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Maths counts

- The maths behind monsoons in **India**
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- **Metaverse:** Interview with Liu Jianya and Guo Liang
- Complex equation of maths education in **South Africa**

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OUR GUEST

Vinciane Despret, philosopher: "To combat species decline, we need passions of joy"

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Editorial

Perceived as abstract, intimidating and even traumatic, mathematics does not always get good reviews from students and the general public, who reduce it to a purely theoretical discipline, disconnected from reality. Yet the opposite is true. Mathematics is omnipresent in our daily lives.

Algorithms, at the heart of artificial intelligence, have made search engines and medical imaging possible. Mathematical models play a key role in a wide range of fields, from optimizing transportation networks to predicting cyclone trajectory to controlling the spread of an epidemic or the impact of a vaccination campaign.

Mathematics also tells a part of the world's history. Our past has been enriched by Sumerian tablets, the astronomical calculations of ancient Egypt and classical Greece, the scholars of the Mayan Empire and China, Indian arithmetic, and Arabic algebra.

Perhaps more than any other, this abstract science lends itself to dialogue between cultures and to international scientific cooperation. UNESCO recognized the importance of this science very early on when it set up the Latin American Centre for Mathematics in Buenos Aires, Argentina, in 1962. The Organization, which recently proclaimed 14 March as International Day of Mathematics, is now reflecting on the challenges of artificial intelligence and is developing programmes for access to the basic sciences, of which mathematics is a pillar.

Maths may be everywhere, but many people are excluded from it. The obstacles related to this discipline are still numerous. Starting with gender disparities. It was not until 2014 that a woman – Maryam Mirzhakani of Iran – was awarded the prestigious Fields Medal. Although girls are now catching up in mathematics by the end of primary school, boys are still overrepresented among the top performers in this subject in primary and secondary education worldwide, according to statistics cited in the April 2022 Education for All Global Monitoring Report. Even when they are graduates, young women do not always feel empowered to pursue careers in science.

Moreover, the profession is struggling to recruit. At a time when the need has never been greater, the shortage of qualified mathematics teachers around the world is a threat to the future. And the range of this discipline's application is still limited. Mathematical models, so useful for understanding the climate, biodiversity or medical research, remain largely confined to the fields of finance or economics. As the world faces social, climatic and technological challenges, it is crucial that the power of mathematics be more widely explored and, above all, more widely shared.

Agnès Bardon
Editor-in-Chief

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Christiane Rousseau

Professor in the Department of Mathematics and Statistics at the University of Montreal (Canada), and one of the authors of the UNESCO study Mathematics for Action.

Maths counts

Mathematics is omnipresent in our lives. Whether we are using our phones, credit cards, or driving our cars, maths is involved. Algorithms and mathematical models play a key role in areas as diverse as weather forecasting, train scheduling and modelling virus spread. A recent UNESCO study, *Mathematics for Action*, highlights how maths can also help tackle challenges such as poverty alleviation, biodiversity loss and climate change – provided that enough qualified mathematicians and teachers are recruited.

It is often said that mathematics is everywhere. And so it is. A GPS receiver calculates its position by using the time it takes for satellite signals to reach it. Secure communications are encrypted so that they are opaque to anyone other than the recipient. The JPEG format of photos taken by a phone camera is a mathematical compression of the information contained in the photo. Without this clever compression, the photo files would be enormous.

And since any transmission of information introduces errors, correction codes are all-pervading in telecommunications networks, including those of mobile phones and television. Without them, remote-controlled robots on Mars would not be able to execute commands received from Earth. This omnipresence of mathematics explains why the theme of the first International Day of Mathematics in 2020 was precisely “Mathematics is everywhere”.

Mathematics is indeed omnipresent in understanding our planet and the organisation of our civilization. As early as 1623 Galileo wrote that “The book of the universe is written in mathematical language”. Four centuries later, environmental challenges have become one of humanity’s priorities. The population of the planet continues to grow – according to United Nations projections it reached eight billion people in November 2022 and should stabilize at around 11 billion, while at the same time climate change is affecting agricultural yields.

> “ **Mathematics is omnipresent in understanding our planet and the organisation of our civilization**

Earth Overshoot Day, which marks the moment when humanity has consumed all the resources the planet can generate in a year, is occurring earlier and earlier. While it came at the end of December in 1970, in 2021 it occurred on 29 July. The Sustainable Development Goals of the United Nations Agenda 2030 are the international community’s response to these challenges, and the mathematical sciences have a key role to play.

Powerful algorithms

Climate modelling involves putting into equations the interactions between various climate agents – sun, atmosphere (including greenhouse gases), oceans, soils, glaciers, plant systems, etc. It is essential to collect data if we want to predict the evolution of climate systems, and this prediction is the preserve of mathematics. Simulating these systems and establishing major trends →

is a *tour de force* that requires enormous computing power, ever more powerful algorithms and the optimal use of data. The work, carried out on several fronts, includes identifying long-term trends and highlighting regional trends.

It is also important to accurately quantify the degree of uncertainty. Techniques exist to improve weather forecasting and to anticipate seasonal trends. This is particularly useful, as climate change increases the frequency and magnitude of extreme events.

Hurricane track forecasting is an area where spectacular progress has been made – it is now possible to predict the path of hurricanes almost seven days ahead. A better knowledge of the risks makes it possible to anticipate and guard against their consequences in the coming decades. How high should a dyke be built? Should a neighbourhood be rebuilt or relocated after a flood? How often will droughts threaten water availability? How can cities be modified to reduce the impact of heat waves?

Maths matters at UNESCO

In 2019 UNESCO proclaimed 14 March International Day of Mathematics – as a reference to the constant, π, which can be rounded to 3.14 – but the Organization's interest in this discipline goes back much further. In 1962 it founded the Latin American Centre for Mathematics (CLAM) in Buenos Aires (Argentina), in order to promote mathematical knowledge in the developing world.

UNESCO played a decisive role in proclaiming 2000 World Mathematical Year and, since its creation, has set itself the goal of strengthening maths education and promoting access for all to this discipline and the professional opportunities it offers. It does this through its educational programmes and regional mathematics centres in Hanoi (Vietnam) and Santoe (Ghana), its Beninese, Chilean, Nigerian, Palestinian, and Zambian Chairs, as well as the programmes in Asia, Africa and the Americas of the Centre Internationale de Mathématiques Pures et Appliquées in Nice (France).

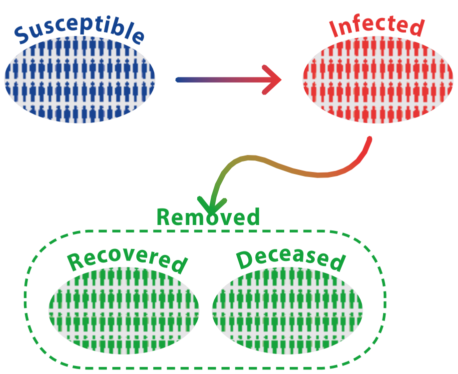
Modelling reality

These forecasts are based on mathematical modelling, in other words a drastic simplification of reality. A good model allows you to see the big picture that may be hidden by too much detail. Let's take the case of an epidemic. The simplest model, called the SIR model, classifies individuals into three compartments: the Susceptible, the Infected and the Removed (recovered or deceased).

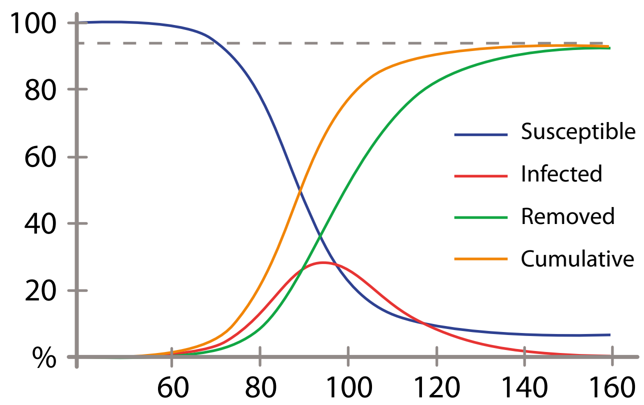
In this model, the basic rule explains the movements between compartments from one day to the next. It is then possible to calculate how the populations of the compartments evolve over a long period of time.

This model, simplistic as it is, reveals the main laws of an epidemic: the *exponential growth*, the *peak of the epidemic*, the *herd immunity phenomenon* by which the epidemic dies out before the whole population has been infected, the *flattening of the curve* of cumulative cases (orange curve), the *basic reproduction number* (R number), which measures the average number of infections generated by a primary infection and which characterizes the contagiousness of a disease.

These general laws inform decision-makers about the evolution of the epidemic. The model can then be improved for more accurate predictions.



The mathematical model SIR
(susceptible-infected-removed) is used to predict the evolution of an epidemic in a given population.



Evolution of the different compartments of the SIR model
over days and weeks.

For example, the basic rule for day-to-day movement can be adjusted to take account of health measures or the appearance of new, more contagious variants. The compartments can also be divided into sub-compartments (age groups, social classes, gender, recovered and deceased), etc.

Planning train timetables

Another field of action of mathematics is that of *optimization*. How to organize the transport and distribution of mail or goods? How can train timetables be planned to facilitate connections, minimize the number of trains, and optimize staff working hours? The question also arises for urban public transport and aviation companies. These problems are part of what is known as *operations research* and, while they are easy to state, the number of possibilities is too large to find an optimal solution by trial and error.

Finding the best solutions requires the development of very clever and effective algorithms. These same techniques can be applied to the ecological transition, which requires moving from over-consumption of resources to optimization of their use. How can we save energy or water, reduce food waste, make the most of limited resources by using them equitably? These are areas where mathematics has a role to play.

> **"Artificial intelligence is breaking new ground in mathematics and statistics**

Artificial intelligence (AI) is breaking new ground in mathematics and statistics. The breakthrough comes from the fact that we can now programme computers or robots to learn. For example, a human can recognize a cat. A computer is taught to do the same. To do this, it is trained with hundreds of thousands of images and corrected when it makes mistakes. The computer continuously improves its programme and learns to recognize a cat, even in a position it has never seen before. In image and sound recognition, the successes of artificial intelligence are spectacular and are more than a match for humans.

Applications are multiplying. Artificial intelligence can be used to produce low-cost maps of poverty, for example, using public domain satellite images. Daytime images reveal man-made infrastructure. Combined with night-time images, AI identifies inhabited areas that are not lit at night – a sign of poverty. Artificial intelligence is also being used in semi-arid regions of northern Kenya to secure access to water. Using the data, it is possible to predict areas where water shortages might occur and develop mitigation strategies.

With countless and highly varied applications, mathematics constitutes an exceptional toolbox. It is no coincidence, then, that it is all around us. ■

Mathematicians urgently needed

A tropical cyclone's track can now be predicted up to one week in advance with new mathematical approaches, giving communities time to evacuate. Mathematical models have also proved useful in managing the COVID-19 pandemic. Poverty data can be mapped by applying tools like machine learning algorithms, enabling the identification of areas in need of public investment.

Insights on applications of mathematics are shared by thirty-two mathematicians and thought leaders in *Mathematics for action – supporting science-based decision-making*, released by UNESCO on 14 March 2022. The publication illustrates how mathematics can empower sustainable development in a wide range of fields, including food security, data privacy, biodiversity, resilient digitized systems, and water management.

Designed for policy-makers, the toolkit presents stories and research on how mathematics is used to tackle the complex challenges we face, from climate change and poverty to pandemics. Furthermore, the publication describes how mathematical models enable the exploration of multiple "what-if" scenarios to inform the decision-making process. Scientists use climate models in combination with storylines to produce plausible alternative scenarios for the future.

There is, however, a problem: while mathematical models have never been so widely applied, mathematicians themselves are in short supply. There may not be enough of them to solve the complex challenges we face, the publication finds, highlighting the shortage of quality mathematics teachers around the world.

Gayathri Vaidyanathan

Indian journalist

The maths behind monsoons in India

Monsoon forecasting can make or break Indian farmers' prospects. Simulating atmospheric systems with computer models allows scientists to get the most accurate predictions.

Few weather events are as eagerly awaited as the Indian summer monsoon. The overcast skies cool down the blistering temperatures over much of the Indian subcontinent. For farmers, who make up nearly half the population and mostly depend on rain-fed agriculture, every aspect of the monsoon matters – which states will receive rain, when and how much. Therefore annual monsoon forecasts make headline news every year.

Scientists are now racing to better understand the monsoon and improve their forecast models. "Developing mathematical models is the only way we know of understanding the system", says Amit Apte, an applied mathematician at the Indian Institute of Science Education and Research.

