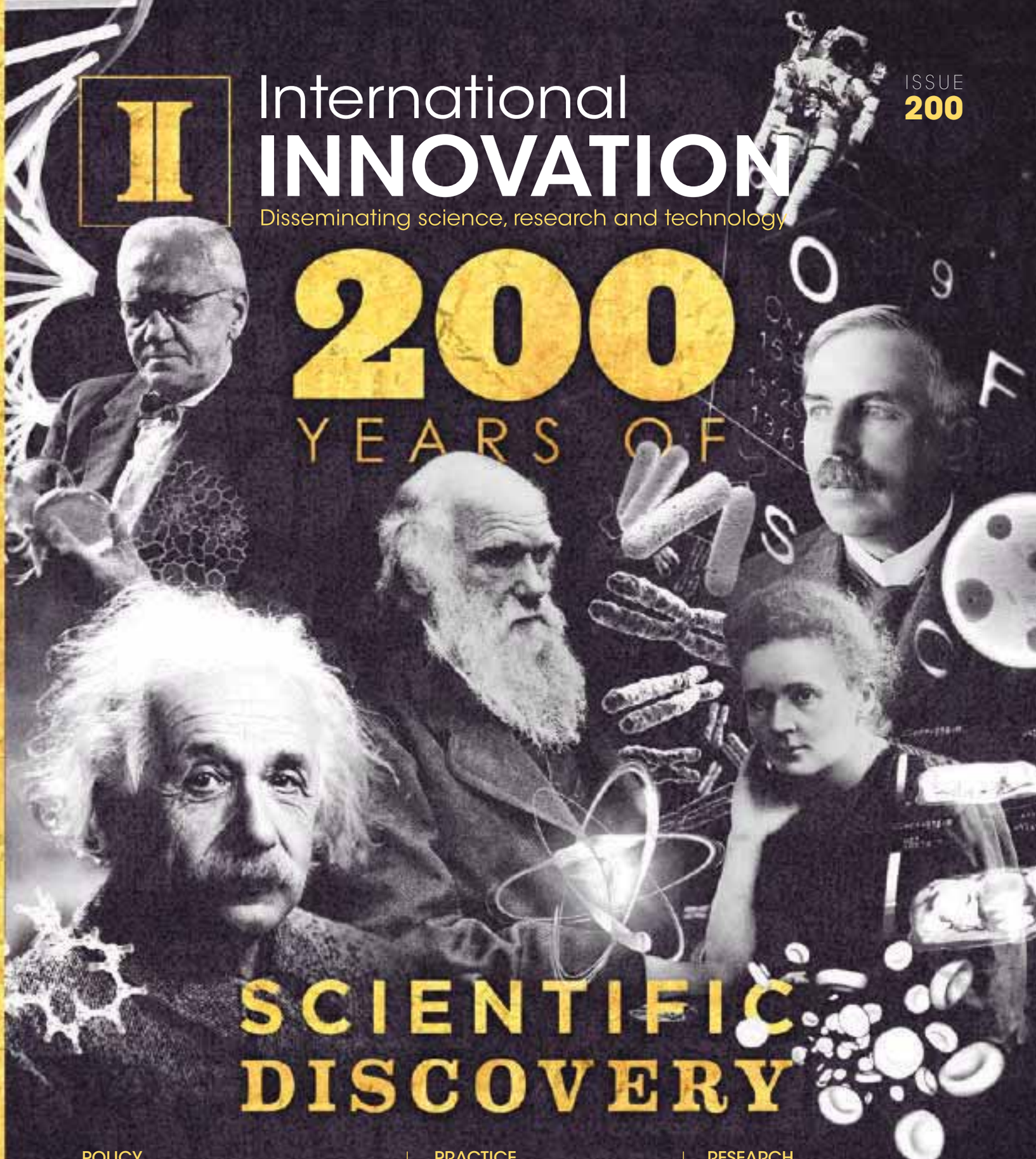
RESEARCH IMPACTS

International INNOVATION

Disseminating science, research and technology

ISSUE 200



200 YEARS OF SCIENTIFIC DISCOVERY

POLICY

Carlos Moedas, **European Commissioner for Research, Science and Innovation**, discusses Horizon 2020 and the benefits of addressing societal issues through science excellence and collaboration

PRACTICE

Director of the **National Science Foundation**, Dr France A Córdova, explains how every scientific discovery travels its own path from inspiration to success

RESEARCH

Dr Arturo Izurieta, Executive Director of the **Charles Darwin Foundation**, describes the natural and humanmade activities threatening wildlife and plant survival on the Galapagos Islands

WWW.INTERNATIONALINNOVATION.COM

BRINGING RESEARCH TO THE SURFACE

Getting research to stand out can prove challenging. Non-specialist audiences may struggle to understand formal communications and are therefore unable to keep abreast of scholarly and scientific developments. Creating engaging, accessible and easy-to-understand content is essential to increasing impact.

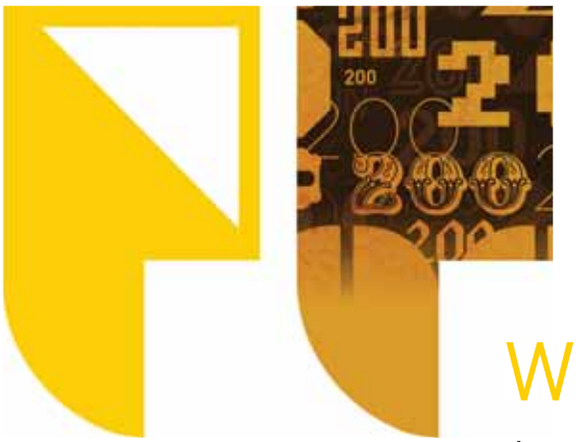
Research Media is a creative communications agency, specialising in the research sector. We translate the language of research to fuel engagement, uniting research, policy and practice.

Drop us a line to discover how we can make your research resonate through bespoke, creative and personal outputs, helping your work to tell its story.

RESEARCH **MEDIA**

ROS HEWLETT, BUSINESS DEVELOPMENT MANAGER
rhewlett@researchmedia.com

RESEARCHMEDIA.COM
+44 (0) 117 332 4961



Welcome to
International Innovation

PUBLISHED BY
Research Media Ltd

Trading address: Whitefriars, Lewins Mead, Bristol, BS1 2NT, UK
T +44 117 332 4961
F +44 117 981 1586
E info@researchmedia.com
www.researchmedia.com

Registered office: Howard House, Wagon Lane, Bingley, BD16 1WA, UK

CEO
Vicky Williams
vwilliams@researchmedia.com

Commercial Director
Caroline Herbert
cherbert@researchmedia.com

EDITORIAL

Editorial Director
Janine Burr-Willans

Senior Editors
Rebecca Torr
Karen Lindsay

Lead Content Editor
Rosemary Peters

Content Editors
Stephanie Spurr
Rebecca Norman
Katie Lewis
Lauren Haigh

Staff Writers
Paul Redmond
James Harle

Editorial Assistants
Katherine MacInnes
Gianina Turner

DESIGN

Head of Design
Paul Martin

Senior Designer
Mike Hill

Designers
Mark Evans
Orlagh Murphy
Simon Howe

Junior Designers
Laurie Atkins
Suzie Eland
Tom Sydenham
Myles Skinner

PROJECT MANAGERS

Brett Langenberg
+44 117 981 8261
blangenberg@researchmedia.com

Adam Soan
+44 117 981 8260
asoan@researchmedia.com

MARKETING AND DISTRIBUTION

Head of Marketing
Laura Stanley
lstanley@researchmedia.com

Digital Editor
April-Rose James
ajames@researchmedia.com

Marketing Executive
Kate Lewis
katelewis@researchmedia.com

Marketing Assistant
Ruth Curtis
rcurtis@researchmedia.com

THE PAST 200 years have witnessed astounding scientific innovation, shaping the world in which we live today. What would many of our societies look like without internet or antibiotics? The men and women who dedicated their lives to addressing the grand challenges of their day – when technology, resources and international collaboration were far more scarce – have enabled researchers in the present day to break new ground.

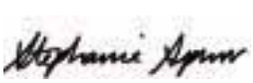
This is perhaps most notable when we consider the correlations between pioneering findings. For example, in 1988 Max Planck discovered quanta – the basis of quantum theory and a fundamental turning point for physics. Then, in 2012, the Higgs boson was discovered at CERN, contributing even further to our understanding of particle physics. Another example is the discovery of the double helix structure of DNA in 1953 and, subsequently, the first draft of the Human Genome Project being published in 2001, which has enabled further insights for personalised medicine and targeted treatments. Although not a great deal of time passed between these discoveries, the steps forward were gigantic.

This 200th issue of *International Innovation* celebrates the incredible progress researchers have made across the globe and highlights the challenges we are still surmounting as our population burgeons and our resources decline. The individual projects and studies we feature span the multifaceted fields of health, technology, environment and social sciences.

In recognition of past scientists' renowned contributions, we also interview key representatives from their eponymous organisations, including the Charles Darwin Foundation and Institut Pasteur. In addition, we commemorate more recent discoveries such as the finding of *Homo naledi* by the Rising Star Expedition, and speak with experts from the National Human Genome Research Institute, European Science Foundation, European Commission and National Science Foundation about the breakthroughs being made by these leading organisations.

What we cover in this edition only begins to scratch the surface of how STEM has sewn the fabric of our societies and enabled so many individuals around the world to live healthy, productive and fascinating lives. What many of us take for granted today, such as smartphones and aeroplane travel, are the results of hard work by scientists with imagination, a thirst for knowledge and determination. I am excited to see what comes next.

Enjoy the issue!



STEPHANIE SPURR
sspurr@researchmedia.com

June 2016

International **INNOVATION** ISSUE 200
200 YEARS OF SCIENTIFIC DISCOVERY

RESEARCH MEDIA

Mixed Sources
Product group from well-managed forests and other controlled sources
www.fsc.org Cert no. TT-COC-2200
© 1996 Forest Stewardship Council

Working in partnership with

Available on

ANDROID APP ON Google play

Download on the App Store

Contents

200

> Evolution takes place every second; this is the legacy of the thinking of Charles Darwin and we continue to study how nature changes

Dr Arturo Izurieta, Charles Darwin Foundation

103

Regulars

Policy

Practice

> We all have a role in future-making; it should not be left only to the tech-savvy, quant-heavy code writers

David Guston, School for the Future of Innovation in Society

50

> With regard to genomics and the practice of medicine, the past decade has revealed the very tip of the iceberg
>
> **Dr Eric Green, National Human Genome Research Institute**

81

Research

Want more information?

