respect for human rights'.

20 See also this blog: www.unesco.org/new/en/media-services/single-view/news/regional_economic_communities_a_conduit_for_southsouth_co/

21 https://cddrl.fsi.stanford.edu/global-digital-policy-incubator/front-global-digital-policy-incubator

Within the United Nations, UNESCO's Commission on the Ethics of Science and Technology (COMEST) is mandated to formulate ethical principles that could provide decision-makers with criteria that extend beyond purely economic considerations. COMEST published a report on Robotics Ethics in 2018 and submitted a preliminary study on the ethics of AI22 to UNESCO's Executive Board in April 2019. COMEST began reflecting on the ethics of the Internet of Things in 2017, the year UNESCO's International Bioethics Committee adopted its own report on *Big Data and Health*.

> The time is more than ripe to define the ethical principles [which will] ensure that AI serves collective choices, based on humanistic values
> *Audrey Azoulay*

For the Director-General of UNESCO, Audrey Azoulay, 'the issues raised by artificial intelligence are not technological. They concern our own humanity, raising scientific, political, philosophical and ethical questions [...]. The time is more than ripe to define the ethical principles that must serve as a foundation and framework for this disruption, to ensure that artificial intelligence serves collective choices, based on humanist values'. She made these comments in Paris on 4 March 2019, while opening UNESCO's global conference23 on the theme of Principles for AI: towards a Humanistic Approach?

At the conference, Angel Gurría, Secretary-General of the OECD, spoke of the need to work with UNESCO in a concerted effort to 'make AI less artificial and more intelligent'. He stated that 'we must progress together on AI-related technical, ethical and legal issues, to foster alignment of standards and codes of conduct, and inter-operability of laws and regulations... Our goal is to ensure consistency and complementarity between OECD work and other international initiatives, including under the G20 and G7, the European Commission, organizations such as the Institute of Electrical and Electronic Engineers and the United Nations, including, importantly, UNESCO itself'. A succession of government ministers and participants from academia, intergovernmental organizations, the private sector, technical community, media and civil society all called for the development of ethical principles to govern AI on the basis of transparency and accountability.

> If we let the invisible hand of the market operate freely, we will get useful apps but our privacy will be eroded and inequalities will grow
> *Fabrizio Hochschild*

Fabrizio Hochschild Drummond, Assistant Secretary-General for Strategic Coordination within the Executive office of the Secretary-General of the United Nations, warned that 'the current preference for non-binding international agreements, part of the shift from cooperation to competition, is making non-binding treaties much more attractive but we cannot rely on everyone to be good. [...] If we let the invisible hand of the market operate freely, we will get useful applications but our privacy will be eroded and inequalities will grow, contributing to the polarization of our societies', he argued. Recently, some leading public figures have come out in favour of global governance of data (see Box 6).

Within the global community, the United Nations' Convention on Certain Conventional Weapons has, meanwhile, been discussing an international treaty which would ban lethal autonomous weapons. Several countries are investing heavily in this field. As of late 2018, member states had not reached consensus on the need for such a treaty.

22 Preliminary Study of the Technical and Legal Aspects relating to the desirability of a Standard-setting Instrument on the Ethics of Artificial Intelligence (document 206 EX/42): https://unesdoc.unesco.org/ark:/48223/pf0000367422

23 See : https://en.unesco.org/news/participants-global-unesco-conference-artificial-intelligence-urge-rights-based-governance-ai