Small variations, huge impact

Monsoons are seasonal shifts in the atmospheric circulation and rainfall after the sun heats up the Earth. They usually occur in the summer. There are also monsoons in North and South America, West Africa, East Asia and Australia, but the South Asian monsoon, known colloquially as the Indian summer monsoon, is the best known. It's unique because it is bounded by significant Earth systems, including the Himalayas, the Western Ghats in India and the Arakan Yoma range in Myanmar, and the Indian Ocean.

> **"Scientists are experimenting with neural networks that can detect patterns in data**

The Indian monsoon begins after the hottest period of the year, when the lands are heated up while the ocean remains cool. The difference in temperature causes the winds to reverse over the northern Indian Ocean, pushing oceanic clouds over the subcontinent and triggering rains in the southwestern state of Kerala. Like clockwork, the monsoons begin around 1 June and end by 15 October after about 850 millimetres of rainfall have been dumped throughout the country. That's more than 75 per cent of India's total annual rainfall.

The monsoons may be late by a week, or 10 per cent less rain might fall compared to average. Such variations may seem small, but they have outsize impacts on India's economy. In 2020, the Indian Meteorological Department (IMD) used an ensemble of models to correctly forecast the start of the rains, but failed to anticipate the increase in precipitation levels. Farmers' profits increased by 3-5 per cent per hectare according to Crisil Research; however, if the farmers had known about the excess rain, they may have sown more land.

Research impeded by knowledge gaps

Much remains to be discovered about the Indian monsoon phenomenon. For Amit Apte, this is partly due to the fact that they occur in the tropics. Research has focused more on temperate zones, as most atmospheric scientists were based in Europe and the United States in the mid-20th century. Tropical weather systems are more complicated to understand than systems in more temperate regions, which are controlled predominantly by the rotation of the Earth. Representing the monsoons in a model requires accounting for numerous variables.

Cloud formation is an example of a variable that scientists do not fully understand. "In fact, clouds are probably one of the largest uncertainties in the climate models these days, and they have a huge impact on the tropics." The oceans around the subcontinent — the Bay of Bengal, the Arabian Sea and the Indian Ocean – pose another challenge for scientists. Amit Apte explains that the mixing of the freshwater of the Ganges River with the salty Bay of Bengal is currently being studied for its impact on oceanic currents.

The monsoon does not pour continuously for four months. Rather, it rains hard for a few days and then stops, and then picks up again. If a model is to be useful to farmers, it should be able to predict these active and break phases of the monsoon.

Monsoons have traditionally been predicted using statistical models based on equations. These were used by Indian meteorologists with limited success; in the 23 years that statistical models were used, monsoon forecasts were correct only 9 times.

In 2012, the Indian Meteorological Department switched to physical models: 3D computer models that simulate atmospheric systems governing the monsoon. Historical data is fed into the model, and after some checks and balances, simulations are run. This is the type of modelling used by most weather services globally.

India's physical monsoon models appear to perform well on some questions, but less well on others due to the lack of knowledge of Indian monsoon mechanisms. The predictions often come with an uncertainty or range of possibilities. Yet, these detailed data can be valuable not only for farmers, but also for insurance companies or for planning water use.

Monsoon rain likely to increase

Climate scientists also use physical models to understand impacts of global warming on the monsoon 30 years out. According to the global climate models of the United Nations' Intergovernmental Panel on Climate Change (IPCC), the South Asian Monsoon weakened in the second half of the twentieth century. But the models project that the monsoon rainfall will increase in the long term.

"Tropical weather systems are less well understood than those in temperate regions

More recently, some scientists are experimenting with neural networks, which are computer algorithms that find patterns in data as if they were human.

Such models can sort through an immense amount of satellite data to find patterns. But according to Amit Apte, these models are not as accurate yet as the older statistical models. And even if a computer does get it right, scientists would not rest until they figure out what physical phenomena lie behind the code: "Even if the code is doing something, we still don't know how the clouds are formed, so it'll remain a big vacuum in my mind", Apte says. ■

© Prashant Rana

New Delhi after two days of uninterrupted rain.

Clémence Cluzel

Journalist in Dakar

Using Big Data to diagnose poverty in Senegal

To reduce poverty, we need to be able to measure it accurately. In Senegal, a precise mapping of the country's socio-economic situation has been achieved by using an innovative mathematical approach.

In Senegal, more than seven out of ten people are considered poor. This estimate is based on data collected through household income and consumption surveys, coupled with the population census. The problem is that such an approach is costly and requires significant human resources. In fact, many developing countries conduct such surveys only at rare intervals, which limits the monitoring of poverty. Another pitfall is that the traditional approach also provides an inaccurate picture of the situation.

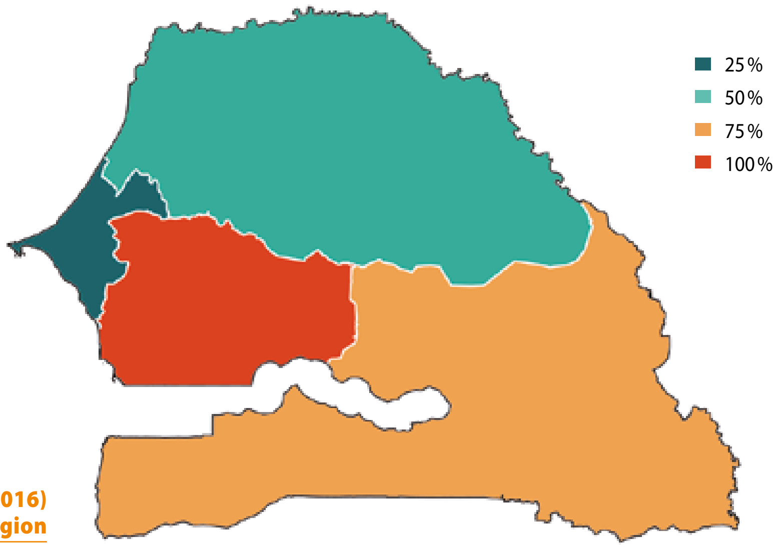
"In Senegal, the method used to measure poverty is the monetary approach based on income or consumption. It does not account for the deprivation suffered by individuals in such areas as health care, education, etc. But the tools for measuring poverty should allow public authorities to understand the phenomenon in its different facets", explains Mamadou Amouzou, a demographer at National Agency of Statistics and Demography of Senegal (ANSD, *Agence Nationale de Statistique et de la Démographie*).

The mathematical approach based on Big Data is proving to be a good way to fill in these gaps. The study "Combining disparate data sources to improve poverty prediction and mapping" by Neeti Pokhriyal and Damien Christophe Jacques (2017) is an example. It combines traditional data such as census, income and consumption statistics with unconventional data, such as those provided by cell phones.

Digital footprints

Call data records provide information on the habits of users over a large part of the country. Generated with each call or message sent, they can tell when, where and with whom users communicate. These digital footprints provide information on literacy levels, mobility and access to the electricity grid, which correlates with regional wealth distribution.

In the Senegal survey, the data provided by the telephone operator Sonatel included eleven billion calls and texts from nine million cell phone users. To this information, the researchers added satellite images that indicate parameters such as night lighting, paved roads, density of infrastructure and the type of roofing on houses.



The poverty map (2016) of Senegal by geographic region

These elements, combined with census data, provide a more complete and accurate picture of the inhabitants' standard of living. "Artificial intelligence makes it possible to use traditional survey data to build machine learning algorithms to recognize patterns of poverty. The goal is to learn how to make data talk about poverty also when this was not their original purpose. Using such enriched data is much cheaper, more accurate and easier to update", explains Christiane Rousseau, a professor in the Department of Mathematics and Statistics at the University of Montréal.

These enriched data have made it possible to develop poverty maps that provide a more dynamic view of the phenomenon. These maps, produced at the commune level, reflect a spatial and temporal distribution of socio-economic deprivation. For example, they show that the communes in the interior of Senegal have higher levels of poverty than the capital, Dakar, and the coastal communes.

A gold mine for development projects

These maps are a tool for policy-makers to direct aid to the poorest. "Mapping has a role to play in the organization of the country. By using telephone data, we can define who is eligible for humanitarian aid. This is what the organization Give Directly, which promotes direct money transfers, has done in Togo", notes Damien Christophe Jacques, a doctoral researcher in geomatics and co-author of the survey on Senegal. "Mathematics allows us to optimize limited resources", adds Christiane Rousseau.

The opportunities offered by Big Data are promising, but they do raise certain questions. Indeed, telephone data belong to cell phone operators who have no real interest in communicating these data and are not always inclined to share them. Moreover, the data, which most often come from a single operator, do not reflect the situation of the entire population. "Some people have several SIM cards, while others, such as the ultra-poor, the elderly or children, do not own a phone," says Jacques, adding that "even if the information provided is very rich, these biases can raise questions in the context of rigorous studies".

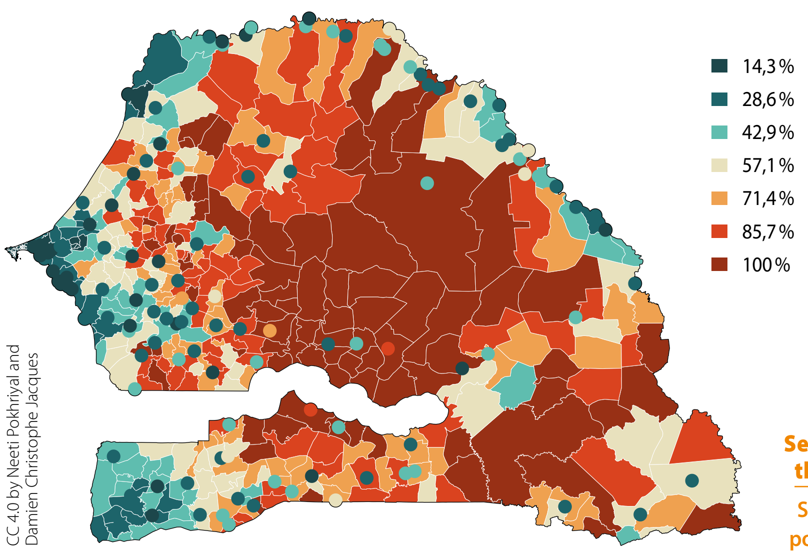
Another drawback, the use of these personal data, even if they are aggregated by area, meaning they are studied by group and not individually, raises ethical questions. "This sensitive information offers a gold mine for development projects, but it also presents a danger to privacy. We must therefore find a balance between protection of individual interests and benefits for the public interest", says Jacques.

> **"Big Data can fill in the gaps of traditional census methods**

> **"The opportunities offered by Big Data are promising, but they do raise certain questions**

"Non-traditional data represent a complement of information. They are a substitution model, in case of absence of census data, or an information augmentation model, when data are already available. The method gives real signals, but it is not a miracle solution", emphasizes Jacques. This view is shared by Emmanuel Letouzé, director of the NGO Data-Pop Alliance and founder of OPAL (Open Algorithms) – a programme that aims to facilitate access to cell phone data and their use for social purposes in low-income countries.

"Globally, the areas and causes of poverty are already known. The real question is what to do with this information", he says. For now, the results of the study in Senegal are not yet translated into policy changes on the ground. "But it isn't useless, because it helps to raise awareness among policy-makers", he says. "It takes time to change habits and perceptions." ■



Senegal's poverty map 2016 updated for the 552 communes, created using Big Data

Source: "Combining disparate data sources for improved poverty prediction and mapping", 2017.

Lisbet Jære
Journalist in Oslo, Norway

COVID-19: The Norwegian model

During the COVID-19 crisis Norwegian authorities were among the first to develop mathematical models based on mobile phone data. Accurate information about people's movements allowed statisticians to better predict the spread of the virus.

From March 2020 to June 2022, Arnoldo Frigessi had a full agenda every day. The professor in statistics at the University of Oslo (UiO) and Oslo University Hospital was one of the scientists who worked for the Norwegian Institute of Public Health's (NIPH) modelling team for COVID-19. Day and night.

The health authorities needed to estimate how the pandemic outbreak would impact the population: how the infection would spread, how many people would be hospitalized, and how many would die. This was done by the modelling team.

"It was not uncommon that we worked for 17 hours. My salary is paid for by the taxpayers, and this comes with a great responsibility to the public. Mathematical models are good at explaining or representing complex situations. The pandemic was an example of such a complicated situation; the models tried to show the complex relationship between the behaviour of people, the virus, and the Norwegian health authorities' measures", Frigessi says.