For more information about the contributors in this issue:

www.ctoeurope.net

www.darwinfoundation.org/en

www.esf.org

www.pujiangforum.org/index.aspx

https://sfis.asu.edu

www.pasteur.fr/en

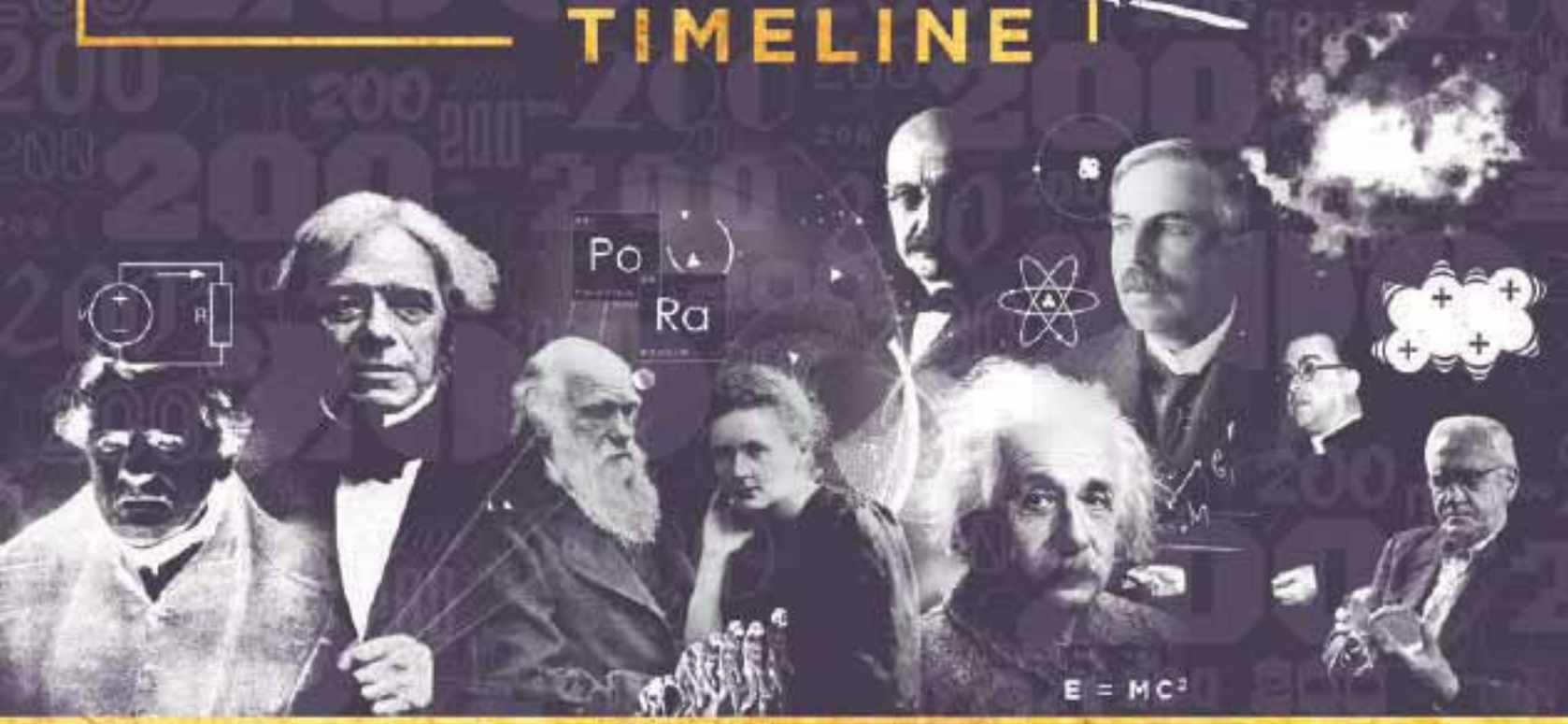
www.genome.gov

Register

Keep up to date with the very latest content and register for the weekly *International Innovation* newsletter: **www.internationalinnovation.com/newsletter-sign-up**

AN INNOVATION TIMELINE

In celebration of our 200th issue, we look at some of the incredible scientific discoveries made internationally in the past 200 years



1827

George Ohm proposes Ohm's Law about the relationship between voltage and electric current

1831

Michael Faraday discovers electromagnetic induction

1858/9

Charles Darwin and Alfred Wallace propose the theory of evolution by natural selection

1898

Marie Curie discovers polonium and radium, and coins the term radioactivity

1900

Max Planck discovers quanta, the basis of quantum theory

1903

The Wright brothers successfully fly the first motor-powered aeroplane

1905

Albert Einstein proposes the theory of special relativity

1913

Niels Bohr and Ernest Rutherford identify the structure of an atom

1924

Edwin Hubble discovers a galaxy other than our own

1927

Georges Lemaitre proposes the Big Bang Theory as the origin of the universe

1928

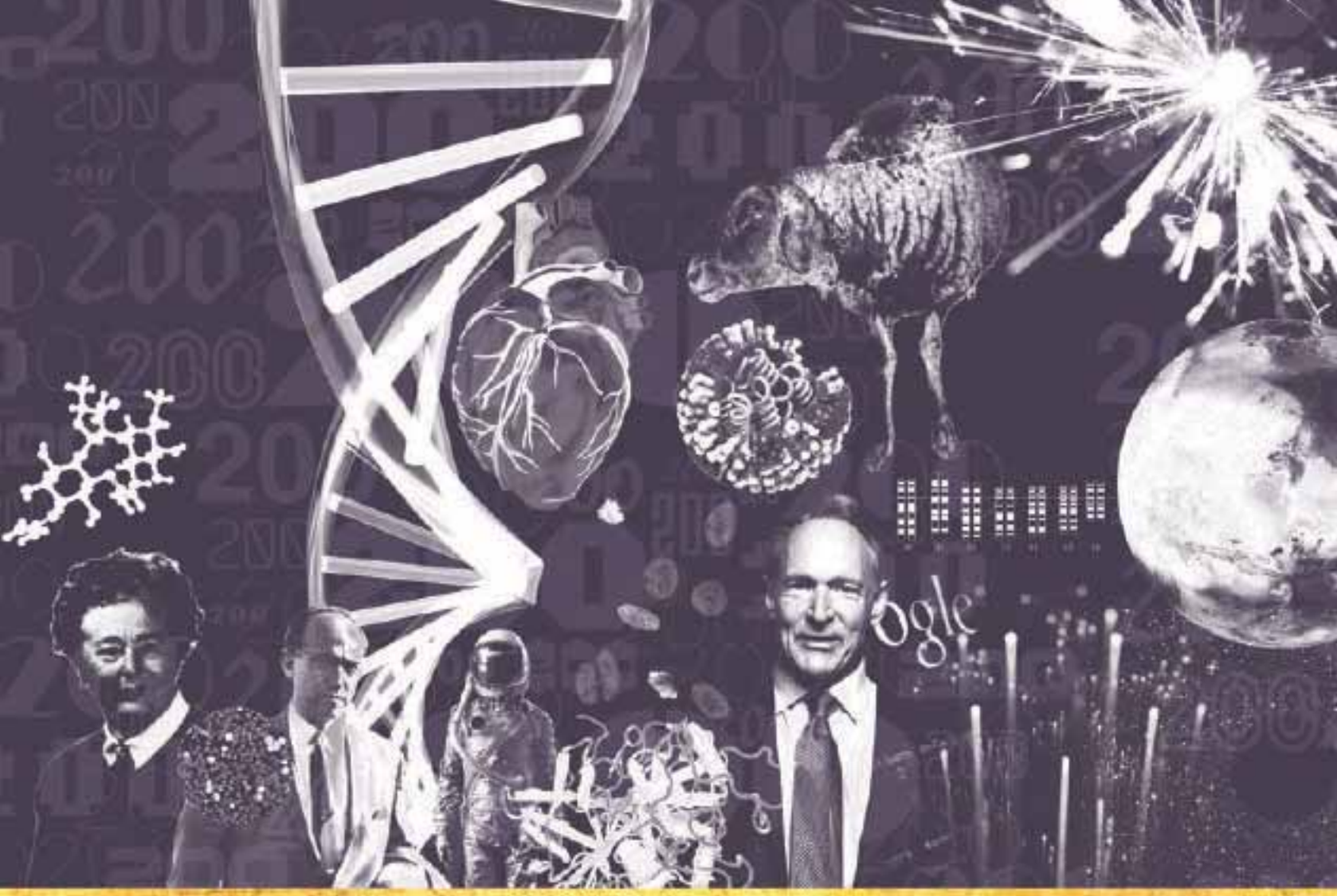
Alexander Fleming discovers penicillin

1942

Enrico Fermi creates the first controlled nuclear reaction

1943

Streptomycin is discovered, which has yielded most of the antibiotics used in clinical medicine today



1950

Gertrude Elion develops chemotherapy to treat leukaemia

1952

Jonas Salk invents a vaccine to treat poliomyelitis

1953

With contributions from Rosalind Franklin and others, Francis Crick and James Watson co-discover the double helix structure of DNA

1960s

Restriction enzymes for gene engineering, commonly known as splicing 'scissors', are discovered

1961

The first astronaut, hailing from the Soviet Union, orbits around the Earth

1967

Christiaan Barnard undertakes the first human heart transplant

1969

Dorothy Hodgkin describes the molecular structure of insulin

1975

Cesar Milstein and his colleagues develop monoclonal antibodies that target specific antigens and thus disease-specific organisms

1983

Luc Montagnier and Robert Gallo isolate the HIV virus

1989

Sir Tim Berners-Lee invents the World Wide Web

1996

Dolly the sheep is born in Scotland, created by cloning a single mammary cell

2001

The first draft of the Human Genome Project is published

2012

The Higgs boson is discovered at CERN

Photonic molecules are identified at MIT

2015

Traces of liquid water are found on Mars

2016

The LIGO team detects gravitational waves from a black hole merger

CARLOS MOEDAS

EUROPEAN COMMISSIONER FOR RESEARCH, SCIENCE AND INNOVATION

Through Horizon 2020, the European Commission is supporting innovative R&D and industrial leadership. Carlos Moedas explains how solving key societal issues can be achieved through excellence in science and multidisciplinary partnerships

As European Commissioner for Research, Science and Innovation, how can Europe keep its competitive edge?