Box 6. Leaders in Davos endorse principle of global governance of data

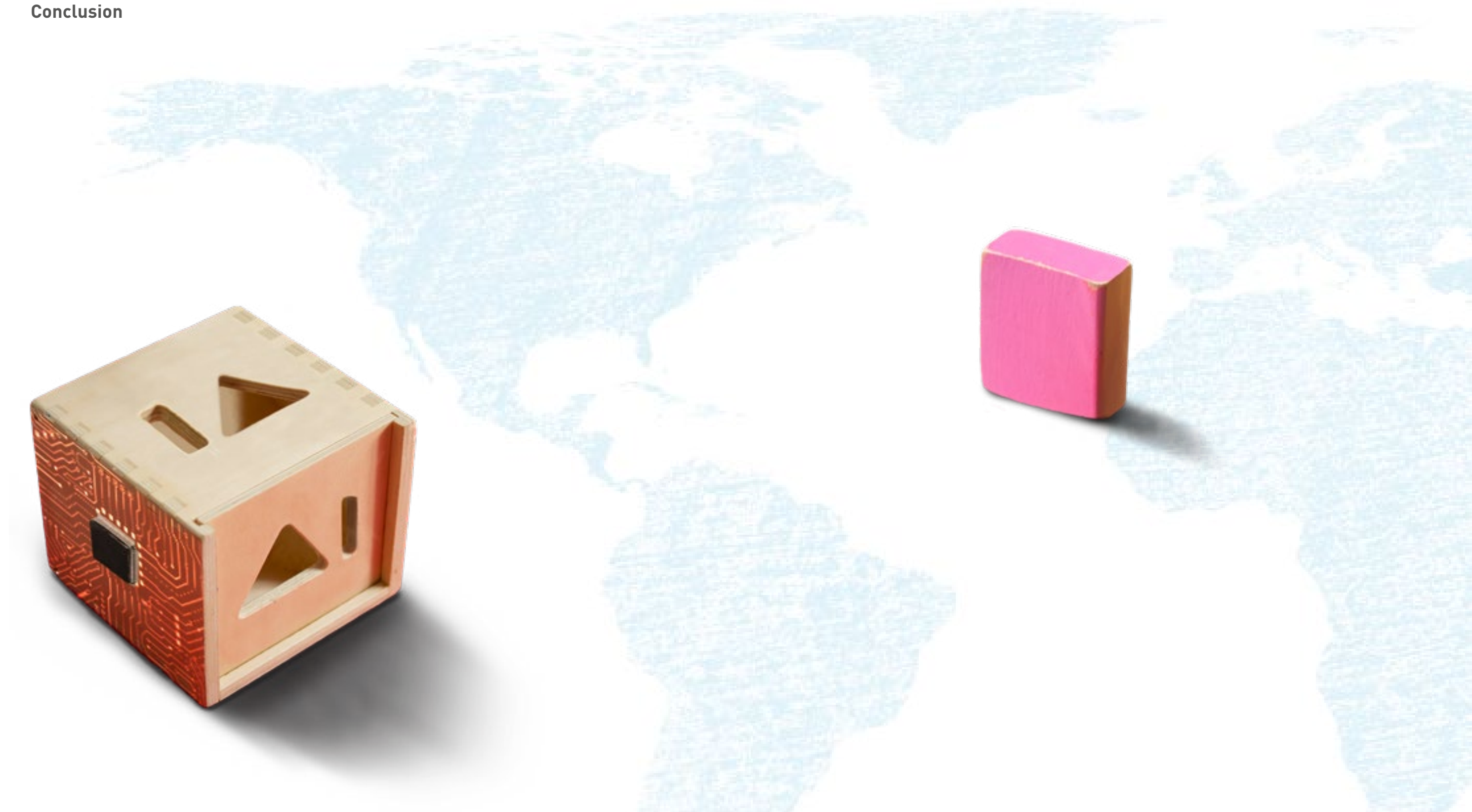
There is already some public discourse in favour of global governance of data. In separate interventions at the World Economic Forum in Davos in January 2019, for instance, the leaders of Japan, South Africa and Germany all called for greater international oversight of data usage.

Prime Minister Shinzo Abe announced that Japan would be using its chairmanship of the Group of 20 nations (G20) in 2019 to promote the idea of expanding World Trade Organization rules beyond goods and services to encompass trade in data as well; he expressed the hope that the G20 in Osaka would be remembered as the start of global data governance.

Citing cybersecurity as a priority, President Cyril Ramaphosa of South Africa said that greater oversight of the technology sector would be on the agenda of African Union leaders meeting in February 2019 in Addis Ababa, Ethiopia (Bradsher and Bennhold, 2019).