Complex interdependencies

"Norway was one of the first in the world to have a good model based on mobile data", Frigessi says. "In addition, we had good population data from before, and good data on the number of hospital admissions and infection rates." He emphasizes, however, that although a mathematical model can manage to keep track of many individuals and factors that influence the course of infection, it can never be exactly like reality.

Frigessi explains that in Norway, as in many countries, the basis was the so-called SEIR model. SEIR is an epidemiological model used to predict infectious disease dynamics by compartmentalizing the population into four possible states: Susceptible [S], Exposed or latent [E], Infectious [I] or Removed [R]. They created a model adapted to COVID-19 based on population data, mobility data and data about the COVID-19 epidemic.

Simpler models, such as those used with cancer, are built on the assumption that the risk factors are constant over time and place. The challenge with creating a model of a pandemic is precisely that one individual can infect another, and this creates complex dependencies.

> **A mathematical model can manage to keep track of many individuals and factors that influence the course of infection**

Frigessi has extensive experience with modelling infectious diseases. In the early 1990s, for example, he worked on models showing how the HIV infection developed. "A big difference is that HIV developed slowly, whereas COVID-19 did so at record speed. One similarity is that with both COVID-19 and HIV, one can be a carrier of the infection without having symptoms, which was one of the challenges in making the model."

"The Corona hunter"

It's the use of mobile data that made the Norwegian model truly stand out. Data from mobile phones can be used to forecast the spread of Covid-19 much more accurately since they provide information about the movement of people.

In 2020, Solveig Engebretsen was named one of the Norwegian leading stars under 30 years old by the newspaper Norwegian Business Daily. Her Ph.D. dealt with the use of mobile phone data in mathematical modelling for the spread of influenza. Frigessi was her supervisor. It was early in 2020 that Engebretsen joined a modelling group, earning the nickname "the Corona hunter".

The group was allowed to use mobile phone data from the telecommunications company Telenor, which

© Itziar Barrios for *The UNESCO Courier*

covers around half of the Norwegian population.

"Every six hours, we received mobile phone data showing people's movements across municipal boundaries. By mapping how people move, we have created models for how the infection will spread in Norwegian municipalities", Engebretsen explains.

> "
> **Mobile data helped refine patterns of infection spread**

Challenges in handling the unknown

How quickly COVID-19 is transmitted is described by the R number. R stands for reproduction number and shows how many people a person with the virus infects. A pandemic dies out when the R number is less than 1. In the model, the R number was based on hospital data and test data. Today, the model is just based on hospitalizations as testing is no longer mandatory.

"We were constantly worried about making a mistake", says Arnoldo Frigessi. He emphasizes that if he had worked on a normal research project, the results would have been double-, or triple-checked. Now there was no time for this.

Lack of time was just one of the challenges. The modelling group had to constantly monitor changes in policies, behaviour, testing regimes, and viral variants. As mutations emerged, the model had to be changed.

"We humans have a difficult time dealing with the unknown and large numbers. Mathematical models and statistics provide a systematic tool for gathering all the information we have about the virus", says Engebretsen, pointing out that the NIPH also used other models.

Communicating the complexity to the public presented another challenge. "In some cases, we were criticized for being overly pessimistic in our predictions of for example hospital admissions. However, in these cases, additional intervention measures had been introduced. It is important to communicate that our predictions were only valid if measures were *not* introduced", Engebretsen adds.

Frigessi shares a similar view: "Scientists must learn to explain complicated things, but on the other hand it must be recognized by politicians and people in general that this is complex information that demands their efforts. It is not possible to simplify everything", he says, adding that pandemic management is not only about numbers and statistics. "Ethics, societal and economic values are also important when decisions are made." ■

Interview by
Chen Xiaorong

UNESCO

Liu Jianya and Guo Liang: "The carbon footprint of the metaverse can be reduced"

The metaverse relies on artificial intelligence models and cloud services that require large amounts of energy. According to researchers Liu Jianya and Guo Liang, mathematics can be used to reduce its environmental impact.

If we set an analogy, what is the relationship between the metaverse and mathematics?

It's been nearly one year since Facebook announced it was rebranding to Meta and would focus its future on the upcoming 'metaverse'. Since then, what that term means hasn't gotten any clearer.

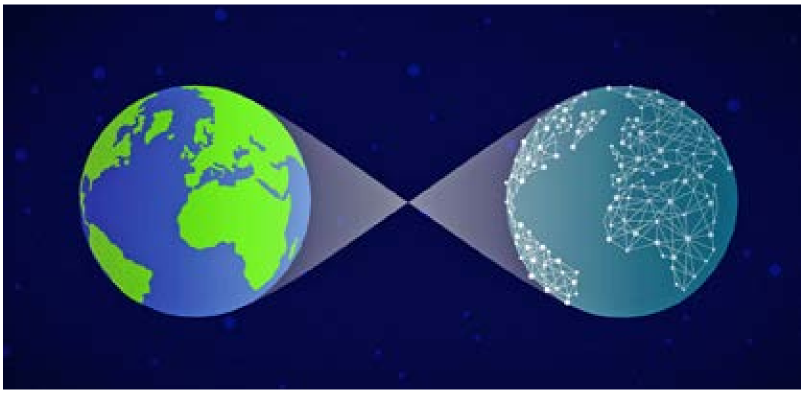
Mathematically, we define that the metaverse is a function that is represented by two sets of objects with arrows drawn between them to show the relationships between the objects: one set represents objects in real life, say, the palace of Versailles. The second one refers to computer models of real-world objects, such as a digital palace of Versailles, which can be shown and manipulated on the screen.

In short, metaverses can be regarded as the mathematical operation that associates each element in the real world with one or more elements in the digital or virtual world.

Can we fully realize the metaverse with the current computing power?

Maybe, but for what purpose and at what cost? Broadly speaking, there are two technologies related to the metaverse: data acquisition and virtual reality technologies. Data acquisition is the technique of capturing the shape and look of natural things in computer vision using cameras or laser scanners. Virtual reality (or digital twin) means generating digital objects to reconstruct the physical worlds. Both techniques are computationally expensive. Both heavily rely on artificial intelligence models and cloud services that require quite large amounts of energy.

A recent study conducted by researchers at University of Massachusetts estimates that training just one AI model could generate 284 tons of carbon dioxide, which is more than five times the amount of greenhouse gases emitted by a car in its lifetime. Cloud computing, which is necessary for virtual reality, online gaming and high-



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> **"Training just one AI model generates approximately 284 tons of carbon dioxide**

Guo Liang

Professor of data science at Shandong University, China, he obtained his Ph.D. from Cambridge University, UK. Before joining Shandong University he was deputy head of the BNP-KPMG Endowed Center for Innovation at NEOMA Business School, France.

Liu Jianya

Co-editor-in-chief of Mathematical Culture, he is a distinguished professor of mathematics at Shandong University, China. He was appointed as the Chair Scholar of the Ministry of Education of China in 2003 and received China's National Science Award in 2014.

The parallel universe of the metaverse

A contraction of the prefix "meta-" (beyond) and "universe", the metaverse designates a world parallel to ours. The word was coined by science fiction writer Neal Stephenson in his book *Snow Crash*. In this visionary novel, published in 1992, citizens use digital avatars to explore a virtual world.

Today, the term metaverse refers to ongoing developments in immersive 3D virtual worlds, in which users, in the form of avatars, can move around, interact socially and sometimes economically. This cyberspace can simulate the real world, or not. It can reproduce the physical laws of the real world, such as gravity, weather, climate, and geography. Or, on the contrary, it can be free of these physical constraints.

There are multiple modes of immersion, such as augmented or virtual reality, with or without a helmet-mounted display, and incarnation in an avatar. The simulation is shared by all connected users and continues in their absence. Everyone is free to join or leave.

There are different types of metaverse – hyperreal, screen-projected, or spatialised (immersion via a headset), more or less sophisticated possibilities for interaction, etc. Metaverses use various technologies, the most advanced of which are helmet-mounted displays and blockchains.

The concept has been widely taken up by online games and social networking giants. But the applications are not limited to entertainment; they cover fields as varied as remote working, tourism, education, health, and real estate.

resolution image processing, could also significantly raise carbon emissions.

Therefore, the metaverse should be held environmentally accountable. A 3D reconstruction of the palace of Versailles is useful, as a virtual tour website enables people from all over the world to plunge into interactive frescoes and to discover the paintings, sculptures, and engravings in a new way. On the contrary, there is no point in wasting energy on a digital twin of an ugly town hall, as there is no need for a citizen to wear a virtual reality gadget to 'walk' in the digital mock-up of a dreary concrete building to access public services.

What is the environmental impact of the metaverse?

The metaverse is one of today's hottest technological and socioeconomic topics. Lots of companies are already working on creating services for this new digital world. However, the applications of metaverse-related technologies like artificial intelligence (AI), virtual reality (VR), 3D animation, blockchain and many others, are still human-centric: people make decisions that prioritize humanity over the environment.

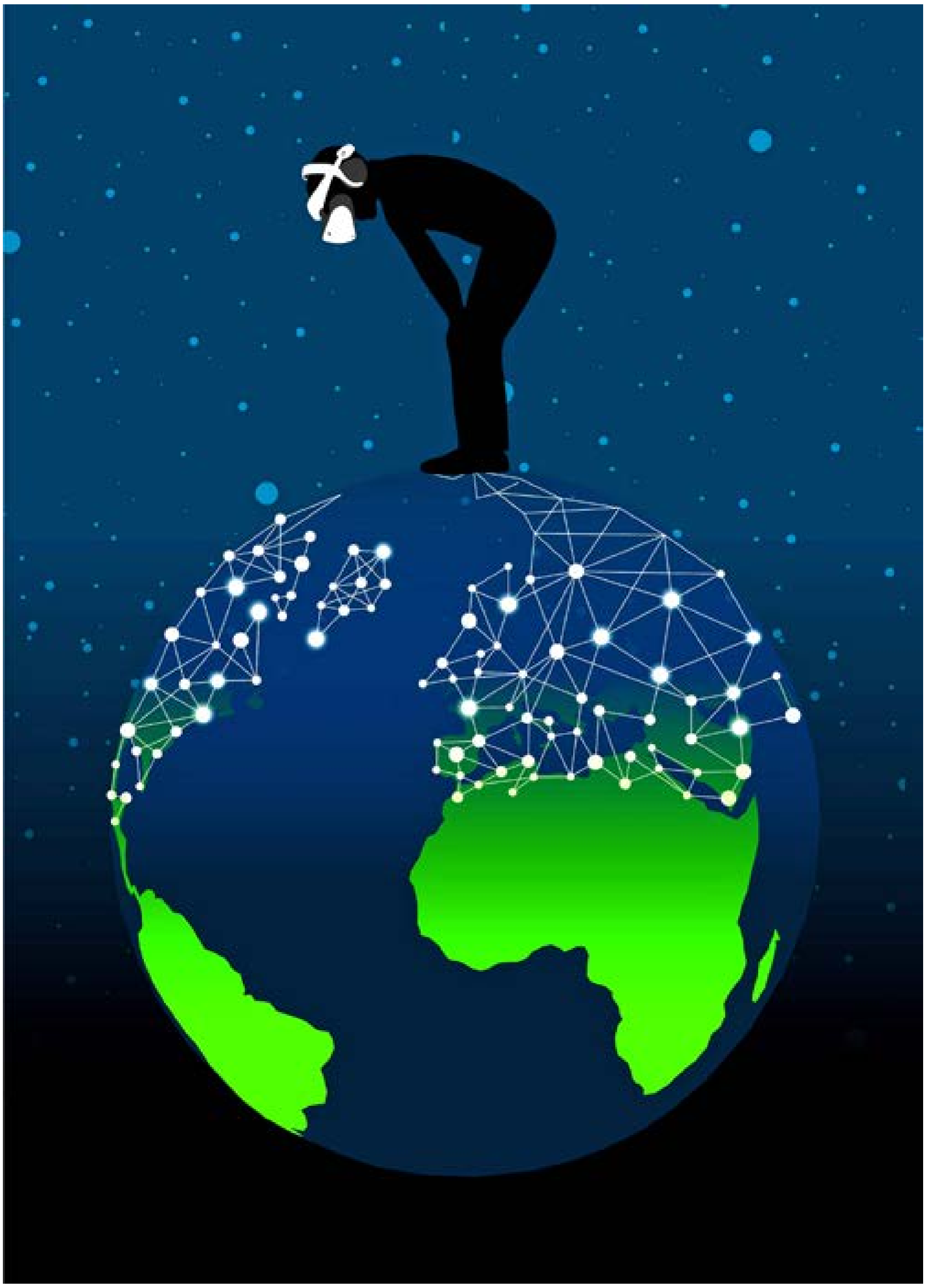
Furthermore, artificial intelligence and its supporting systems cause increased environmental costs. It is becoming increasingly energy and computation intensive to train deep learning models that use artificial neural networks to work with large datasets. Thus, financial and environmental concerns are growing.