The future of Europe's competitive edge is all down to openness and diversity. One of my three priorities is open innovation. I want to involve as many different people and organisations in European research, science and innovation processes as possible. My aim is to bring companies, researchers, universities, policy makers, start-ups, civil society and citizens together, because diversity stimulates creativity while compelling us to confront new ideas and fresh perspectives. A lot of work is already being done on this through our biggest funding programme yet, Horizon 2020. Put simply, diversity leads to better research. If we want to keep our competitive edge, we have to open up within Europe, as well as invest in wider international cooperation.

Can you provide an insight into the concept of an 'innovation union' and describe how funding practices have changed to support this objective?

Any innovation union has to embrace the exchange of knowledge and ideas across sectors and borders. In the 21st Century, we find more and more innovation succeeding at the intersection of disciplines. Take, for example, Organs-on-Chips, which won the London Design Museum's Design of the Year Prize. These beautiful chips push air, blood or nutrients past real human cells, simulating how our organs work – and their design is simply stunning. It's their simplicity that gives Organs-on-Chips so much potential for pre-clinical trials, for example. We see this kind of thing happening all around us, whether we're using digital solutions for health or robotics for driverless transport. This is why we've designed Horizon 2020 to support many cross-cutting initiatives for research and innovation in multidisciplinary areas, such as the circular economy or smart and sustainable cities, and opened up the programme to the world.

Three of Horizon 2020's goals are to boost the economy, create jobs and improve lives. How is Horizon 2020 helping innovators get their ideas to market faster?

It's no secret that we have to get better at commercialising European ideas in Europe. There is still a great deal of work to be done, but getting ideas from the lab to the market is exactly what we want to accomplish with Horizon 2020 and we're approaching the issue from many different angles. One example is our SME instrument, which has around €3 billion

(2014-2020) available for innovative SMEs that wish to tap into international markets. We're also supporting access to risk finance for research and innovation projects that might find it difficult to overcome financial barriers. Horizon 2020 is always working to bridge the gap between basic and applied research, promoting world-class science, removing barriers to innovation and making it easier for the public and private sectors to work together in delivering innovation.

Could you explain how the European Commission works with industry to apply research dedicated to addressing existing challenges faced by society?

We want to deepen the relationship between the public sector and industry in working together to solve universal societal challenges. One of the ways in which we do this is through public-private partnerships and public-private initiatives. The Innovative Medicines Initiative, for example, supports collaborative research and builds networks of industrial and academic experts to boost pharmaceutical innovation. Other partnerships cover many different areas, like the European Green Vehicles Initiative and Energy-efficient Buildings and Factories of the Future. We also regularly call on industry to work with us in identifying barriers to innovation in Europe, so that we can come up with better ways of doing things for everyone.

What is the public's role in supporting aims such as clean energy and better healthcare?

As citizens, it's important to let the public and private sectors know what's important to us. We can achieve this through elections, public consultations, advocacy or by changing our behaviour – for example, by reducing the consumption of unethical products, or demanding that new innovations are made widely available and affordable.

But it's not just up to citizens. Policy makers and the scientific community need to work together to ensure that decisions made with public money, in the public interest, are based on the best possible scientific advice. In 2015, we set our new Scientific Advice Mechanism, which will give us a stronger relationship with the wider scientific community and help us tap into the wealth of expertise that exists in EU Member States and elsewhere. The Commission already has a wealth of scientific advice, for example, via expert groups and the Joint Research Centre. But this comes down to ensuring we have the best scientific evidence in front of us wherever it comes from. Nowadays, it's not enough to rely on your own work. We need to understand what all the evidence is telling us, where its limits are and how independent it is before we make public policy decisions.

http://ec.europa.eu

@Moedas

@EU_Commission

200 YEARS OF POLICY

200 years is a long time by almost any human scale – but the last two centuries, in particular, have seen radical changes to life across the globe, many initiated by scientific discoveries. *International Innovation*'s James Harle takes a look at how policy makers in different fields have risen – and continue to rise – to the challenge of supporting progress with effective regulation

HEALTH

One of the greatest stories in medical policy over the last 100 years has been legislation surrounding the use of recreational drugs; it was at the end of the 19th Century that Britain's opium wars with China prompted missionaries in the country to conduct the first scientific study into the health impacts of opium. The publication that emerged from their survey, *Opinions of Over 100 Physicians on the Use of Opium in China*, helped to influence drug policy on narcotics all over the world for many years.

Restrictions like those placed on opium – born in many cases out of trade necessities – gave rise to the modern regulation of pharmaceuticals as distinct from the medical profession itself. The American 'war on drugs' initiated in the 1970s by President Richard Nixon was a natural continuation of the increasingly restrictive legislation surrounding dangerous substances. However, its legacy has been a raft of policy so prohibitive that it has all but killed research on psychoactive substances like lysergic acid diethylamide, better known as LSD.

Forty years later, with the total legalisation of marijuana in four US states and other countries pursuing even more relaxed drug policies, research on psychoactive substances is making a cautious return. In fact, a Google Scholar search for 'lysergic acid diethylamide' shows that the five years between 2010 and 2015 saw more papers published on the chemical than any decade between 1970 and 2000.

The problem caused by the preceding era of prohibition underlines the fundamental link between insightful research and sound policy. Under a restrictive legal framework that stymies scientific investigations of a particular subject, effective legislation becomes impossible – leading to the diverse approaches being taken worldwide. As the Multidisciplinary Association for Psychedelic Studies puts it, the ultimate goal should be 'a world where psychedelics and marijuana are safely and legally available for beneficial uses, and where research is governed by rigorous scientific evaluation of their risks and benefits'.

ENVIRONMENT

In August 2015, the UN agreed on a historic new set of Sustainable Development Goals that will serve to guide the 193 Member States in their environmental policy making over the next 15 years. The new goals are emblematic of environmental policy over the last 150 years or so, in that they balance human goals against environmental concerns.

It was in 1864 – almost 200 years ago – that the British Raj established India's Imperial Forestry Service, an institution widely regarded as the first in the world to provide scientific forest management, and therefore one of the first bastions of the conservation movement. But things have changed radically since then, and the battleground of conservation is shifting – in terms of increased funding allocation, at least – from the unspoiled wilderness to the city.

The number of people living in cities already exceeds the number of people living in rural areas, and is expected to rise from 54 per cent today to 66 per cent by 2050; around three-quarters of humanity's total resource consumption takes place in cities.

The past 20 years or so have seen some dramatic changes in urban planning policy all over the world, and an ever-increasing emphasis on the goal of smart cities. Some states are particularly renowned for their successes; Singapore is a prime example of this, and it is easy to see why. Its position as both an island and a city-state necessitates absolute attention to sustainable methods – and in this sense, it acts as a predictor of the likely route that urban planning policy will follow worldwide. Integrated transport systems, the establishment of a national water agency and a firm commitment to reduce carbon emissions have all stood the country in good stead in recent years.

TECHNOLOGY

Policy making to encourage technological achievement, a field of human ingenuity that appears to move faster than any other, is a very difficult area – and one that has been fraught over the last 200 years. Of course, technology plays a significant role in both the environment and health. Today, some of the biggest challenges faced by technology policy makers involve areas like transport and telecommunications.

The most prominent innovations in this area in the last two centuries have required the concomitant implementation of huge infrastructure; roads for cars, railways for steam engines and cables for telephone and internet services have all required significant public spending. Essentially, these systems were so immensely profitable that they have had an influence on regulatory processes, and vice versa.

At present, however, the problem of creating timely and effective policy to cover these areas is more a problem of classifying the technological systems that come under them. There is little doubt that the internet is a telecommunication tool – but when only one active user is involved in the 'telecommunication', which in fact takes place between a number of machines, the water becomes murkier. Most legal systems consider the act of downloading to be reproducing, but it bends our historical definition of that term. Similarly, camera drones are not a form of transport – yet they make use of airspace that has not been utilised before, and could, in theory, compete with other air traffic.

To give an example, an Irish man was sentenced to four years in prison for running a site that archived links to copyrighted material. He did not download the material himself, or even host it – he simply made it possible for others to find it. In this instance, and in many others, technology policy highlights how far we have to go to adapt to a changing world – and how far we have already come.

WHERE DISCOVERIES BEGIN

A photograph and a rendering mix, showing a view of the Large Synoptic Survey Telescope's exterior building, from the road leading up to the site, a mountain peak in northern Chile called Cerro Pachon. © LSST.

"Every scientific discovery travels its own path from inspiration to success," says Dr France A Córdova, Director of the National Science Foundation – an agency that has supported researchers in discovering some of the most prominent scientific innovations over the last several decades. Providing financial support to conduct fundamental research, which leads over time to applied research, and ultimately to technological advances in the marketplace, NSF is an integral part of the journey to scientific discovery

This issue of *International Innovation* celebrates scientific breakthroughs and discoveries in the last 200 years. Could you provide some insight into the National Science Foundation (NSF)'s achievements?

It's tough to single out a few breakthroughs among the thousands of discoveries NSF has fostered. For more than 60 years, NSF investments in fundamental research have fuelled innovation across all sectors of science, engineering and technology. Collectively, NSF-funded researchers have won more than 210 Nobel Prizes for their work in the fields of physics, chemistry, physiology and medicine, and economics. Because of this comprehensive commitment to science, NSF has helped keep our nation at the very forefront of the science and engineering research and education enterprise.

How has the Foundation evolved since its establishment in 1950?

One amazing – but also sometimes frustrating – aspect of science is that you don't know where the next huge discovery, like the internet, will come from. NSF has always supported fundamental scientific research, but such work takes time, inspiration, dedication – and funding support. As a result, more recently NSF has been developing new approaches focused on bringing the results of basic research into the broader scientific and engineering community. We call it 'faster discovery to delivery'.

We were the first US federal agency to start the small business innovation research and technology transfer programmes. A few years ago, we launched the Innovation Corps programme – or I-Corps – which enables young graduate researchers to identify valuable product opportunities that emerge from NSF-funded research. I-Corps uses public-private partnerships to create a national ecosystem for innovation that couples scientific discovery with technology development and societal needs. It's a fast track from innovation to market.

As one of the largest independent funding agencies, and with an annual budget of US $7.3 billion (FY 2015), how does NSF maintain its

DR FRANCE A CÓRDOVA
DIRECTOR, NATIONAL SCIENCE FOUNDATION

sterling reputation? What factors are taken into consideration when distributing funds across the scientific areas?