In Davos, Chancellor Angela Merkel of Germany called for a 'common digital market' within the European Union. She cited the need for ethical standards in AI and genetic engineering, as well as for the handling and ownership of data. The European Union's General Data Protection Regulation (GDPR) took effect in May 2018; it imposes stricter data privacy rules on all entities doing business in the European Union (Bradsher and Bennhold, 2019).

Speaking in Davos in January 2019, the CEO of Microsoft himself voiced support for a common standard on data privacy rules. Satya Nadella argued that US citizens deserved the same level of protection for data misuse as Europeans and expressed the hope that 'in the United States, we do something similar [to the GDPR] and that the world converges on a common standard'. He tweeted from Davos that 'privacy is a human right, we need a GDPR for the world (*see tweet*)'.



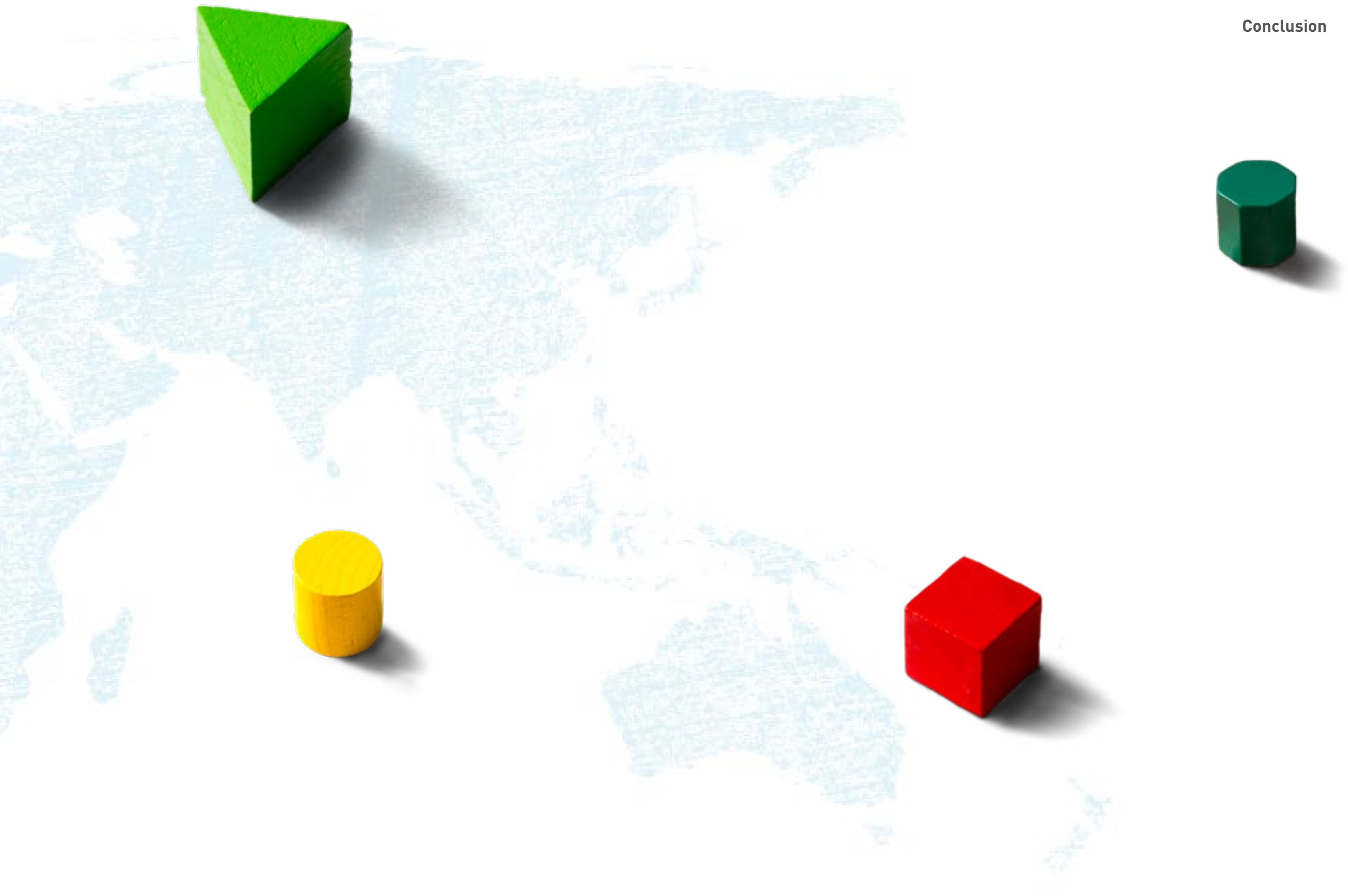
7. Conclusion

From the foregoing, it is evident that the Fourth Industrial Revolution offers UNESCO's science programmes numerous opportunities to improve their service delivery to member states. The predictive and prescriptive capabilities of AI systems have enormous potential for fields as diverse as medical research and diagnostics, ecological and biodiversity research, freshwater management, geoscience research, disaster risk reduction and strategic foresight.

AI systems are already helping scientists working with UNESCO to analyse an unprecedented volume of data in fields ranging from theoretical physics to ecological research, water management and climate change assessments.

AI also presents a number of challenges. In a mid- to long-term perspective, it could fundamentally alter the way in which research is conducted, structured and understood. This evolution will require scientists and engineers to learn new skills and could eventually result in AI outcompeting research organized by, and for, humans. AI is already mimicking the scientific method by generating hypotheses and verifying them through simple experiments. However, the accuracy of machine learning techniques has been called into question, since an AI algorithm is not always capable of producing the same answer twice to the same question. This inconsistency poses a problem for reproductibility in science. It also sheds doubt on the reliability of some decisions currently being made by AI algorithms, such as in determining the length of a prison sentence. AI algorithms may also contain gender or racial biases. It will be very important for scientists to preserve their critical thinking in approaching AI.