As the metaverse becomes more complex, we must use even more data. There's a problem here, since data centers use an incredible amount of energy. It's unclear how much energy is required to store the data generated for and by the metaverse, but the number is likely staggering. A data center's building and cooling systems also produce a lot of CO_2.

In short, metaverse is energy-intensive, and the higher the demand for it and its related technologies, the more power we use. It is the responsibility of the technology industry and researchers to learn from the environmental impact of metaverse. In all technological decisions, we must factor in the earth experience.

Can mathematics contribute to a more environment-friendly metaverse?

Mathematics can be used in various ways to reduce the energy consumption of the metaverse. For instance, the method from Nanyang Technology University researchers in Singapore focuses on selective scanning to create virtual environments. Instead of transmitting the entire captured image, the camera first automatically selects the objects of interest and transmits →



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> **"Innovative calculation methods can reduce the energy consumption of metaverse technologies**

only these objects to metaverse service providers. For example, to transmit images or data of a public transportation scene, pedestrians and vehicles would be selectively scanned by innovative calculation, whereas other objects in the scene would require less calculation and energy.

Our team at Shandong University has been working on a sampling method derived from analytic number theory to reduce the power consumption of metaverse technologies. Our focus is on laser scanning, which is the most effective way to create digital representation and 3D digital models for metaverse.

A laser scanner emits a beam of infrared laser light onto a rotating mirror that paints the surrounding environment with light. Objects in the path of the laser reflect the beam back to the scanner, providing the geometry that is interpreted into 3D data. At the same time, the scanner head rotates and sweeps the laser across the object's surface, creating a multitude of points. It is computationally expensive to register, display and process these large point clouds.

Let's say we intend to generate the metaverse of the obelisk in the Place de la Concorde in Paris. To create the digital twin, a laser scanner would normally need to produce one million measurement points to obtain the precise parameters of the obelisk. Using our method, the scanner can produce 40 per cent less measurement points while maintaining the same accuracy of a digital twin produced using traditional methods. This method allows us to significantly reduce the energy and time needed to create a metaverse. Faster computing means less carbon emissions. ■

Interview by
Linda Klaassen

UNESCO

Dan Meyer: "Maths has an obvious perception problem among students"

Dan Meyer

Previously a high school mathematics teacher, Dan Meyer holds a Ph.D. degree in mathematics education from Stanford University (United States). He is currently a Director of Research at Desmos, a company developing free maths software tools and programs for educators around the world.

Why is maths perceived as difficult, even humiliating by many? Dan Meyer, specialist in mathematics education, questions the way the subject is taught at school. He calls for new curricula that encourage students to share their own ideas and knowledge about mathematics rather than requiring them to repeat canonical knowledge.

What sparked your interest in maths?

I've always been interested in school and maths. I've myself had a series of disappointing and frustrating experiences with mathematics that I hold on to, to give me empathy towards those who feel that way. But I've also benefited from some exceptional teachers who emphasized the value of my own ideas, even if they had seen those ideas many times in the past. As part of their work, they made an effort to be curious about students.

I also had some powerful experiences using mathematics to accomplish particular goals and to answer questions I had. It was not just something I did for a mark in school or to pass a credential, I was curious which grocery line at the supermarket was the fastest – is it the express lane with lots of people who have few items? Or is it the other line that has fewer people with lots of items? It's a very powerful experience to take a question that everyone wonders when they go shopping at the market, and to use mathematics to help answer it.

Why are so many students "traumatized" by this discipline?

If you look on Google, 'Why am I so bad at mathematics?' has multiple amounts of searches compared to the same question about subjects like language, science or history. Maths has an obvious perception problem among students. Culture plays a role and home plays a role, but teachers have a lot of influence there.

In other subjects, there is often an effort to determine what it is that students already know. In mathematics, we often assume that students come in knowing very little, until we tell them things. Success in mathematics often requires that they alienate themselves from the knowledge they have about numbers, shapes, patterns – and about how the world works – for the sake of some canonical knowledge. We shouldn't be giving students word problems where someone will run ten miles at a constant rate, when they know that people don't run ten miles at a constant rate. This happens all the time, and makes students come to regard maths class as a kind of unreality, a place where they need to suspend their sense of themselves and their world in order to be successful.

The perception is often that either you're a maths person, or you're not. In the humanities, truth is often decided by a community consensus, where experts and non-specialists alike can express their opinions. In maths class, you're trying to please long-dead historians who created the mathematical canon. That can be an alienating experience. I don't know if I want to, every day for twelve years of my life, come to a class and try to make dead people happy with me.

How should maths be taught to make it attractive to students?

We need to make an effort to give students experiences that awaken their senses and bring to the surface the valuable knowledge they have. It's important that students feel interested in, and see the value of, the activities we ask them to do for twelve years of the only childhood they have, full stop. Often, students leave their experience in mathematics feeling worse about themselves as humans, feeling less capable, and less valuable, than they did before they started their maths education. That's a shame. That's why we should focus a lot of energy on how we teach mathematics.

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At the moment, I spend much of my time trying to figure out how we do justice to the incredible value of the human lives that teachers get to be a part of for a brief moment. If students don't feel loved by their environment, this should motivate us to consider changes.

How can teachers be encouraged to change their practice?

Teachers are absolutely essential. While I have a lot of criticisms for how educators operate with maths students, I also have enormous respect for that work. Right now I work in education technology, and one thing teachers can do better than technology is to offer students experiences in a way that inspires them to share the contents of their brain, to share their knowledge about mathematics. For instance, putting on the board several similar but different shapes, and asking them: 'What's the same or different about these shapes? Which one doesn't belong?' The teacher creates an environment of safety where students offer their ideas. That is the process by which people learn, and love learning, anything.

When I was a teacher, I spent a lot of time modifying and creating curricula. Effective curriculum is an area in which teachers need a lot of support. Most curricula on the market say: 'We don't care what you know, students. Here's what we know. We'll tell it to you and then you repeat it back to us'. We need to support teachers with pedagogies that go beyond this. We need to help teachers know when not to talk, how to listen effectively, how to connect different ideas together. It's such a huge job. Anyone who has taught is well aware of the complexity of the work, how it requires you to be a sociologist, a therapist, an academic, all these different things at the same time. It's a real challenge. There's lots of room for support here.

What will the mathematics textbook of the future look like?

The textbook of the future needs to make abundant room for developing student ideas – as much room as it provides for the ideas of the past, which are also important. This curriculum needs to ask itself on every page: 'Why did we invent this new mathematics, and what problem was this meant to solve? Why couldn't we just stick with the older mathematics?' The textbook of the future needs to say: 'Why do we need this mathematics?', and help students encounter that need. We need to do justice to very real needs that humans have in their learning process. ■

Rachel Genevieve Chia

Journalist in Singapore

Paradox in Singapore: Women steering clear of maths careers

Women dominate mathematical science courses in Singapore's universities, but few persevere in the field after graduation. Why? It turns out that a key factor in the equation is confidence.

For Joelle Lim, bouts of imposter syndrome sometimes hit when she falls short at work. In times like these, the 27-year-old cryptographer finds herself thinking of derogatory comments made by male acquaintances about female colleagues getting jobs because of affirmative action rather than merit.

Lim, who applies her abilities in maths research to the service of defending the Southeast Asian island nation of nearly 5.9 million, is among its small but growing body of women in science, technology, engineering and mathematics (STEM).

Amid the persistent outflow of female talent from these fields, the city-state is ramping up efforts to keep women in their STEM careers by addressing their reasons for leaving, such as the glass ceiling and inadequate childcare support. But, as illustrated by Joelle Lim's experiences, there is a less visible, more insidious barrier: lack of confidence.

> **"Half of scientific, technical, engineering, and maths-educated women work in non-related occupations**

A numbers game

Singapore's women are significantly less confident in their maths abilities compared to men, according to a recent study by Nanyang Technological University (NTU). This eyebrow-raising find comes even as girls in Singapore are performing on a par with boys in math.

The national maths curriculum is known to produce cohorts that consistently top global tests like PISA (the Programme for International Student Assessment), regardless of gender. Math textbooks and learning materials are also carefully selected to avoid gender stereotyping, says a spokesperson from the nation's Ministry of Education.

One could even argue Singapore's girls fare better than boys. According to government data, between 2005 and 2020 women graduates of natural, physical and mathematical science courses at university consistently outnumbered men: the "fairer sex" took up an average of 62 per cent of seats at the graduation ceremony.

But come time to join the workforce, this lead seems to vanish. The percentage of women in STEM careers is surprisingly low, says the NTU study author, associate professor in bioengineering Sierin Lim. Her findings revealed nearly half of STEM-educated women work in non-related occupations. As of 2020, women comprised just a third of those working in STEM jobs, according to data from Singapore's Ministry of Manpower.

Subtracting confidence

Cheng Chi-Ying, psychology professor at Singapore Management University (SMU) is tracking the confidence levels of female undergraduates who study information systems and computer science. Her study's interim results are sobering. For one, female students start off with lower confidence than men from the very first semester. Their confidence levels sink further as the year progresses.

Cheng points the finger at gender stereotypes. "The industry believes the ideal STEM professional is male-oriented, so women must spend more effort to figure out how to fit in", she says.

Such pressures manifest in various ways, from women behaving more assertively, to maintaining stoic facades to avoid appearing emotional. "Female students are striving to reconcile their professional and gender identities, but quite a few are not successful", Professor Cheng says.

But it is too late to tackle these issues at the university level. The window where gender perceptions on STEM can →

be changed closes at around the age of 14 to 15, says Georgette Tan, president of United Women Singapore, a non-profit organization devoted to gender equality. “Girls tell us that at home, they get less encouragement from their parents than their male siblings to take up STEM jobs. Some parents still think STEM jobs aren’t feminine”, she adds. “The cultural overhang is still there.”

To counter this, United Women has run a programme since 2014 that has been attended by some 26,000 girls aged 10 to 16. “We’re hoping parents see their daughter can be extremely good at STEM, secure a good job and make very decent money”, says Tan.

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Model answers

Tackling preconceived notions could contribute significantly to restoring confidence. But the second piece in the puzzle is to follow up with role models, which women can use as evidence that it’s possible to achieve desired careers. “Girls are asking for mentors”, confirms Tan. “They want someone to aspire to.”

In response, her organization launched a mentorship component to its STEM programme last year. Tan’s team is lining up internships and training girls how to capitalize on these opportunities, by imparting skills such as how to prepare for meetings. “When these girls enter the workforce, they must hit the ground running”, she explains. “Preparing them for their first job hasn’t been stressed upon enough.”

Similarly, NTU plans to connect students in STEM with industry mentors, and run workshops to teach soft skills such as communication and self-management, in order to “build resilience”.

Meanwhile, Singapore’s education ministry plans to roll out in 2023 an engineering and tech scholarship programme, giving pre-university students with strong science and maths foundations early access to work experience.

Multiple possibilities

Though women have much to offer the maths field, the limited career paths for those keen on pure – not applied – mathematics could be another stumbling block.

“It was: you do your bachelors degree, and we’ll see after that”, says Charmaine Sia, a Clinical Assistant Professor of Mathematics at New York

Girls now equal boys in school, says UNESCO report

When they first start school, boys do better than girls in maths, but the gap then closes, even in the poorest countries. This is one of the findings revealed by the gender report of the UNESCO Global education monitoring report, presented in April 2022, which has sifted through data from primary and secondary schools in 120 countries.

The trend is the same everywhere – after just a few years in school, girls make up for lost ground. In some countries the tendency is even reversed. In eighth grade, girls are ahead of boys in maths in Cambodia, Congo, Malaysia and the Philippines.

That said, stereotypes die hard and, despite these good results, girls still face obstacles to equal access to scientific opportunities. Indeed, even if girls have caught up by the end of primary and in secondary school, boys are still over-represented among the best students in this subject, all countries taken together. Furthermore, in middle- and high-income countries, while girls perform much better at secondary level, they are still less likely to choose careers in the sciences.

Maryam Mirzakhani, the first woman to bend the curve

A glass ceiling was broken in 2014 when Iranian mathematician Maryam Mirzakhani was honored with the Fields Medal. She was the first woman and the first Iranian to win this top award in mathematics.