NSF funds fundamental research and education across all fields of science and engineering, reaching all 50 states and US territories through grants to nearly 2,000 colleges, universities and other institutions. Each year, NSF receives over 50,000 competitive requests for funding and makes about 11,000 new funding awards. We provide funding for a highly diverse population of investigators, who contribute to literally thousands of journals, articles, books, juried papers, filings for patents, instructional videos, testing and calibration devices, and so on.

NSF's approach to accomplishing strategic goals is based on investing in fundamental research and education projects that are recommended for NSF support by the science and engineering communities using our merit review selection process, widely regarded as a gold standard among science funding agencies around the world. NSF's policies and procedures maintain an open system of competition that identifies and enables pursuit of the most promising ideas for major advances.

You were nominated by President Barack Obama to head NSF and sworn in as Director on March 31, 2014. What skills and experience do you bring to this role?

I have about 150 scientific papers to my credit, many in journals like *The Astrophysical Journal*, as well as *Science* and *Nature*. I have also participated in many satellite-born telescope projects and used large ground-based telescope facilities all over the world.

My earlier background, however, was broader than strictly science. I didn't have science role models as a young girl, and it wasn't until I graduated from Stanford University with a degree in English that I realised I could be anything that I wanted to be. I received a doctorate in Physics from Caltech in 1979. Then, I spent a decade at Los Alamos National Laboratory in New Mexico, before making my first foray into administration at Penn State, where I served as Head of the Astronomy and Astrophysics Department.

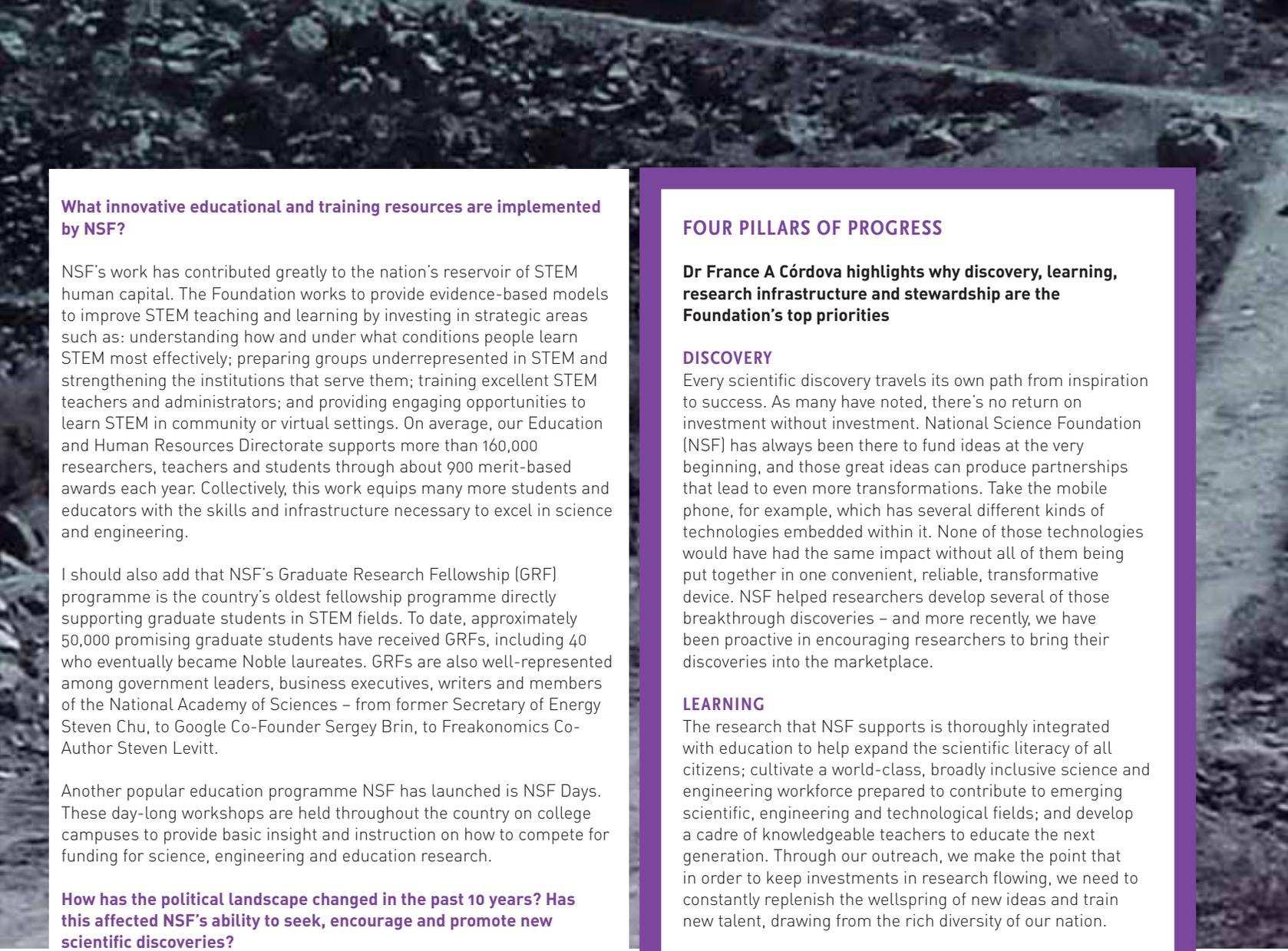
My subsequent moves included becoming the first female – and youngest – Chief Scientist of NASA, and later serving as Vice-Chancellor for Research and a professor of Physics at the University of California at Santa Barbara, and as Chancellor and Distinguished Professor of Physics and Astronomy at the University of California at Riverside. At Riverside, I initiated the process for the first new medical school in California in over 40 years.

In 2007, I became President of Purdue University, where I presided over the establishment of Purdue's College of Health and Human Sciences and its Global Policy Research Institute. I was appointed to the National Science Board in 2008, and then also chaired the governing board of the Smithsonian Institution in Washington, DC, the world's largest museum complex. I have also served on the Board of the Mayo Clinic.

Georgia Institute of Technology (Georgia Tech) graduate students Yike Hu and John Hankinson observe a high-temperature furnace used to produce graphene on a silicon wafer. © Gary Meek, Georgia Tech.

A dinosaur skull printed at the National Center for Rapid Technologies (RapidTech) on a Stratasys Dimension 3D printer, equipped with fused deposition modeling technology. ©RapidTech.

The newest Doppler-On-Wheels (DOW) observing the Goshen County, Wyoming tornado on 5 June 2009. The DOWs and VORTEX2 observed this tornado from before birth, through its intensification, until its dissipation. A scientist engaged in photogrammetry research stands behind the DOW. © Herb Stein/Center for Severe Weather Research.



What innovative educational and training resources are implemented by NSF?

NSF's work has contributed greatly to the nation's reservoir of STEM human capital. The Foundation works to provide evidence-based models to improve STEM teaching and learning by investing in strategic areas such as: understanding how and under what conditions people learn STEM most effectively; preparing groups underrepresented in STEM and strengthening the institutions that serve them; training excellent STEM teachers and administrators; and providing engaging opportunities to learn STEM in community or virtual settings. On average, our Education and Human Resources Directorate supports more than 160,000 researchers, teachers and students through about 900 merit-based awards each year. Collectively, this work equips many more students and educators with the skills and infrastructure necessary to excel in science and engineering.

I should also add that NSF's Graduate Research Fellowship (GRF) programme is the country's oldest fellowship programme directly supporting graduate students in STEM fields. To date, approximately 50,000 promising graduate students have received GRFs, including 40 who eventually became Noble laureates. GRFs are also well-represented among government leaders, business executives, writers and members of the National Academy of Sciences – from former Secretary of Energy Steven Chu, to Google Co-Founder Sergey Brin, to Freakonomics Co-Author Steven Levitt.

Another popular education programme NSF has launched is NSF Days. These day-long workshops are held throughout the country on college campuses to provide basic insight and instruction on how to compete for funding for science, engineering and education research.

How has the political landscape changed in the past 10 years? Has this affected NSF's ability to seek, encourage and promote new scientific discoveries?

The findings from NSF-funded research may be transformative in ways that can have important implications for policy and ultimately impact upon it. This is particularly true for research supported by our Directorate for Social, Behavioral and Economic Sciences. For example, basic research in economics led to the Federal Communications Commission's current policy for spectrum auctions to apportion the airwaves. I am told that these auctions have brought in well over $60 billion in revenue to the Federal Government. Fundamental research on emotion recognition using nonverbal cues such as facial expression, tone of voice and body language has led the Army Research Institute to incorporate education in nonverbal communication into soldier training. This education has enhanced troops' interpersonal skills, enabling them to anticipate and diffuse conflict, as well as facilitating cooperation, negotiation and compromise.

Research that produces computer simulations of water availability and demand is informing public policy for water management in Phoenix, Arizona, a desert city challenged by an expanding population, increased demands on land and water use, and expectations of a warmer and drier climate future. Similarly, research funded in our Directorate for Education and Human Resources in such areas as measuring STEM teacher knowledge and assessing student understanding of complex STEM concepts can provide useful background for education policy makers. These are but a few of many examples I could cite.

Although the political landscape changes over time, science is not a partisan issue. NSF's highly regarded merit review process and criteria – intellectual merit and broader impact – also change very little.

FOUR PILLARS OF PROGRESS

Dr France A Córdova highlights why discovery, learning, research infrastructure and stewardship are the Foundation's top priorities

DISCOVERY

Every scientific discovery travels its own path from inspiration to success. As many have noted, there's no return on investment without investment. National Science Foundation (NSF) has always been there to fund ideas at the very beginning, and those great ideas can produce partnerships that lead to even more transformations. Take the mobile phone, for example, which has several different kinds of technologies embedded within it. None of those technologies would have had the same impact without all of them being put together in one convenient, reliable, transformative device. NSF helped researchers develop several of those breakthrough discoveries – and more recently, we have been proactive in encouraging researchers to bring their discoveries into the marketplace.

LEARNING

The research that NSF supports is thoroughly integrated with education to help expand the scientific literacy of all citizens; cultivate a world-class, broadly inclusive science and engineering workforce prepared to contribute to emerging scientific, engineering and technological fields; and develop a cadre of knowledgeable teachers to educate the next generation. Through our outreach, we make the point that in order to keep investments in research flowing, we need to constantly replenish the wellspring of new ideas and train new talent, drawing from the rich diversity of our nation.