For countries to reap the benefits of AI, they will need to have the requisite human and institutional capacity. That will require investment in research infrastructure and equipment and a critical mass of well-trained scientists and engineers. UNESCO can provide policy advice and guidance and help countries to benchmark their progress against that of other countries, through tools such as the *UNESCO Science Report*, *World Water Development Report*, the database of the UNESCO Institute for Statistics and the Global Observatory of Science, Technology and Innovation Policy Instruments.



There are opportunities for developing countries. The availability of cloud computing infrastructure and the increasing processing power of common computers are lowering the cost of AI research infrastructure. Open science and open source movements are striving to level the playing field. The adoption of policies encouraging transparency and sharing of core datasets across both public and private actors could stimulate innovation-oriented competition while enhancing research productivity, including in developing countries.

The current domination of AI research by a small number of multinational corporations, and their propensity to take over smaller competitors, is in danger of widening the technological divide, if this trend goes unchecked. In developing countries, the private sector has less access to finance, hampering the emergence of start-ups in AI and reducing employment opportunities. Talented researchers are being snapped up by multinational corporations able to offer higher wages and other benefits. UNESCO can advise governments on their best policy options for tackling these and other challenges.

The third key component of AI after computer power and algorithms is data, vast quantities of it. Developing countries must not become simply data subjects and users of data produced elsewhere. UNESCO can help them to collect, develop and manage quality data for their own benefit, thereby helping to narrow the scientific divide.

Up until now, data collection has been a costly, difficult task. As a result, the data gathered are often incomplete, especially in developing countries and remote areas. The Internet of Things could radically change that, as this low-cost, low-power technology does not require any pre-existing infrastructure and can be deployed in most remote areas. UNESCO has been advocating the use of the Internet of Things for development, since sensors can be attached to the nodes to support a wide range of applications, such as water or air quality monitoring, animal tracking and disease mapping.

UNESCO could also add value to current studies mapping trends in AI, which tend to focus on the leaders in this field (or hotspots). By mapping the so-called 'coldspots' in AI and analysing the reasons why these mainly developing countries are lagging behind, UNESCO could not only help to form a more rounded picture of global trends in AI but also pinpoint some of the policy challenges faced by these 'coldspots'.