The award recognized Mirzakhani's "outstanding contributions to the fields of geometry and dynamical systems, particularly in understanding the symmetry of curved surfaces, such as spheres, the surfaces of doughnuts and of hyperbolic objects".

Mirzakhani was born in Tehran, Iran in 1977. Her childhood dream of becoming a writer was replaced by another passion: maths. As a high school junior, she was among the first Iranian women to qualify for the International Mathematical Olympiads, where she won two gold medals. After graduating from the Sharif University of Technology in Tehran, she moved to the United States where she earned a Ph.D. from Harvard University in 2004. In 2009, she became a professor of mathematics at Stanford University in California.

Today, Mirzakhani is a global icon for women in science. »I am sure there will be many more women winning this kind of award in coming years«, Mirzakhani said in 2014. Sadly, she was not there to witness the second woman to win the Fields Medal in 2022: Ukrainian Maryna Viazovska. Maryam Mirzakhani died in 2017 of breast cancer at the age of 40.

Described as one of the greatest mathematicians of her generation, several mathematics prizes have been named after her, including the Maryam Mirzakhani New Frontiers Prize and the Maryam Mirzakhani Price in Mathematics, and her birthday is commemorated by the May12 initiative which brings together events celebrating women in mathematics.

University. Back in 2006, the 35-year-old Singaporean found no scholarships would permit applicants to study a Ph.D. in pure maths overseas and then pursue it as a career locally, though she believes the situation has now changed. Still, adds the Alice T. Schafer Mathematics Prize winner: "Who would have expected that Wall Street companies are trying to hire all the maths and computer science graduates?"

The highly-transferable numeracy skill underpinning mathematics means degree holders can pick from a veritable buffet of jobs, especially in the field of finance.

Jaya Dass, the managing director of Ranstad in Singapore, reveals that the recruitment agency has placed half of the 15 women with maths backgrounds in finance within the past six months. "Even if they hold maths qualifications, women are starting to think: are there more sexy ways of utilizing this?", she adds.

Career switches like these have been occurring for decades, as demonstrated by the case of Angeline Tan, a 54-year-old director of financial services at a Singapore financial advisory firm. It was the long working hours that made this degree-holder of combined maths and physics leave teaching in 1995. It has nothing to do with confidence, she says: "The ability to not be afraid of numbers makes me confident".

> **"Initiatives have mushroomed in recent years to smoothen women's transition into STEM**

Perhaps it is inevitable that women in maths will stream into other fields. The latest temptation is the sizzling tech industry, which seduces with hot careers in data, software and artificial intelligence.

Jamie Lim, for one, wants to read computer science when she applies to university in two years time. "The career path is more well-defined, and I would still get to do maths", says the 17-year-old pupil at NUS High School of Mathematics and Science. She has already represented the nation at regional mathematical and informatics olympiads. Secure in her own ability, she regrets that qualified women are leaving maths-related professions. "They've already made it this far. I think that if it's something I really enjoy and want to do, I wouldn't give up so easily. But it's hard to say, since I'm not there yet." ■

Nick Dall

Journalist in Cape Town, South Africa

Complex equation of maths education in South Africa

South African schools' maths results are alarming. What explains the low scores of children in a country with world-class universities? The cause is partly attributed to the lack of qualified mathematics teachers and the effects of past segregation policies. To reverse the negative trend, maths education should be reinforced from the very first grade, experts say.

The latest Trends in International Mathematics and Science Study (TIMMS) 2019 confirms what those on the ground have known for decades: South African school students are bad at maths. At primary school level, South Africa had the third lowest score out of the 64 countries. Things are no better at high school, where South Africa's Grade 9 learners received the second lowest score out of 39 countries. Moreover, less than a third of all students in the final year of high school take maths – and only half of them pass their exams, according to data from the South African Institute of Professional Accountants (Midrand, Greater Johannesburg).

Understanding the problem starts with understanding South Africa's history, says distinguished professor Jonathan Jansen of Stellenbosch University, about fifty kilometres from Cape Town. During apartheid, the Bantu Education Act of 1953 resulted in the under-education of people of colour. As Hendrik Verwoerd, Prime Minister from 1958 to 1966, infamously said: "What is the use of teaching the Bantu child mathematics when it cannot use it in practice? That is quite absurd. Education must train people in accordance with their opportunities in life, according to the sphere in which they live."

Now, almost 70 years later, South Africa's education system still bears the stains of Bantu Education – even though the policy was abandoned at the end of apartheid. Children at former Blacks-only schools continue to deliver abysmal maths results, while those at former whites-only schools perform on a par with their contemporaries in the US and Europe. While it's extremely important to acknowledge this legacy of discrimination, says Jansen, the country should not be crippled by it. "All the other countries in southern Africa have similar histories", he explains. "But when it comes to maths performance, we are by far the worst in the region."

> "Understanding the problem starts with understanding South Africa's history

Lack of qualified teachers

Among the reasons for South Africa's poor maths results is a shortage of qualified teachers. Undesirable working conditions mean that for many students teaching is a last resort. To address the shortage of competent teachers, one-year courses were introduced to train graduates as teachers. Dr Jacques Verster's qualitative case study focused on one of these post-graduate courses at one of the country's universities of technology. He found that the university struggled to cope with the drastic increase in the course's popularity (between 2014 and 2015 student numbers doubled, for example) and was "expected to do more with less".

Moreover, low levels of engagement between students and lecturers (the course was mainly taught by part-time lecturers in the evening) meant that many trainee teachers were woefully underprepared at the end of the year-long course. But perhaps the biggest problem, according to Verster, was the lack of continuous professional development following completion of the course. "We graduate people," he said. "And then we leave them on their own."

© Sydelle Willow Smith / Equal Education

School in Eastern Cape Province, South Africa. In 2013, the citizen movement Equal Education organized mediatized school visits as part of a campaign to improve school infrastructure.

Consequently, the general level of mathematics teachers is largely inadequate. Faith Ngwenya, a standards executive at the South African Institute of Professional Accountants, pulls no punches in her assessment: "Those who do teach the subject are not comfortable doing it. They teach learners solutions which they cannot explain themselves."

Early learning is key

For Professor Jansen, teacher training is not the only issue. Along with other senior colleagues, he is concerned that, in recent years, rather than focusing on maths education at the foundation phase (students aged 5 – 9 years), efforts have been aimed at improving Grade 12 results – notably by introducing a soft-option subject called Maths Literacy. But the first years of education are crucial because "in mathematics you build on knowledge acquired earlier", explains Jansen.

Weak maths results at foundation phase tend to persist throughout the education phase. "Needless to say, children who went to preschool do better at maths than those who didn't. And children who come from homes with cultural capital do even better," he says. "If you're in the poor working class and you don't have your home, preschool and primary school working in your favour you will be constantly left behind."

The legacy of apartheid will not be easy to overcome, but the experts refuse to give up. The stakes are high: maths develops cognitive skills which are part of 21st-century learning, explains Ngwenya. Beyond counting, these include the ability to think critically, communicate, collaborate and be creative. "It has nothing to do with crunching the numbers. It is all about being able to interpret, analyze, and solve problems." Jansen agrees wholeheartedly, and adds: "It's not just about skills, it's also about attitude. Students get used to constant failure, and eventually they give up". For Jansen, it's time to break this spiral of failure.

Soluble problem

Taking action now can help prevent the situation from recurring and affecting the next generation. "This is a soluble problem," Jansen stresses. "If we invested in literacy and numeracy in the foundation phase, the Grade 12 outcomes would be better."

University education departments around the country are already doing their bit, working with poorer schools to improve their maths programmes. But involvement at the national level is the only way to reach all 26,000 public schools. "It is possible," Jansen insists. "Namibia did it in the 1990s and they have far fewer resources than we do… South Africa has 26 very good universities, seven of which are world-class. Are you telling me you can't solve this problem?"

When asked how to go about fixing the problem, his answer is surprisingly simple: "First, we need a plan. And second, we need to put teachers at the centre of the plan." ■

Moroccan oases:

Mustapha is responsible for water distribution in Tighmert oasis, January 2021.

Photos: **Seif Kousmate**

Text: **Katerina Markelova**, UNESCO

On the other side of the mirage

A rising star in Moroccan photography, Seif Kousmate documents life as it is today in the oases of southern Morocco. His project *Waha* (oasis in Arabic) takes us far beyond the trite clichés and fantasized representations of these oases.

To reveal the degradation of these fragile ecosystems, the former engineer does not merely show it. He uses the creative possibilities of photography to give concrete form to the evils that plague these islands of life. Some of his photos are burned, corroded with acid, taking a striking shortcut between the medium of the image and its subject: the oases, victims of intensive agriculture and climate change, prey to drought and silting.

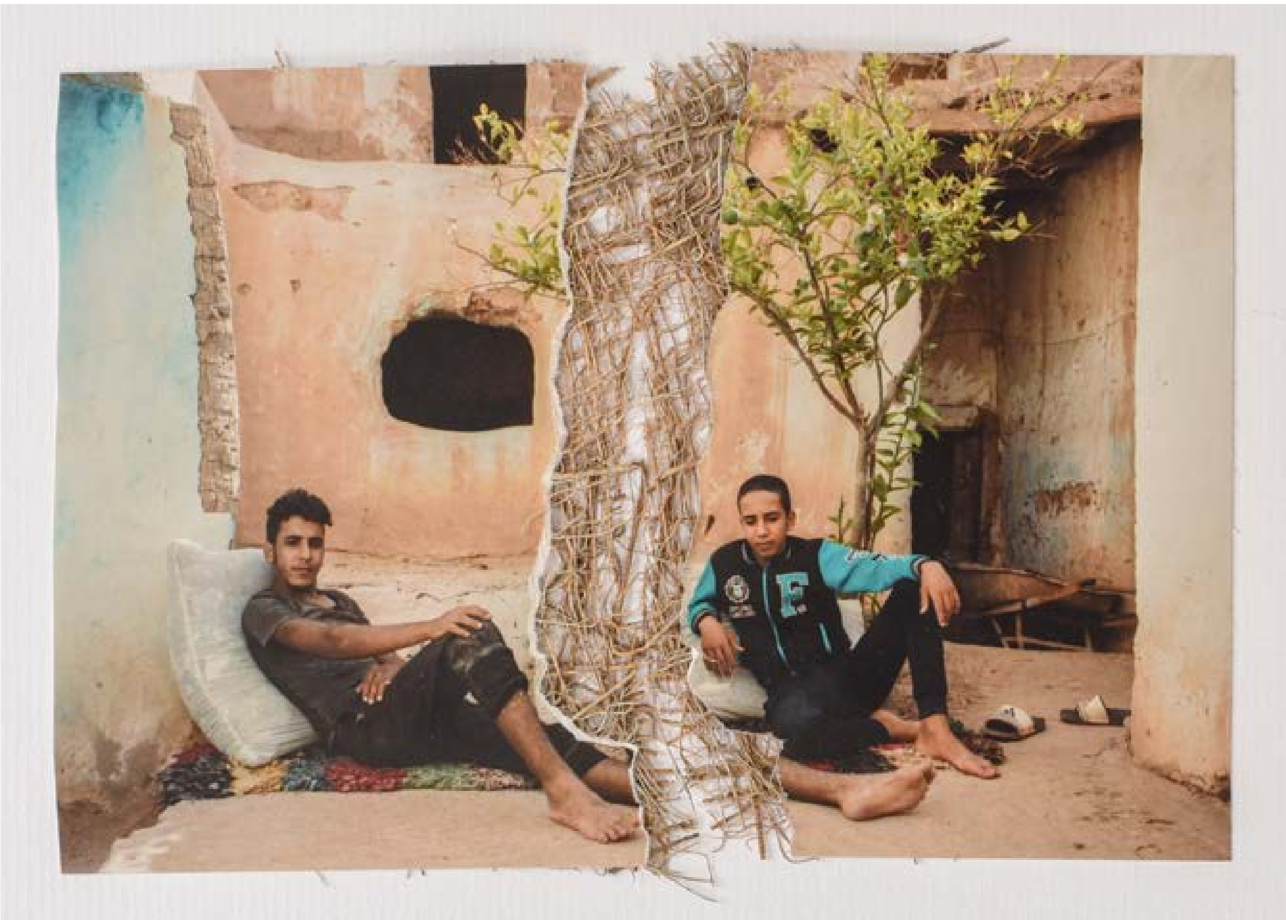
In the space of a generation, the oasis areas have indeed changed their physiognomy: the palm groves have been stripped of vegetation, the soil has cracked from lack of water, endangering the extraordinary biodiversity of these areas, which still shelter more than two million inhabitants and most of the animal species of Morocco[1]. Kousmate's work shows the beauty of this fragile world that can still be saved. "As long as there continues to be life in these places", he assures us, "there is the hope we can preserve them". ■

1. Since 2000, the oases of southern Morocco have been part of the UNESCO world network of biosphere reserves.

Opposite above: Ahmed collecting seaweed to facilitate the arrival of water in the Tighmert oasis irrigation system, September 2020.