RESEARCH INFRASTRUCTURE

Our recent Budget Request to Congress states that among NSF's performance goals is to 'ensure programme integrity and responsible stewardship of major research facilities and infrastructure'. Having concluded the construction of the Advanced Laser Interferometer Gravitational-wave Observatory and the Ocean Observatories Initiative, NSF is turning its attention to continuing construction of three major projects: the Daniel K Inouye Solar Telescope, the National Ecological Observatory Network and the Large Synoptic Survey Telescope (LSST). I might add that LSST was ranked the number one priority for ground-based astronomical facilities in the National Academies' most recent Decadal Survey of Astronomy and Astrophysics. So NSF is demonstrating its continuing commitment to investing in major research infrastructure.

STEWARDSHIP

In order for science to be viewed as impartial, we must ensure that it is truthful. The public and those who fund research must know that we have put safeguards into place to ensure integrity in research; fund research that seeks to reproduce results; facilitate open access to data and publications; and conduct proper reviews. Plus, we consistently make the case that the types of investments we make are central to the agency's mission and reflect a wise stewardship of taxpayer dollars while ensuring a strong return on taxpayers' investments.

NSF FUNDING HAS FACILITATED MULTIPLE TECHNOLOGICAL LEAPS THAT HAVE DIRECTLY IMPROVED OUR DAILY LIVES

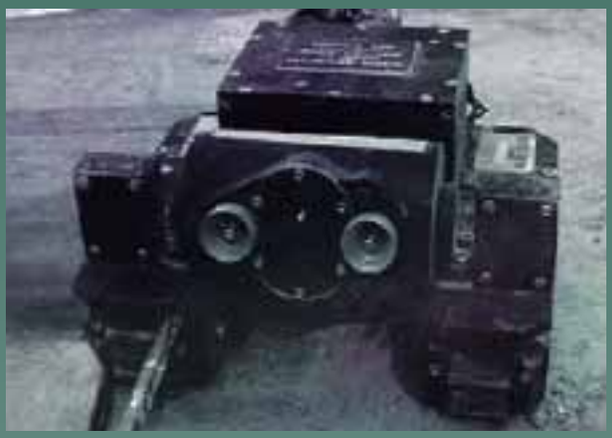
- Modern computers, the internet and web browsers
- Doppler radar
- Magnetic resonance imaging (MRI) scanning technology
- Improved laser eye surgery
- Barcodes
- Radio-frequency identification (RFID)
- Fibre optics
- Speech recognition
- Computer-aided design (CAD)
- The Global Positioning System (GPS)
- 3D printing
- Touch-screen technology
- DNA fingerprinting
- Screening for counterfeit pharmaceuticals
- Reducing blood infections
- Improved accuracy of 911 calls
- Improved detection of improvised explosive devices (IEDs)
- Search-and-rescue robots

Non-partisan panels of scientists provide fair and thorough reviews of proposals, ensuring that the research we fund is of the highest quality. While we can never predict with certainty whether a research project will generate findings that have transformative implications, we do know that the NSF process results in discoveries that have had important implications for policy and practice, and I am confident that this will continue into the future.

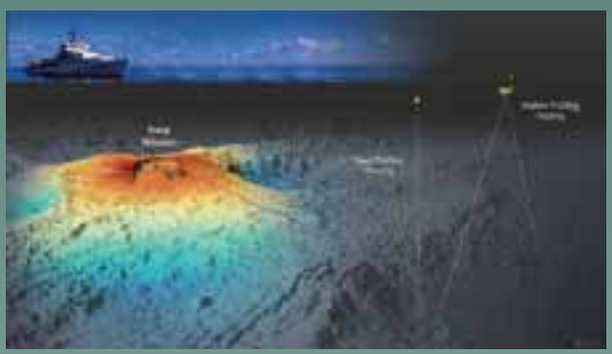
What is your vision for the future of NSF, and what mark do you hope to leave at the end of your tenure at the Foundation?

We never know where the next discoveries will come from, that's why we are always looking for flexibility in funding. Making sure people understand the vital role of NSF as an investment in fundamental research – supporting a stronger economy, enhancing our quality of life, protecting national security and bringing that message to a wider audience. This is a role unique to us. Industry doesn't invest in early stage research. Other government agencies utilise our basic research discoveries to further their missions. We need to make sure we maintain a stable foundation for discovery and innovation.

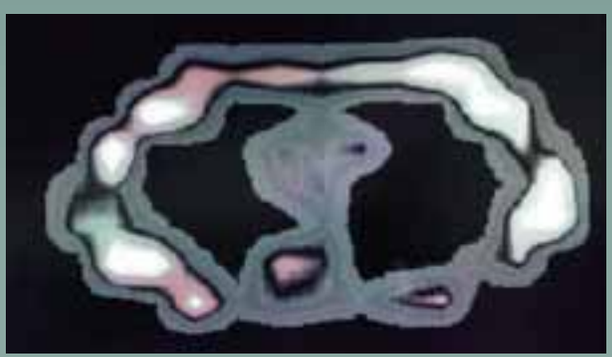
https://vk.com/readinglecture



A search-and-rescue robot. NSF funded its creation. ©Robin Murphy, University of South Florida.



The Axial Volcano Seamount is the largest and most magmatically active volcano off the Oregon-Washington coast. It erupted in 1998, 2011 and again in 2015. The Ocean Observatories Initiative (OOI) Cabled Array infrastructure at the site is the most advanced submarine volcanic observatory in the world's oceans. © University of Washington/Center for Environmental Visualization, OOI and NSF.



The first magnetic resonance imaging (MRI) scan of a live human body (a cross section of the human chest). NSF-supported fundamental research led to the development of MRI technology. © Courtesy FONAR Corporation.

WWW.NSF.GOV

CTO OF THE YEAR 2015

THE CTO OF THE YEAR AWARD HIGHLIGHTS LEADERS IN INDUSTRY WHO HAVE CONTRIBUTED TO THE SUCCESSFUL PERFORMANCE OR DEVELOPMENT OF A COMPANY THROUGH PIONEERING EXPERTISE IN TECHNOLOGY R&D. AS A MEDIA PARTNER, *INTERNATIONAL INNOVATION* PROVIDES AN INSIDE LOOK INTO THE EVENT AND SPEAKS WITH THE WINNERS ABOUT THEIR MOTIVATIONS AND ACCOMPLISHMENTS

Innovation is a core component of European competitiveness, and central to the 2015 CTO (Chief Technology Officer) of the Year awards were sustainability and the creation of strong and broad technology-based communities. Organised by Spinverse, the Nordic leader in innovation consulting, and the European Industrial Research Management Association (EIRMA), the event was held on 15 October in Utrecht in the Netherlands.

"The European CTO of the Year award is a unique way to recognise outstanding individuals whose vision and passion have made a big difference in keeping their companies at the forefront of innovation," outlines Dr Carlos Härtel, jury member and Managing Director for Europe at GE Global Research. "All the winners have shown exemplary leadership as technology managers; we're happy and proud to recognise them for their impressive accomplishments."

The joint winners of the large corporation category were Professor Martin Curley, Vice President of Intel Labs and Director and Senior Principal Engineer of Intel Labs Europe, and Dr Marcel Wubbolts, CTO at DSM.

"Martin Curley has provided inspired technical leadership for Intel in Europe. He has been so successful that Europe – not the US – is now the leader for several product lines," says Professor Richard Parker, Director of Research and Technology at Rolls-Royce, jury member, and CTO of the Year 2014 winner. Data storage and processing are at the heart of innovation in the technology field today, and through his leadership, Curley has successfully built a European ecosystem consisting of over 600 partners.

Wubbolts has played a pivotal role in transforming DSM from a petrochemical company into a global science-based company active in health, nutrition and materials, and a leading biotech player. "The frontrunner development and commercialisation of lignocellulosic ethanol technology is only one very relevant example of many in which Dr Wubbolts is intimately involved. His enthusiasm and drive for science and sustainable innovation for society is an inspiration for many," comments CTO of Avantium, jury member and CTO of the Year 2014 winner, Dr Gert-Jan Gruter.

Jonathan O'Halloran, Co-Founder and Chief Scientific Officer at QuantuMDx, was selected as the winner of the SME category for his revolutionary handheld diagnostics technology, Q-POC™. "O'Halloran has unlocked a robust and affordable solution for medical diagnostics with massive application potential," outlines Léopold Demiddeleer, jury member and Founder and Administrator at TechBridgeOne. "Small seeds pave the way to the future and shake giants' certitudes."

@CTO_EUROPE

CTOEUROPE.NET

To read the CTO of the Year 2014 event report, visit:

INTERNATIONALINNOVATION.COM/CTO-OF-THE-YEAR-2014

AS AN ORGANISER OF THE CTO OF THE YEAR EVENTS, PEKKA KOPONEN, FOUNDER AND CEO OF SPINVERSE, SHARES HIS THOUGHTS ON LEADERSHIP IN THE TECHNOLOGY FIELD AND THE RELEVANCE OF INTERNATIONAL ECOSYSTEMS

How can CTOs (or equivalent) boost a company's performance through technology? What are the important criteria to consider?

As this was the second European CTO of the Year award, we have spent a lot of time with leading and former CTOs to define the criteria; what does it take to win? It's quite a challenging combination because a good CTO has to, first and foremost, be a good leader – and not only with regard to R&D but also the management team around him. That person must be able to communicate with marketing, sales, CFOs, CEOs and, if necessary, the Board of Directors – but also all external partners, including other companies, research institutes and so on.

Second, a good CTO needs to take into account, in addition to the traditional, commercial benefits of technical functionalities, the competitiveness of the technology with technically measurable outcomes. It has to be commercially competitive and sustainable.

Third, we are looking for an individual who is a good citizen in industry, and is able to contribute and give back to society what he or she has gained.

Can you explain the relationship between sustainable development and responsible innovation in the context of technology?

Good question! They go hand in hand. You can no longer develop an innovative business without considering its sustainability. There are no shortcuts, and if you do take one, it is very likely you will be caught out sooner or later – and later can be very expensive!

What are the core benefits of open innovation ecosystems? How does Spinverse contribute to their creation and development?

Open innovation is the only way to innovate radically and grow a company's capabilities. The traditional difference between closed and open innovation is that there are companies who build everything using their own R&D and people, which is based on the belief that both the business and its employees know everything. But, in order to be truly competitive, you have to work with external connections.