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Glossary of terms

Artificial intelligence makes it possible for machines to learn from experience. Intelligent systems use a combination of big data analytics, cloud computing, machine-to-machine communication and the Internet of Things to learn to perform cognitive tasks: sensing, processing of oral language, reasoning, decision-making, displacement and manipulation of objects, etc. AI is empowering new kinds of software and robots to act as self-governing agents capable of operating much more independently from the decisions of their human creators and operators than machines have previously done. There is also potential for them to adapt to new working environments without any reprogramming (OECD, 2016). The term artificial intelligence was coined at a conference at Dartmouth College in New Hampshire, USA, in 1956.

Black box refers to the use of a device without an understanding of its inner workings. Black box solutions may discriminate between the signal and background, for instance, without providing the operator with an understanding of the relationship between input and output.

Blockchain technology is a distributed, decentralized and peer-to-peer database that can be used to store information in a transparent and tamper-proof manner. It acts as a ledger that houses historical data in the form of blocks. Blockchain can also be used to execute trade among parties through a protocol called smart contracts that does not require a centralized authority to authenticate the trade. The technology has been used extensively within a cryptocurrency framework but, recently, has also found an outlet in energy management-related areas.

Data mining is a process by which anomalies, patterns and correlations are identified within large data sets to predict outcomes. Using a broad range of techniques, you can use this information to increase revenue, cut costs, reduce risks, etc. (sas.com).

Deep learning is a type of machine learning that trains a computer to perform tasks such as recognizing speech, identifying images or making predictions. Instead of organizing data to run through predefined equations, deep learning sets up basic parameters about the data and trains the computer to learn on its own by recognizing patterns from processing many layers of data (sas.com).

Filter bubble (or **Echo chamber**) is an unwanted feature of an algorithm which, when used as a black box, can do things that were not explicitly intended by its programmer. For example, the algorithm that builds a person's Facebook feed filters information to show the person the things they like most. In this way, it is easy to convince a person of an idea that is false, such as that vaccines cause autism. The person can then live in a virtual bubble in which almost everyone in their feed is convinced that vaccines cause autism. A programmer can 'open' the black box to see how it works then try to fix the unwanted feature.

Internet of things refers to the extension of Internet connectivity to physical devices by embedding the latter with electronics, software, sensors, etc. to enable them to communicate and interact over the Internet while being remotely controlled and monitored. By 2017, there were more than 8 billion 'smart' devices embedded in clothing, vehicles, electrical goods (watches, home appliances), etc.

Machine learning is a method of data analysis that automates analytical model building. It is a branch of artificial intelligence based on the idea that systems can learn from data, identify patterns and make decisions with minimal human intervention (sas.com).

Overfitting of data is a cause of poor performance in machine learning. Machine learning algorithms use training datasets to build a model. If they learn for too long, they begin to assimilate irrelevant detail in the training dataset, impairing their ability to apply the learned model to new data. (When a machine-learning algorithm learns for too short a time, this is called underfitting.)

Robot refers to a machine characterized by four main features: mobility, in order to function in human environments like hospitals and factories; interactivity, made possible by sensors and actuators; communication, made possible by computer interfaces or voice recognition and speech synthesis systems; and autonomy, in the sense of an ability to 'think' for themselves and make their own decisions to act upon their environment, without direct external control. Robots perform tasks through two types of algorithm: deterministic algorithms and AI (or stochastic) algorithms. A deterministic robot's behaviour is basically preprogrammed and essentially determined. However, AI-based, cognitive robots will learn from past experiences and calibrate their algorithms themselves, so their behaviour will not be perfectly predictable (UNESCO, 2017).

ARTIFICIAL INTELLIGENCE FOR SUSTAINABLE DEVELOPMENT:

challenges and opportunities for UNESCO's science and engineering programmes

In 2018, UNESCO's Natural Sciences Sector undertook a foresight exercise, in order to identify emerging opportunities and challenges arising from the rapid development of artificial intelligence and evaluate the implications of this silent revolution for its programmes.

As part of this exercise, the Natural Sciences Sector surveyed staff at headquarters and in the field, as well as UNESCO chairholders and centres. Respondents were asked to identify opportunities and challenges for UNESCO's work in the following areas: scientific research and experimental development; ecosystem and environmental management; and science governance and foresight.

The current paper summarizes the findings of this exercise.

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Sustainable Development Goals