Below: Akka oasis, February 2021.

Opposite below: Hassan (left) and his brother Abderrahman live in the oasis of Tighmert. After their father passed away in 2013, Hassan left school to take care of his family. The younger brother Abderrahman does not see his future in the oasis. September 2020.

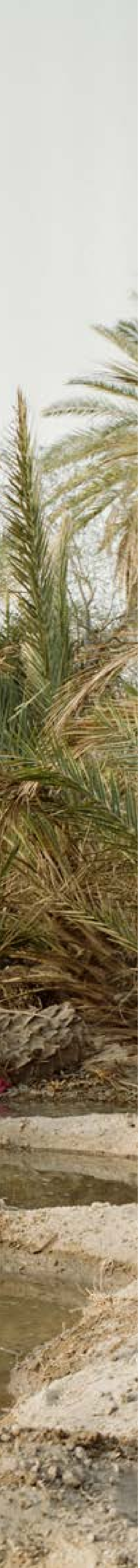


Above: Poem composed by Ibrahim Rajeaa, a resident of the Tighmert oasis. It tells of the suffering of the inhabitants and the deterioration of the oasis. September 2020.

Left: Akka oasis, February 2021.

Opposite: Zayna's hands, Akka oasis, February 2021.

The irrigation system in the oasis involves sharing resources. Now it's Saidia's turn with his nephew Nourdine to water her crops in Tata. September 2020.



Ali is one of the last craftsmen in the Akka oasis to continue the traditional cob construction. February 2021.

Alifal cleaning the irrigation gallery in the Tighmert Oasis in September 2020.

Portrait of Ilyas, Aguinane Oasis, February 2021.




Kids on the streets of London, 1967

Hayley Christian

Associate Professor at the Telethon Kids Institute and School of Population and Global Health, University of Western Australia, she leads the PLAYCE research programme which focuses on improving children's physical activity, health and well-being.

Time to go out and play

Outdoor play is essential for healthy bodies and brains, but research shows children across the world aren't getting enough play time outside. Urbanization, screen time and "helicopter parenting" are a few factors contributing to the phenomenon.

Children occupying public places is a common theme in early 20th century street photography: they carry loads, wear backpacks to school, run around, float paper boats in Parisian gutters, or play in water sprayed from fire hydrants in New York – without an adult in sight. Nowadays, it's hard to get such shots. The sight of young children playing, walking or cycling in public places without adult supervision has become rare.

The world has indeed witnessed a significant decline over recent generations in outdoor play and children's independent mobility. The drop in outdoor play time is our first clue to declining physical activity levels – the two are inextricably entwined, with the amount of time a child spends outdoors being the biggest determinant of how much physical activity they get.

The World Health Organization recommends children from one to five years old spend at least three hours per day in a variety of physical activities, while children aged between five and seventeen should engage in at least one hour of moderate to vigorous intensity physical activity daily. However, based on a recent review covering 29 countries, children aged from three to twelve years receive 60–165 minutes of outdoor play each day.

The Active Kids Global Alliance reports similar findings. Their Global Matrix 4.0 from October 2022 provides a comprehensive assessment of child and youth physical activity across 57 countries and six continents. The conclusion is that children's physical activity levels are clearly insufficient around the world.

Countless benefits of outdoor play

The situation is alarming when we consider how important outdoor activities are for a child's health and development. The concept of play is so critical for a child that the right to play is preserved in the United Nations Convention of the Rights of the Child. What makes outdoor play so unique is that it involves activity that is freely chosen, spontaneous, self-directed and enjoyable. It supports children's social-emotional, cognitive and physical development.

> **"Research shows children have improved attention and concentrate better in the classroom following periods of outdoor play**

In addition, it's good for your health. Children who meet physical activity guidelines have a reduced risk of chronic diseases such as obesity, cardiovascular disease and type 2 diabetes. They also have better mental health, improved cognitive and executive function, and greater overall well-being.

Good habits are more likely to become permanent if they are started early. Similarly, sedentary behaviours, as well as overweight and obesity, tend to track across childhood into adulthood. Daily outdoor play helps children develop the essential fundamental movement skills, such as running, hopping, skipping, and jumping, required to help them become confident movers throughout life.

Also, playing outdoors gives children the opportunity to interact with family members, peers and other community members. It helps them develop skills such as social competence, risk management and creativity, as well as independence and self-determination – essential life skills – and encourages →

them to navigate and learn about their environment.

Research shows children have improved attention and concentrate better in the classroom following periods of outdoor play. Active outdoor play increases blood flow to the brain which can assist with tasks involving executive functions.

When play happens "in nature" it provides additional benefits. It facilitates greater exploration, imagination and interaction with people, plants and animals, and helps children to develop environmentally friendly behaviours.

"Risky play", which can involve speed, tools, or play near fire or water, also has a role to play in a child's development. This kind of play teaches children how to master risk and evolve with it. However, society has increasingly restricted risky play opportunities through social norms that insist on constant supervision and consider parents to be neglectful if they don't conform. Parents themselves have incorporated these social norms, driven by the perception of the "outside" as a potentially dangerous place.

Closer to home, parents act as gatekeepers who either provide opportunities or barriers to children's outdoor play. Many parents are concerned about traffic hazards or kidnappings – despite data from the United Nations Office on Drugs and Crime showing that child abduction rates have remained stable. Social media has fuelled these concerns, creating risk-averse societies. Research has confirmed an increase over time in overprotective behavior and hyper-parenting styles, such as so-called "helicopter parenting".

Rapid urbanization

Modern society presents another big barrier. We schedule so much more into our day – leaving little or no time for unstructured outdoor time with children. As any parent knows, the influence of screen time constantly competes with children's desire to be outdoors.

Another major long-term limiting factor is rapid urbanization. More than one billion children globally live in urban environments, and 70 per cent of the world's population will live in cities by 2050. This phenomenon can lead to increased traffic, air pollution and urban heat island effects while reducing natural green spaces and biodiversity – all of which negatively impact children's opportunities to play outdoors.

Enabling children's right to daily outdoor play

Children will play outdoors more if their parents and carers are positive about physical activity and about being outdoors in nature. Therefore, one of the most practical steps families can take is to make sure there is unstructured time for family play every day, especially on weekends.

Providing opportunities for children to play outdoors is easier when the social, physical and policy environment supports their right to play. We need to wrap children and families in supportive environments that make outdoor play an easy, safe and enjoyable experience. Building neighbourhood social capital and a sense of community can help alleviate some of parents' perceived concerns about how safe their area is when it comes to outdoor play. One way to push back against the hyper-parenting trend is to highlight that it can disadvantage children by depriving them of activities that are essential for their development.

Children need access to safe, local green space and parks with age-appropriate, universally designed, child-friendly features. Other key ingredients for outdoor play-friendly environments include low traffic volumes and speeds, traffic-calming strategies such as school crossings, and pedestrian infrastructure (connected footpaths and cycle lanes). For younger children, the home yard and safe, accessible spaces close to the home – such as the front of the house, adjoining footpaths and verges – are also key outdoor play spaces.

Ultimately there is no single solution when it comes to reversing declining levels of outdoor play. It's an issue we need to tackle at every level – parent and child, neighbourhood, the physical and policy environment, all the way up to societal level.

The most powerful voice in all of this is that of children – especially those experiencing disadvantage. Every child has the right to play outside every day, and we must protect that right. The time to play is now. It is our global responsibility to fiercely protect the right of every child to play outdoors each and every day – now and into the future. ■

◥ Three cages, *mural painted by the French artist SETH (seth.fr) in Hashmi Al Shamali in Amman (Jordan), 2021.*

"

Hyper-parenting trend can disadvantage children by depriving them of essential activities for their development


BALADK
SETH.21

Vinciane Despret: *"To combat species decline, we need passions of joy"*

© Valentin Bianchi / Hans Lucas

Interview by Agnès Bardon

UNESCO

Vinciane Despret is a philosopher and psychologist who teaches at the University of Liège and the Free University of Brussels (Belgium). She impudently questions our relationship with animals in works such as *Quand le loup habitera avec l'agneau (When the Wolf Lives with the Lamb), Penser comme un rat (Thinking Like a Rat)* and *Habiter en oiseau (Living as a Bird)*. Through close observation of animal behaviour, she seeks to change the way we look at living things, including through fiction, as in her latest book, *Autobiographie d'un poulpe (Autobiography of an Octopus)*.

For centuries, the Western philosophical tradition has promoted the superiority of humans over animals. When did this view begin to change?

French philosophy is dominated by a view that animals have no soul and by the idea of human exceptionalism. This view has largely determined our behaviour towards animals, whether it is the way we eat them, imprison them or constrain them. It is reflected in the very structure of language. When we talk about animals, we tend to use syntactic constructions that make them passive beings. We say that they are determined, that they are acted upon by their hormones, their impulses, by biological or ecological factors. In his book *Melodie: A memoir of love and longing*, the Japanese-born author Akira Mizubayashi wonders what words he should use to talk about his dog when he speaks in the language of Descartes, which was forged against animals.

◥ *Sky of Ostende (Belgium) by the Belgian artist Jean-François Spricigo.*

> **“This vision of the animal machine was not questioned until the early 1990s**

The behaviourist tradition has had the effect of mechanizing animals. This is particularly evident in experiments with rats. When we study learning in this animal, we are not trying to determine its specific skills but to produce a typically human type of learning. A rat released into a maze demonstrates the memory of a pupil memorising a lesson, because it is not allowed to use its own methods – leaving scents in certain places – to find its way around. The mechanization of animals in behaviourism has had important consequences, because its methods can turn an intelligent animal into a clockwork toy if we only get it to press levers.

It was not until the early 1990s that this vision of the *animal machine* began to be questioned, thanks in particular to the French philosopher Jacques Derrida. In his book *The Animal that Therefore I Am*, he stigmatizes the lack of curiosity shown by philosophy towards animals. He denounces what he calls "interested ignorance", which has led philosophers to write about animals without really trying to get to know them. →

Without this ignorance, our relationships with them would have been very different.

Your work on animals, which is now widely recognized, was initially greeted with some scepticism. How do you explain this mistrust in the scientific community?

Animals are problematic subjects for the humanities. The French anthropologist Albert Piette has shown that the study of religion and the study of animals, however far apart these subjects may be, present the same difficulties for those who study them. If you take seriously the fact that God exists, you are doing theology. If you are not interested in God but in his representation, you are doing sociology. The study of animals poses a similar problem: either you talk about animals as such and your work is science – zoology or veterinary science for example – or you consider their symbolic dimension from a social or cultural perspective. Some of my work has been received with suspicion because I wanted to work in the field of philosophy, but on real animals and not on their representation. It is worth noting that it has most often been women who have explored problematic subjects because they had little taste for lofty subjects, such as the question of animality or religion. Being marginalized themselves, to an extent, they had more room for manoeuvre.

Recent discoveries have revealed that animals have abilities that we would never have expected. What consequences might these discoveries have?

It is more interesting to consider animals as having agency because it allows us to enter a different conceptual framework, leaving room for intentionality. The observed phenomena can then give rise to new interpretations. If you see animals as beings driven solely by the need to survive and reproduce, you miss out on a whole range of social and cognitive skills that they employ.

This is even more the case because many forms of animal behaviour are extremely discreet. For example, I had the opportunity to observe the Arabian Babbler (*Argya* squamiceps), a bird that lives in the desert. If one of them – male or female – decides to mate with another, the group must not know about it because as a rule only the alpha male and female reproduce. To achieve this, the Babbler has to use a very elaborate strategy, which consists of taking a small piece of straw and pointing it very slightly in the direction of the potential partner so that a dialogue can take place between them. But this relationship will escape you completely if you can't imagine that birds are capable of such behaviour.

The great British primatologist Thelma Rowell, who has transformed our understanding of baboons, questioned our interest in apes and their cognitive abilities. She asked herself the following question: is it because they are our closest cousins that we have asked monkeys interesting questions and sought to highlight their intelligence? Conversely, sheep are generally thought to be stupid, but perhaps that's just because we haven't tried to investigate their intelligence. Good scientists advance by formulating several hypotheses.

In your latest book,* Autobiography of an Octopus, *you take the route of fiction by imagining that wombats, spiders and octopuses send us coded messages. Is fiction a way for you to push your thinking further?