If you consider Spinverse, there are two ways in which we have been developing this way of working. First, we have looked at our EU projects and focused on developing multi-party collaborations. We want to create an effective consortium with the right players in it.

Second, we are examining how to write a winning bid and coordinate a project with effective results; the end goal is commercialisation. This is where we believe we have the best practice in Europe.

It's important to start with the industrial targets in mind. As the CTO of the Year award also honours SMEs, we analyse how a small company can play a role in the ecosystem, and how large corporations can benefit from them. We have worked on a number of projects to scout SME partners for large companies, built incubation programmes inside companies and created corporate venture capital funds to invest into SMEs.

Are there any emerging technologies that you are particularly excited about?

I am still very much interested in biofuels, and especially biodiesels. It's an area Europe should look at very carefully. The 2014 SME winner Avantium and the 2015 large corporation winner DSM are both working in this field. Soon, we will be facing a decision to stop drilling oil; this will be discussed heavily at the 2015 UN Conference on Climate Change in Paris.

We may find that we need to leave 80 per cent of the oil we've already found in the ground. Unfortunately, there are no easy solutions for replacing that. Electric cars, while they have made good progress in the last couple of years, are far away from being able to replace combustion engines. Therefore, creating fuels that are compatible with existing engines and using renewable materials is important.

SPINVERSE
Capital & Consulting

@SPINVERSE

SPINVERSE.COM

https://vk.com/readinglecture

JOINT WINNER OF THE EUROPEAN CTO OF THE YEAR 2015 AWARD, LARGE COMPANY CATEGORY

PROFESSOR MARTIN CURLEY, VICE PRESIDENT OF INTEL LABS; DIRECTOR AND SENIOR PRINCIPAL ENGINEER OF INTEL LABS EUROPE

PROFESSOR MARTIN CURLEY'S VISION AND EXPERTISE HAS LED TO THE GROWTH OF INTEL LABS EUROPE. IN DISCUSSING THE MULTIFACETED WAYS IN WHICH TECHNOLOGY IS CHANGING OUR LIVES, HE REVEALS HOW INNOVATION ECOSYSTEMS FOSTER GREATER RESEARCH OUTPUTS

What does this award mean to you?

I'm thrilled to have received the accolade of CTO of the Year 2015 in Europe; it's fantastic recognition. But innovation is a team sport, and I'm privileged to be the captain of the Intel Labs Europe team, so I accept the award on behalf of the incredible researchers that we have in Europe who do an outstanding job.

Why did you choose this career and what fascinates you about the work you do?

I was actually inspired by a past pupil of the secondary school I was attending, who had chosen an engineering career and came in to talk to us about it. He described engineering as 'interesting, lots of hard work and a passport to travel', and that certainly got me excited. I chose to do an electronic engineering degree and was lucky enough to get an opportunity to work with Philips Labs in the Netherlands within the systems field.

Systems have always fascinated me. How can we use technology to transform the way a city operates or its air quality? How can we apply technology to cars and motorways so that, in the future, nobody will ever get injured? How can we transform our energy grids to take advantage of renewables and make our energy systems as efficient as possible? While a key consideration is creating financial value for the shareholders, the core value of technology is its capacity to improve people's lives.

Since the founding of Intel Labs Europe, you have heavily contributed to the increase of researchers from 800 to over 4500 and the doubling of European labs to more than 45.

Can you outline the motivations behind and effects of this substantial growth?

We established Intel Labs Europe in 2009 as a central means and mechanism for coordinating our vision and activities across the diverse research presences we had throughout Europe. A core motivation was to significantly improve the impact and reputation of Intel's research in Europe. We had to work with different audiences, external collaborators, large European companies, universities and the European Commission. But we also worked with internal stakeholders at corporate headquarters to change their perception of Europe as a place where research is not only expensive to conduct but also not of the highest quality.

We set about organising our existing labs as a network and started to participate in the development of mechanisms for collaborative research in Europe and triple helix innovation – the alignment of the interests of government, industry and academia to drive structural change far beyond the scope of what any one organisation can do on its own.

Since then, we've participated heavily in the EU Seventh Framework Programme (FP7) with more than 70 programmes, and have taken a strong industrial approach to undertaking research. We have been able to grow the network mostly organically, and today, Intel does quite a lot of its exascale research and Internet of Things (IoT) work in Europe. We also have a leading automotive R&D centre in Germany. Intel has largely achieved its goal of getting very good value for research and money in Europe, especially through our triple helix innovation collaborations; this has amplified the output of our research.

Intel is part of an innovation ecosystem comprising more than 600 European research partners. How is this collaboration fostering more effective technology R&D?

A central principle behind this is recognition that innovation is moving out of the lab and into the ecosystem. Competition has changed; it's no longer how good a particular company or university is, but how strong and vibrant its ecosystem is. We talk about the 4As:

We have a customer relationship management system to keep track of those relationships. Intel has a well-articulated vision of Europe, and how can we use technology to transform different sectors of European society – be it

transportation, energy or healthcare. All of this means we have stronger and quicker impact.

There is a strong focus on technology for education and accessing new experiences at Intel. What are some of the biggest projects at present?

There is general recognition that we have moved into the 'experience economy', where people are less interested in buying products or services and more interested in buying experiences. As a company, on the one hand, we have to focus on enabling new experiences in the world of PCs and laptops, and on the other hand, driving new technological developments like the IoT platform we've recently announced that can create all sorts of new and exciting opportunities.

One of the key enabling technologies that Intel has released recently is RealSense, which is a platform for implementing basic human-computer interactions. It has traditional cameras, infrared lasers and a microphone, which creates the opportunity for an array of experiences. One education-focused example can be seen in our open lab in Istanbul, where we have an adaptive learning research project using RealSense to measure the engagement state of learners who are using eLearning solutions, so that we can detect whether they're engaged, bored or tired. We can then suggest specific interactions or interventions to make the learning experience better. In January, we are going to conduct RealSense trials with Turkish schools. Intel as a company is invested from a philanthropic as well as a technological standpoint to transforming education.

A less obvious but equally valuable use of the RealSense technology can be seen in a company in the UK called GPC, who are using RealSense technology for wound management. Public health nurses out in the field use the RealSense camera to take a 3D picture of a wound so that we can track how fast it's healing. Then back at the hospital or surgery, they can discuss potential interventions with the doctor or consultant. This kind of technology wasn't available four or five years ago, but now it serves purposes ranging from entertainment to education and healthcare.

ALIGNMENT is the ability to combine the interests of different players with a shared vision to create shared value

AMPLIFICATION is the act of combining resources together to amplify the capacity of an individual company or university

ATTENUATION is the lowered risk associated with partnering with different players

ACCELERATION is the ability to speed up research because of a higher volume of collective resources available

Intel's Robert Noyce building (headquarters) in Santa Clara, California, USA.

"While a key consideration is creating financial value for the shareholders, the core value of technology is its capacity to improve people's lives"

Intel Labs Europe

@INTEL

INTEL.COM

JOINT WINNER OF THE EUROPEAN CTO OF THE YEAR AWARD 2015, LARGE CORPORATION CATEGORY

DR MARCEL WUBBOLTS,
CHIEF TECHNOLOGY OFFICER, DSM

USING RENEWABLE RESOURCES AND DEVELOPING EFFICIENT SOLUTIONS TO FEED THE WORLD ARE AT THE CORE OF CREATING A SUSTAINABLE FUTURE. DR MARCEL WUBBOLTS PROVIDES AN INSIGHT INTO DSM'S PIONEERING ACTIVITIES WITH TWIN FOCI ON ECOLOGICAL PERFORMANCE AND BENEFITS TO SOCIETY

Mercedes Benz A-Class engine cover made from 70 per cent bio-based EcoPaXX.

In your role as CTO, you have channelled DSM's scientific expertise into finding solutions to combat climate change and ensure food and nutrition security. In brief, how did you come to work in this field and decide upon these objectives?

I have been fascinated by nature's chemical reactions ever since I started working in science. I began my academic training as an organic chemist and, later on, studied biochemistry because I wanted to understand how things work, from diseases to nature.

What is so great and fascinating about nature is that it always operates without generating waste so, in principle, it is always cyclical – everything that is built is then degraded and becomes a new source for the next process. We only have one globe, so we have to think of processes in a circular way. Already in my early years at DSM, I was using enzymes to make new drugs and fermentation processes to look at new building blocks for making materials. Another focus was examining how we can produce food in a more efficient way – taking inspiration from nature.

At DSM, sustainability is our core value and everything we do in our product portfolio development is geared towards that. We have sustainability criteria, where we look at whether a process or product is better than the current incumbent in terms of ecological performance (Eco+) and benefits to society (People+). We only proceed with their development if they are Eco+ or People+.

Can you describe a few of DSM's innovative projects on renewable energy sources?

There are quite a few! We are active, for instance, in the area of making antireflective coatings for solar panels, where our coating ensures the energy is better captured as it no longer reflects sunlight. With this smart coating applied to the front

"By working on the basis of open innovation and collaborating with external parties in industry and academia, we have been able to boost R&D, especially in the area of sustainability"

MOTIVATION TO ACT NOW

SCIENCE CAN CHANGE THE WORLD

The **sciencecanchangetheworld.org** website launched by DSM to show just how science is making a difference to our everyday lives by creating and showcasing a poignant film. And it's not just the Nobel Prize winners, it is also the unsung heroes of science, people who are finding solutions to eradicate disease, support the disabled and reduce environmental damage. Every small effort to make our lives better counts. Often scientists face barriers, they struggle with funding, bureaucracy or doubt, but perseverance is paying off.

THE TRUTH ABOUT CLIMATE CHANGE

People are coming to realise that the time to act is now. Climate change is actually happening, despite scepticism by non-believers; we are seeing flooding in places where we wouldn't expect it. Even the Pope and the Dalai Lama are making statements about climate change, and governments are committing to unprecedented targets. The UN Conference on Climate Change in Paris (30 November-11 December 2015) will be an ideal forum in which to discuss matters such as carbon taxing. We need to speak to the highest level decision makers and call upon leaders internationally to take action, so that we can face our children and their children.

Those are two things that motivate me every day to do what I do, and I think they also motivate a lot of scientists who develop solutions to improve the world.

glass of a solar module the overall energy efficiency will increase up to about 4 per cent.

The challenge was developing a material that was also sturdy and robust, because these panels have to last for 20 years – the typical lifetime prescribed by the industry. We have managed to do that, which has put us in a very strong position in this area.

Another example is that we are developing technologies to reuse agricultural surplus like corn crop residue to create bioethanol so we can move away from petrochemical feed stocks like crude oil. For example, with corn, the stems and leaves are leftovers that are ploughed through the soil, which feeds it and prevents erosion. However, approximately 30 per cent of those materials can be taken off the land without causing any damage. We've developed a technology inspired by nature to turn that feedstock into biomass; there are fungi that degrade biomass into CO_2 via sugar. We've taken enzymes from the fungi and developed a special yeast that can then turn this corn crop residue into bioethanol. We recently began project LIBERTY, the first commercial-scale cellulosic bio-ethanol plant in the US established together with our partner POET.

My third example refers to reducing the consumption of energy. For instance, we are working on lightweight materials for automotives. We are reducing the weight of a car such that it emits less CO_2 by replacing metal parts of the car with high-performance polymers, which are able to resist very high temperatures and ensure the engine works more efficiently. We also have a material that we use for engine covers in, for example, the Mercedes Benz A-Class, which is 70 per cent bio-based and reduces up to 40 per cent of the CO_2 emissions of the car in comparison to conventional polyamides.

By what means is DSM bolstering food and nutrition security and reducing waste?

We produce an antifungal component and fermentation product called natamycin that is derived from nature and works effectively against fungi. It was developed for cheese coatings. The outer layer of cheese typically has a waxy layer and coating that prevents fungus growth; if that layer weren't included, everything would look like French cheese! This product has been on the market for many decades.

More recently, we have used a similar antifungal compound called Zivion® in mushroom beds before and in between harvests to prevent unwanted fungi growth, promoting the overall mushroom yield. We are also working with partners to develop an application for Zivion® in post-harvest activities, as the crop has to survive the journey between the farm and the retailer. It is difficult to prevent these products from deteriorating during this period; you either have to package it extremely well or use products derived from nature that inhibit the growth of the fungi to prevent as much food waste as possible. This works well in developed countries. It could also be an interesting option for developing countries where it's even more important that, if farmers produce more than they can consume themselves, they can get it to a market. We really have to work on solutions to help them do that; this could be one of those.

We are also very active in developing efficient food packaging to reduce waste by creating barriers, such as for water, oxygen or nitrogen. Packaging enables the determination of how long a specific type of product can last at the supermarket, where there is a lot of waste. It has been estimated that, worldwide, we throw away 30-40 per cent of food produced; this is unacceptable. In 2050, we will have 2 billion extra people to feed, so we need to find solutions now.

How has DSM's collaboration with industry enhanced sustainable R&D?

We are still a mid-sized company and we have come to the realisation that the tasks we see ahead of us related to climate change, circular economy and food and nutrition security are too big to tackle on our own. We need to produce bioethanol mass on a large scale instead of relying on oil and feeding the world by providing good-quality nutrition for generations today and those to come. You can only realise this by working with partners across the value chain. By working on the basis of open innovation and collaborating with external parties in industry and academia, we have been able to boost R&D, especially in the area of sustainability.

DSM
BRIGHT MINDS, BRIGHTER LIVING.

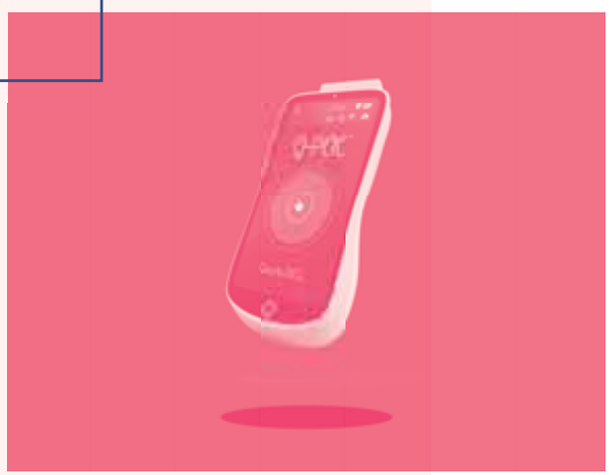
@DSM

WWW.DSM.COM

WINNER OF THE EUROPEAN CTO OF THE YEAR 2015 AWARD, SME CATEGORY

JONATHAN O'HALLORAN, CO-FOUNDER AND CHIEF SCIENTIFIC OFFICER AT QUANTUMDX

AS A PORTABLE LABORATORY, Q-POC™ IS HELPING TO CHANGE THE FACE OF PERSONALISED MEDICINE IN DEVELOPING NATIONS. HEALTHCARE AMBASSADOR AND INVENTOR JONATHAN O'HALLORAN EXPLAINS HOW THE HANDHELD DEVICE ENABLES ACCURATE DISEASE DIAGNOSIS AND ON-SITE DRUG PRESCRIPTION



Q-POC™

The CTO of the Year award recognises your dedication to humanitarian health challenges through your work at QuantuMDx. What led you to devote your research to this cause?

I've always been interested in science, especially genetics, and then more recently, molecular diagnostics. I am colour blind, tone deaf and dyslexic, so I was never going to go into the arts! Genetics seemed like the perfect career path for me; fortunately, I absolutely loved it. When I was 16, my biology teacher (Dr Bishop) gave us a series of experiments using *Drosophila melanogaster* (fruit fly), which is a classic genetic model organism, and I was blown away. So thankfully – after my dream of being a professional footballer died – I got into genetics and that's really where it all started, as a 17-year-old A-level student doing *Drosophila* experiments.

I went on to study at the University of Sussex, and later, as a visiting student at Harvard University, where I spent four amazing years studying genomics. It was such an exciting time of discovery; the human genome was sequenced and Facebook was launched. During that period, I also developed a fascination for epidemiology after reading books like *The Hot Zone* and *Virus Hunters*, which described the efforts of Centers for Disease Control and Prevention epidemiologists

> "We're able to provide a diagnostic result while the patient waits, which is revolutionary"

in Uganda tackling the first Ebola outbreak. It was such an exciting time to be a genetic scientist and one that shaped my initial thoughts on what we are now doing at QuantuMDx.

QuantuMDx is developing Q-POC™ to provide molecular testing in minutes for those in poorer nations who require a rapid, inexpensive and accurate way of diagnosing disease and drug resistance. How did you come up with the idea for the lab, and how does it work?

It seemed simple to me to take a diagnostic product to the patient rather than the patient going in to see a doctor, and then having to send samples to the lab and the results back to the patient. Essentially, we've created a device that condenses these steps. We still need to take a sample in but we're able to provide a diagnostic result while the patient waits, which is revolutionary.

How it works is relatively simple: the patient will provide a sample – a swab, a finger prick of blood or sputum, for example – which is put into a disease-specific cassette and inserted into Q-POC™. We then press 'go' and wait just 15-20 minutes for the results and drug resistance information. As all the magic happens automatically within the disposable cassette, we've spent the past eight years ensuring that the process is seamless.

By what means will you make sure that practitioners on the ground are trained to use your technology?

That's the tricky part; we're doing our bit by making sure it is very simple, so that it will slip into standard clinical practice. Health practitioners and workers on the front line in developing nations are used to running lateral flow tests, like pregnancy tests, so we are trying to make it so that our complex DNA testing is operated in a similar way. There will be minimum training required; we will ensure that the individuals on the front line get the knowledge and experience they require through our partnerships with NGOs, the Bill and Melinda Gates Foundation and the Clinton Foundation.

What are the greatest challenges to tackling global burdens such as antimicrobial resistance?

Cases of drug-resistant tuberculosis (MTB) have been reported for a long time now, but more recently, the alarming rise in extensively-resistant TB (XDR) has emerged. We, the research and medical community, took our eye off the ball after drugs for TB were discovered over 50 years ago. We halted further development and the bug fought back by developing resistance. We are now in an arms race to create new drugs, new diagnostics to stratify patients into new drug regimens that utilise these pharmaceuticals, and surveillance tools to ensure we monitor our enemy to better steward these drugs and watch out for new pockets of resistance in populations.

TB is merely one example of a pathogen that develops drug resistance. HIV rapidly generates resistance to drugs and we are all familiar with MRSA, which is the Methicillin-resistant strain of *Staphylococcus aureus*. Alarmingly, we are seeing sexually transmitted infections such as gonorrhoea developing resistance as well, so the problem is fast running out of control. The O'Neill Review on Antimicrobial Resistance has been tasked to address this problem and has suggested that drug-resistant infections could kill an extra 10 million people across the world every year by 2050 if they are not tackled.

I spend a lot of time speaking with people at the O'Neill Review on Antimicrobial Resistance and trying to impact change via that route. They have recently released a paper on the need for rapid diagnostics and market changes needed to stimulate both innovation and adoption, and they have managed to get the antimicrobial resistance issue on the G7 agenda. It is great to think that we are able to contribute to such an important global issue and we think that technology like our Q-POC™ is well placed to make a significant impact.

How is the work being undertaken by QuantuMDx addressing the lack of healthcare infrastructure and services in developing nations?

We talk about this issue a lot – with anyone who will listen! Having spent time in Africa and seeing firsthand the issues facing health workers in providing quality 'in-field' diagnosis, we have worked hard to ensure our Q-POC™ addresses the lack of healthcare infrastructure, which ranges from no electricity to clinics being located hundreds of miles from patients. By providing battery operated devices that can perform an entire day's shift from a single battery charge and by ensuring that it is portable, we change the access to diagnostics paradigm. By taking this further, and networking the devices and geo-stamping the data, we will not only improve the patient experience with near patient rapid diagnostics, but also address the significant issue of disease/resistance surveillance and monitoring, which will enable a rapid-threat response and better stewardship of antibiotics.

QuantuMDx

@QUANTUMDX

WWW.QUANTUMDX.COM

Pujiang Innovation Forum 2015

With the overarching goal of creating a worldwide community, the theme for the eighth Pujiang Innovation Forum was 'Global Innovation Network: Toward a Convergence of Interests'. As a media partner, *International Innovation* outlines core talking points at the event and provides exclusive interviews with experts in economics and brain science

The 2015 Pujiang Innovation Forum centred on the enormous value of co-creation and cooperation for innovation-driven development in the scientific and technological fields. Held on 27-28 October and hosted at the Dongjiao State Hotel in Shanghai, China, the event represented an international hub for discussions on progress and economic development in areas such as industry, culture, policy and the future of science.