I associate fiction with play. But play is what frees things from their being. My pen can become a sword, my dog a horse, a piece of paper a plane. In fiction, it becomes possible to free oneself from certain constraints of reality and to make them act differently, to emancipate the possibilities that were swarming under the surface and that we did not see.

Fiction also allows us to take things further and explore situations that have not yet occurred. Only twenty years ago, scientists totally rejected the idea of animal culture on the grounds that it could only be a human reality. Today, with hindsight, we wonder how we could have been so stupid.

> **“Talking about extinctions in numbers is useful, but it's not enough, because figures don't move us**

Similarly, no one believed in the possibility of semantic and syntactic use of language in birds. We thought that they used emotional onomatopoeia and ruled out the possibility that there could be words for one predator or another. Language could only be human. Here again, we could laugh at our ignorance.

Fiction is a way for me to imagine what we will be laughing about in fifty years' time. Through these science fiction stories about the wombat and the octopus I have tried to give these animals a little more intentionality. This may not be the direction in which science will go, but it is in any case a way of opening up possibilities. It is also a way of anticipating the laughter that our current lack of knowledge will provoke, not to escape it but to say that we are aware that one day someone will laugh at our current mistakes.

Year after year, scientific reports provide a gloomy chronicle of the decline of life on Earth. Why are we still so insensitive to the disappearance of species?

It is extremely useful to talk about extinctions in terms of numbers. Extinctions need to be documented – this is a precondition for raising the alarm about what is happening, but it is not enough, because the figures do not move us. This is a fact. We are not affected in our bodies by these disappearances because we are so urbanized that we no longer have much contact with the living world. For example,

Monkey, Rome (Italy), by Jean-François Spricigo.

we realized a few years ago that the windscreens of our cars were no longer covered with insects, but we didn't understand what that meant. We didn't make the connection with other phenomena.

Emotions are what the new ecological class lacks, according to the French philosopher and sociologist Bruno Latour. Historically, the left has relied on the emotions of emancipation, justice, and progress, which have all been vectors of mobilisation. The right has also been able to cultivate emotions linked to the ideas of values and grandeur. But what are the emotions of the ecological class, the class that has to fight against the Anthropocene?

A number of researchers are now working to answer this question. The Australian environmental philosopher Glenn Albrecht, for example, has coined the concept of *solastalgia* to describe the pain of no longer recognizing the place where one has lived because it has been too damaged. It is a powerful emotion. Art historian Estelle Zhong and philosopher Baptiste Morizot are young French researchers exploring how emotional toolkits help us attune to the state of the world. The difficulty is that we have to go beyond gloomy passions, which are paralysing, and be able to identify joyful passions too.

In her book *Hope in the Dark*, American writer Rebecca Solnit encourages us to remember past struggles to avoid becoming discouraged. We tend to forget that many victories have been achieved through struggle. Rekindling the memory of these struggles is also a source of joyful passions. ■

Mila Ibrahimova

UNESCO

Global alert: Glaciers are melting at unprecedented rate

Glaciers appear on almost every continent providing a large part of the fresh water we consume. But this indispensable resource is now threatened. Today we know that the glaciers in UNESCO World Heritage sites are retreating at an accelerated rate because of climate change. According to the latest report by UNESCO, in partnership with IUCN, *World heritage glaciers: sentinels of climate change*, they lose on average some 58 billion tons of ice every year – and contribute to almost 5 per cent of global sea-level rise.

One-third of UNESCO World Heritage glaciers will disappear by 2050 because of climate change. If there is a silver-lining, it is that the other two thirds could be saved, should the rise in global temperatures not exceed 1.5 °C compared to the pre-industrial period. Urgent action is needed to preserve these iconic places for future generations. ■

GLACIERS: AT THE HEART OF WATER SECURITY

Every day, **more than half of humanity** relies on **mountain glaciers for water,** used for:

- **Domestic consumption**
- **Industry**
- **Agriculture**
- **Hydropower**

The main cause of glaciers melting is climate change.

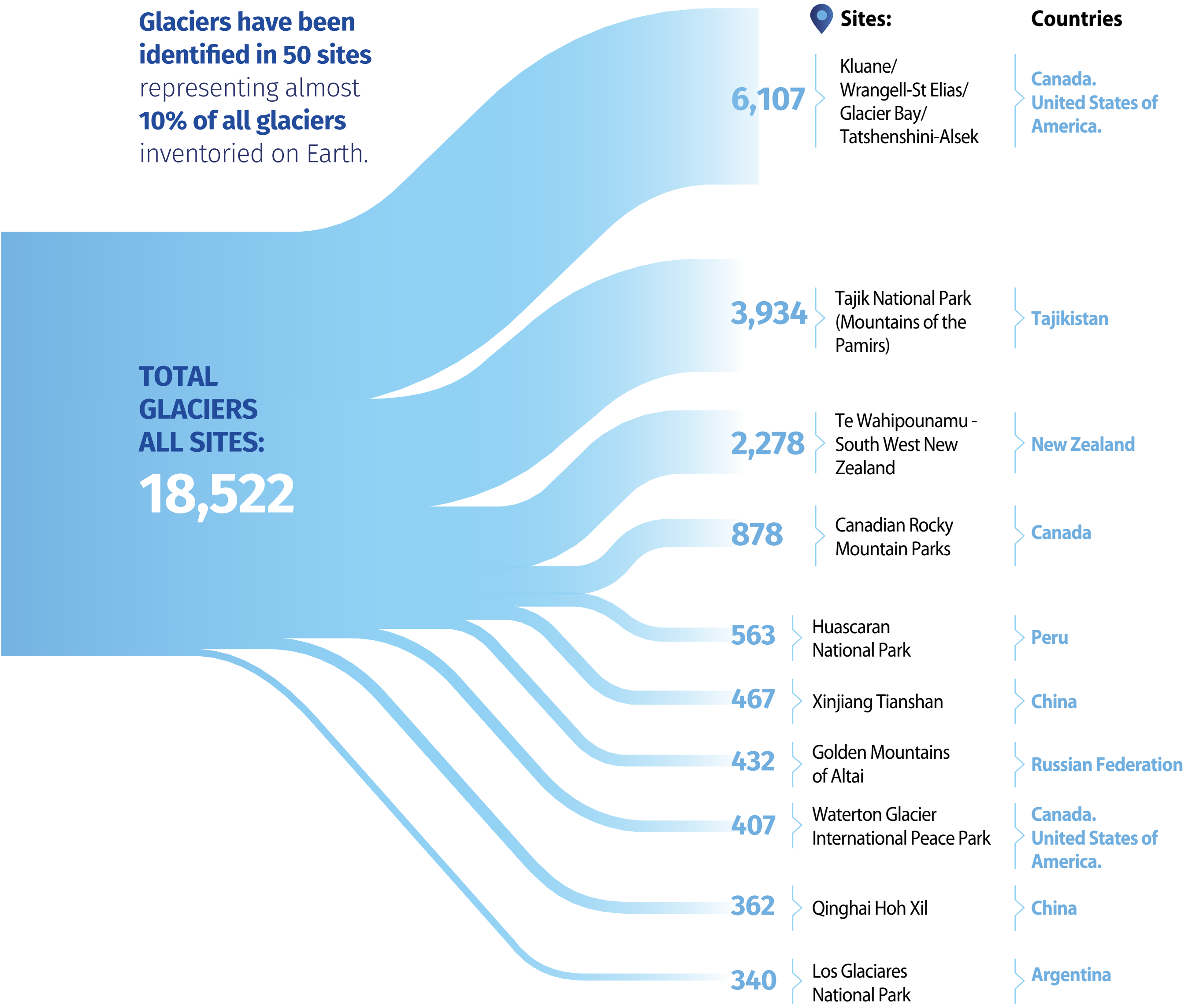
Meltwater from glaciers acts as a buffer **during droughts.**

Glaciers and ice caps **play a key role in climate and ocean regulation.**

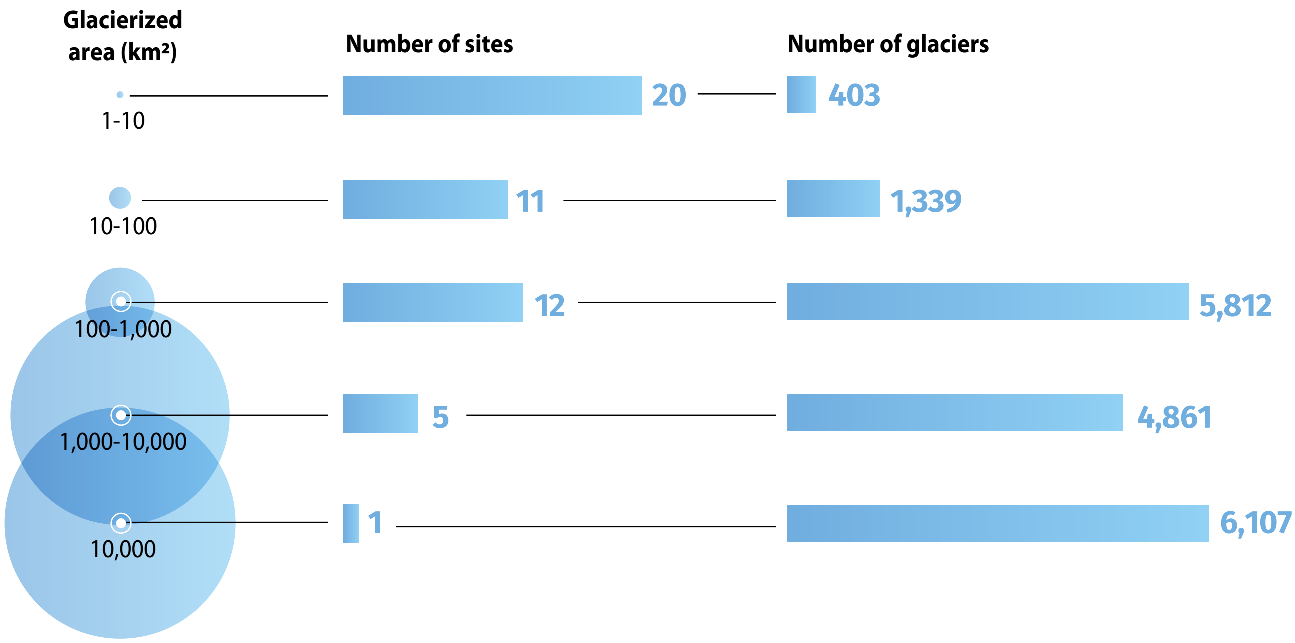
70% **of all fresh water on Earth** is stored in glaciers.

TOP 10 – NUMBER OF GLACIERS PER UNESCO WORLD HERITAGE SITE

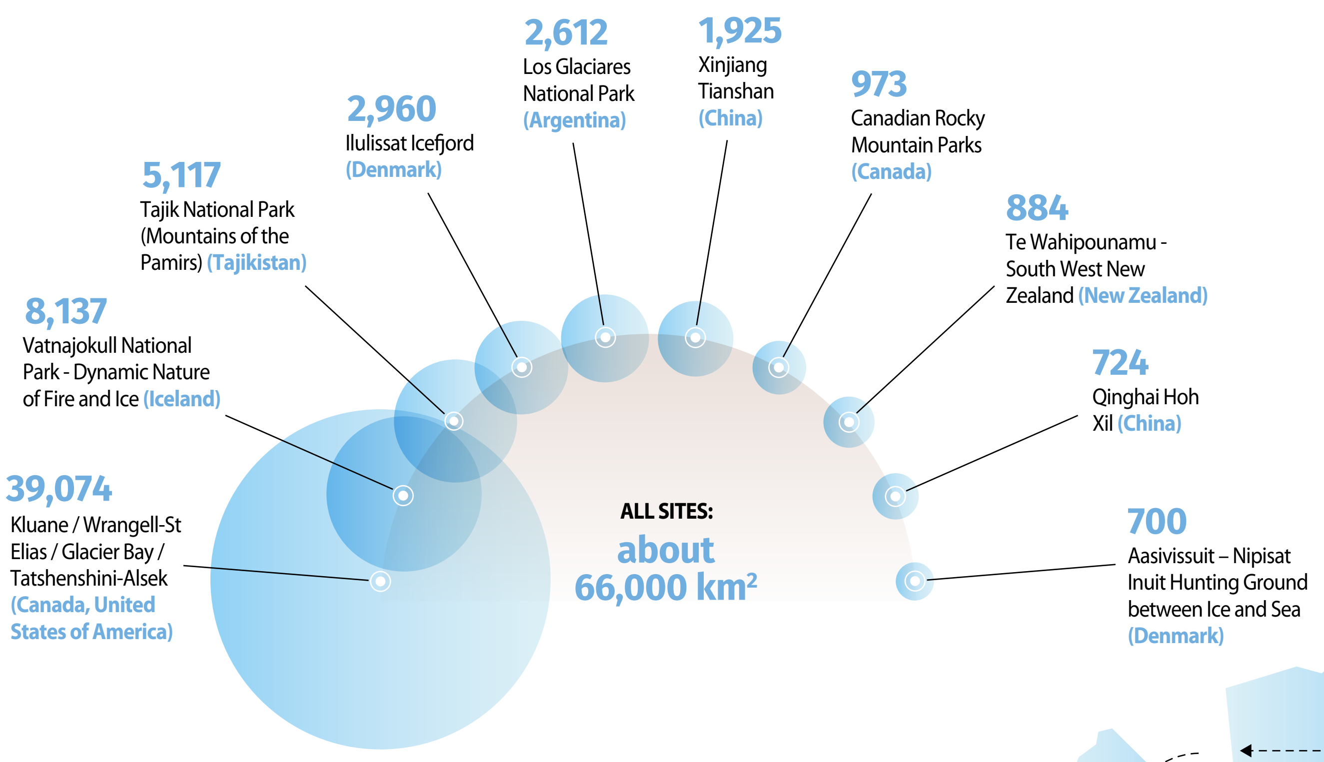
Glaciers have been identified in 50 sites representing almost **10% of all glaciers** inventoried on Earth.



SITES AND GLACIERS GROUPED BY SIZE OF GLACIERIZED AREA

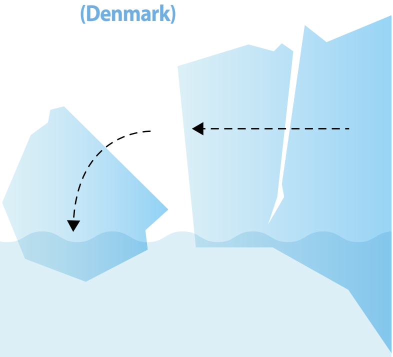


TOP 10 – GLACIERIZED AREA PER UNESCO WORLD HERITAGE SITE (km^2)



RELATIVE VOLUME LOSS 2000-2020

ALL SITES: **5.7%**



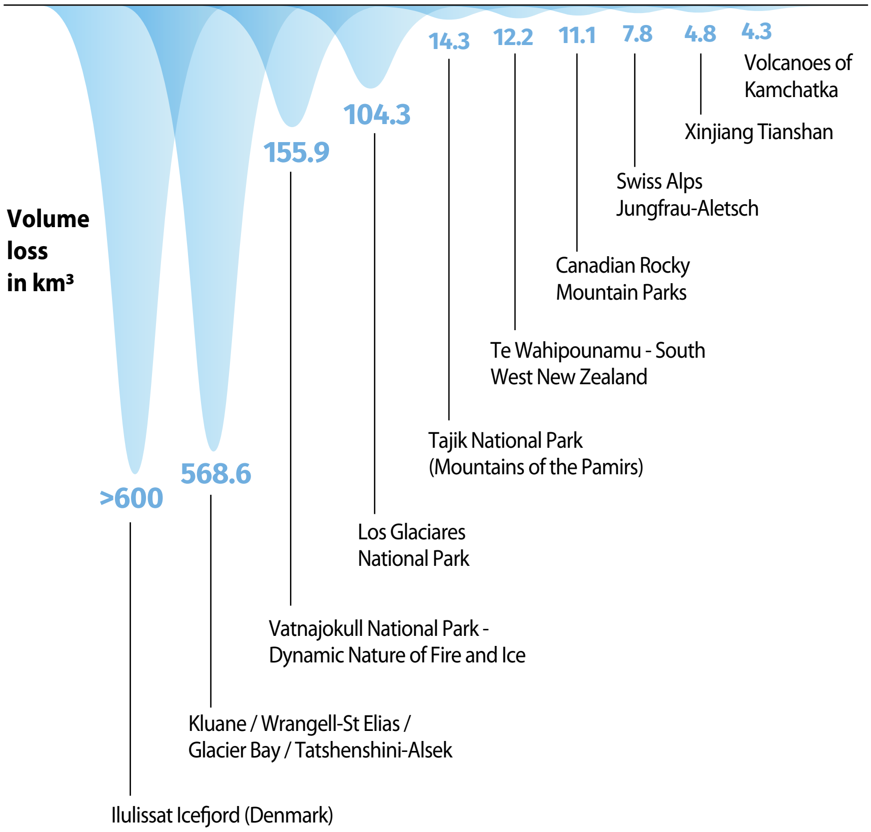
At least 40% of all glaciers in World Heritage sites **have lost more than 15% of their volume since 2000.** Except for a few sites (1,000-10,000 km^2 – 4 sites), World Heritage glaciers **are thinning at an accelerated rate.**

Sites	Volume loss
Three Parallel Rivers of Yunnan Protected Areas (China)	57.2%
Los Alerces National Park (Argentina)	45.6%
Uvs Nuur Basin (Mongolia, Russian Federation)	37.0%
Sichuan Giant Panda Sanctuaries - Wolong, Mt Siguniang, Jiajin Mountains (China)	35.9%
West Norwegian Fjords, Geirangerfjord, Naeroyfjord (Norway)	33.2%
Western Tien-shan (Kazakhstan, Kyrgyzstan, Uzbekistan)	27.1%
Olympic National Park (United States of America)	26.5%
Waterton Glacier International Peace Park (Canada, United States of America)	26.5%
Swiss Alps Jungfrau-Aletsch (Switzerland)	25.9%
Laponian Area (Sweden)	25.7%

* Ilulissat Iceford not considered.

TOP 10 – VOLUME LOSS 2000-2020 (km³)

Glaciers in World Heritage sites **lost more than 1,500 km³ over the past 20 years** (equivalent to 1.5 times the volume of Lake Titicaca, South America's largest lake).



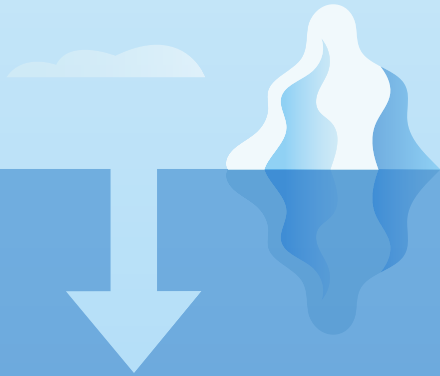
PROJECTIONS

2050

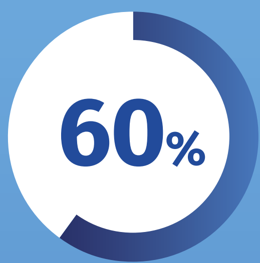
The **smallest glaciers** (1-10 km²) will all disappear **by 2050.**

2100

Glaciers ranging from **10 to 100 km²** will disappear **by 2100.**



More than

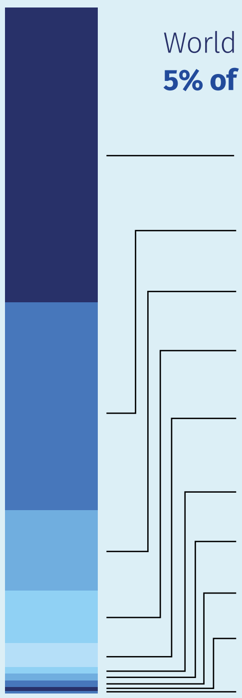


of the World Heritage sites that currently have glaciers **will no longer have them by 2100.**

TOP 10 – CONTRIBUTION TO GLOBAL SEA LEVEL RISE FROM 2000 TO 2020 (mm)

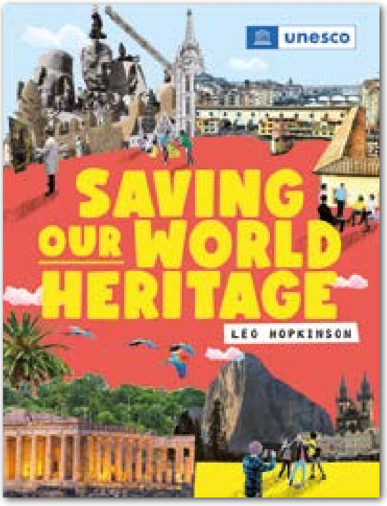
ALL SITES:
3.22 mm

World Heritage glaciers' contribution to around
5% of the observed global sea-level rise.



- **1.35 mm** Kluane / Wrangell-St Elias / Glacier Bay / Tatshenshini-Alsek **(Canada, United States of America)**
- **0.95 mm** Ilulissat Icefjord **(Denmark)**
- **0.37 mm** Vatnajokull National Park - Dynamic Nature of Fire and Ice **(Iceland)**
- **0.24 mm** Los Glaciares National Park **(Argentina)**
- **0.11 mm** Aasivissuit – Nipisat. Inuit Hunting Ground between Ice and Sea **(Denmark)**
- **0.03 mm** Tajik National Park (Mountains of the Pamirs) **(Tajikistan)**
- **0.03 mm** Te Wahipounamu - South West New Zealand **(New Zealand)**
- **0.03 mm** Canadian Rocky Mountain Parks **(Canada)**
- **0.02 mm** Swiss Alps Jungfrau-Aletsch **(Switzerland)**
- **0.01 mm** Xinjiang Tianshan **(China)**

New publications



Saving Our World Heritage

ISBN 978-92-3-100498-8
64 pp., 265 x 216 mm, hardback, €17
UNESCO Publishing/Hachette UK
Purchase here: https://en.dl-servi.com

Our world is full of wonders. From historic cities, castles and cathedrals to magnificent mountains, rainforests and oceans, the world's greatest treasures belong to all humankind. This is our world heritage.

But our heritage is constantly under threat – from natural disasters, wars, climate change, construction, pollution and mass tourism. In this children's book, we visit over 70 World Heritage Sites in 52 countries. We find out how communities, governments and organizations are working to save this extraordinary inheritance.

And we meet the people involved – the experts patiently restoring great works of art, park rangers risking their lives to defend rare wildlife, and young volunteers learning to protect the environment.

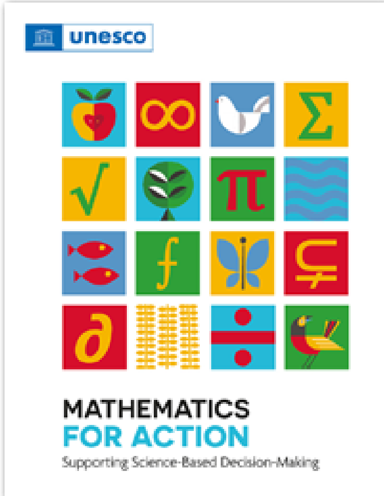
World Heritage No. 103

50th anniversary of the World Heritage Convention

ISSN 1020-4202
64 pp., 220 x 280 mm, paperback, €7.50
UNESCO Publishing/Publishing for Development Ltd.

On 16 November 2022, the World Heritage Convention celebrated its 50th anniversary. This issue traces the evolution of the Convention over these five decades, through emblematic preservation stories and the experiences of experts and site managers.

While an anniversary marks a time to look back at the past, it also calls for looking forward and reflecting on challenges posed by climate change, sustainable tourism, digital transformation, and post-COVID-19 recovery.



Mathematics for Action

Supporting science-based decision-making

ISBN 978-92-3-100517-6
72 pp., 215 x 287 mm, PDF
UNESCO Publishing
Publication available on https://unesdoc.unesco.org

Everything we do is based on some mathematical structure, and although mathematics is often considered abstract, it is fundamental to how we understand nature, the larger universe, with its time and space dimensions and a myriad of uncertainties.

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Providing insightful information for decision-makers and for those seeking proof to challenging questions, it presents new avenues for scientific research.

Many voices, one world

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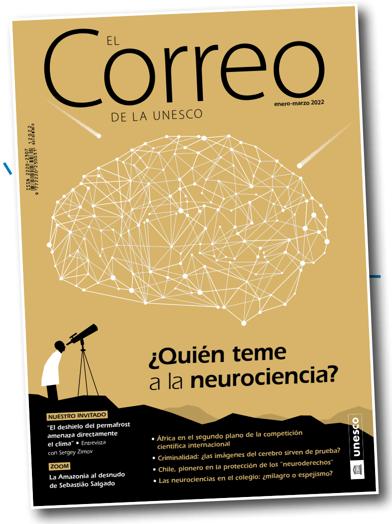

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THE UNESCO ADVENTURE

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