Jointly organised by the Ministry of Science and Technology (MOST) and Shanghai Municipal People's Government, the Forum gathered around 650 high-ranking members from government, academia and enterprises to present on the latest breakthroughs and ideas across the scientific spectrum to over 10,000 delegates.

The 2015 theme, 'Global Innovation Network: Toward a Convergence of Interests', sparked exchanges on the practicalities of creating a synergistic community and focused on both international perspectives and national needs. The two-day event played a notable part in helping Shanghai to become a technology innovation hub with global influence.

The opening ceremony was chaired by Xu Guanhua, President of the Pujiang Innovation Forum and academician at the Chinese Academy of Sciences, followed by opening remarks from Israeli Chief Scientist Avi Hasson of the Ministry of Economy of the State of Israel, and Tu Guangshao, Executive Vice Mayor of the Shanghai Government.

Country and Province of Honor

Since 2012, an important part of the Pujiang Innovation Forum has been the Country of Honor and Province of Honor titles awarded each year to the regions that have shown leadership in innovation-driven development. The 2015 winners were Israel and Jiangsu (China), respectively.

Country of Honor: Israel

China is an important strategic partner for Israel and its economy, and the Pujiang Innovation Forum represented an opportunity to boost bilateral relations between the nations and strengthen cooperation within the framework of the China-Israel Joint Committee on Innovation.

During the event, there was an interactive digital exhibit about the Israeli innovations generated by a partnership between the Israeli Foreign Ministry and the company iConception. A unique project involving Chinese and Israeli children who participated in innovation workshops on Israeli modes of working was also presented.

The Israeli representatives hosted 'A night in honour of Israel and China' with participation from Chinese and Israeli artists. The main event was a grand dinner, with dishes prepared by Chef Uri Navon (Machaneyuda Restaurant) and a musical performance including bagpipes and a shofar by Amir Gvirtzman.

Enhancing the cultural focus of the event was the ensemble of Israeli and Chinese actors featuring in a popular musical in China, *The Jews of Shanghai*.

Province of Honor: Jiangsu

Representatives from the Jiangsu province participated in the organisation of the event and, particularly, the planning of the Regional & Urban Forum. Adhering to the core goal of innovation-driven development, the province is a national leader in the implementation of pioneering technology projects.

The 2015 Forum was held at an important turning point for Shanghai, as it continues to build its reputation as a technology innovation leader. The participation of Jiangsu played a part in effectively enhancing communication and cooperation between Shanghai and Jiangsu and generated ideas for the development of the technology innovation centre planned for the city.

Imagination Sparks Economic Innovation

Professor Edmund Phelps, winner of the 2006 Nobel Prize in Economic Sciences and Dean of Newhuadu Business School in China explains how the economy can be boosted through creativity and business expertise

Your career in economics was sparked by your father and propelled by your Nobel Prize in 2006 for the 'analysis of intemporal tradeoffs in macroeconomic policy' with a focus on consumption, inflation and unemployment. How much has changed in the past nine years?

What has changed is that I have switched from macroeconomics to the study of innovation – its sources and valuableness. I wrote a paper on innovation in 1966 and came back to it in the early 2000s. But in 2006, I began working full-time to develop further ideas and to test them against evidence.

Can you outline your current endeavours and motivations, and explain how they align with the issues we are facing today?

My main thesis these days is that in any largely developed country, there is tremendous potential for innovation deriving from the creativity of people working in the economy, particularly the business sector. The economy could be organised to offer participants – from experts to workers with ordinary backgrounds – chances to use their imagination and their business savvy to conceive new products and better methods. Such 'grassroots dynamism' would be capable of bringing pervasive innovation. Workers participating in this dynamism would find it more rewarding than doing the mechanical jobs that cranes, computers and robots can now do.

What is the relationship between innovation and standard economics?

Standard economics has no room for creativity since this familiar economics supposes that everything that can be known is already known. If business knowledge is already complete, there is no possibility of conceiving new products and methods not previously known.

How might an economist navigate barriers to the development of new products and ways of selling?

An economist who thinks like me would call for breaking up any vested interests that are blocking the entry of new firms with innovative ideas. Such an economist would also call on the nation's government, community or family to stop their efforts to supress innovation through regulations and bureaucracy. Furthermore, such an economist would attack educational systems that fail to inspire students with the vitalist literature of adventure, exploration and discovery that lies at the core of the Western cannon. Such an economist would also attack the sort of family that, in its over-protectiveness of children, prevents them from growing into healthy adults who think for themselves, who want a life of excitement and change, and who are willing to chance journeys into the unknown.

Can you comment on the twin foci of the Newhuadu Business School: business and education?

The Newhuadu was one of the first, if not the first, business school to recognise the importance of innovative enterprises managed and staffed by people exercising their imagination and ingenuity.

Could you briefly introduce the speech you gave at the Pujiang Innovation Forum 2015?

I argued that China will not get out of the 'middle income trap' simply by copying the innovations being made in the West; even if the copying did bring rising wages to China, the innovations can be expected to contribute to rising wages in the West too, so the copying will not pull China out of the middle-income category. To have a top economy, China must be able to produce sustained indigenous innovation of its own, just as the US, UK, Canada and Sweden are doing.

Furthermore, we may suppose that most Chinese people want the experience of prospering or succeeding – getting better at the work one is doing, thus obtaining better terms and recognition, and having a sense of achievement. Many Chinese individuals may also come to want the experience of flourishing – to have the fascination of the journey and to attain unimagined personal growth. To have this experience, China will have an economy driven by indigenous innovation – innovation that springs from the people, not from Schumpeterian innovations that are merely 'obvious' commercial applications of discoveries made by the world's scientists and explorers or the creations of, say, composers and novelists.

Why did you decide to participate in the Pujiang Innovation Forum?

It was an honour to be selected to give my views on innovation in general and some of my views on Chinese economic development in particular. I also hope that my appearances at such conferences help to make the Newhuadu Business School more visible, where I have been Dean since its inception in 2010.

Key Talking Points

The Enterprise Forum: Forging Open Innovation Organisations

As economic globalisation advances, there is a growing trend towards cyber-based organisations and business models. Evidence-based research, technological innovation and international vision are propelling China's enterprises. With growing competition, such as that triggered by the increasingly prevalent crowdfunded start-ups, businesses are starting to ask questions, including: how can innovation be more efficient and rewarding? How can resources be allocated around the globe so that companies can embed themselves as an organic part of the global innovation network? How can they move up the industrial chain and provide high value-added products and services of superior quality?

The Technology Finance Forum: Jointly Building a Technology Finance Ecosystem

"Technology innovation has become the key factor to enhance the overall national strength as well as the strong lead for the change and advance of the social production mode and people's way of life. The one who holds the key and makes the upper hand move in technology innovation will gain the initiative and the advantage," President Xi Jinping stated. The Forum actively explored how financial firms, in the face of scientific, technological and industrial revolution, can play their role as a strong driving force to build an innovative financial platform to meet the needs of technology start-ups. The core objective of this session was to discuss the creation of a science, technology and finance ecosphere to promote knowledge exchange, resource sharing and continued innovation in mutually beneficial ways.

The Policy Forum: Formulating Open and Inclusive Policies

In the face of economic and technological globalisation, China is becoming increasingly dependent on overseas markets and innovation resources. While cementing its place in the global innovation network, China is aiming to develop more open and inclusive policies that involve a plan for technological progress and draw on both valuable domestic and international expertise. These policies should also enable the viable development of micro and SMEs and the bolstering of weak industries and late-developing regions so that they can participate in innovative activities and share the profit. The aim is also to generate a multidisciplinary collective force that drives progress in the nation.

The Regional & Urban Forum: Construction of the Global Technology Innovation Center and Regional Development

After three decades of rapid growth for China's economy, the pace is beginning to slow. Thus, in order for the country to restructure its economy, it is building innovation centres with regional or even global influence. Regions have set their objectives based on specific geographical advantages, innovation capability and industrial expertise. In its campaign to open itself further to national and international opportunities, China is building a free trade agreement with neighbouring countries, creating unprecedented development opportunities for coastal and border regions. Questions asked during this Forum included: what kind of role should China play in the global arena of development? What should China do to build influential new regional technology innovation centres and growth poles with distinct features so as to realise balanced and sustainable regional development? The aim is to provide forward-looking opinions and policy proposals for governments at various levels to optimise resources and guide regional innovation endeavours.

The Industry Forum: Intelligent Healthcare

The healthcare industry is embracing the surge of technological innovations through the use of the internet, mobile communications, Internet of Things, cloud computing and big data. For example, electronic health records can be created and shared to help clinicians provide personalised treatment. China's goal is to create an interconnected, reliable, intelligent and innovative healthcare industry. In order to do so, the country is working towards an efficient way of learning about the latest breakthroughs and international expertise, identifying the problems associated with the current system and ensuring it is legally sound.

The Culture Forum: A Culture of Innovation in the Internet Age

The Third Industrial Revolution was characterised by the power and possibilities the internet presented, such as more advanced electronics and automated production. Now, some economists are saying the Fourth Industrial Revolution is on the horizon, with the Internet of Things, 3D printing and driverless cars enabling an even closer relationship between human and machine. This surge of technology has prompted a 'from the bottom up' culture, where self-starters are at the core of social reform. As China is accustomed to a 'from the top down' approach, the nation must consider how it will respond to new technologies and reform itself as a leader in this area, moving from 'made in China' labels to products being renowned for being created in China.

The Entrepreneur Forum: Optimising Entrepreneurial Environment with an Open View

Innovation-driven growth is largely influenced by grassroots innovators, micro and small enterprises as well as incubating organisations. There are two factors that impact the development of emerging industries: one is the ability of the entrepreneur to make the most of market opportunity, and the second is the overall social environment in which entrepreneurs work. It is therefore imperative to build a conducive environment and an enabling ecosystem for business creation and innovation. For example, the contest 'Starting Your Business in Shanghai' is becoming a platform through which these objectives are being addressed. This Forum hosted the award ceremony of the contest and invited representative entrepreneurs to network with domestic and foreign business incubating organisations about creating this enabling environment. These 'recipes for success' were then shared with the audience.

The Future Science Forum

Brain science and artificial intelligence (AI) are prominent international research foci. New knowledge and expertise of how the brain works has enabled the simulation of the nervous system and application of its functions for multifaceted purposes in clinics and industry. In recent years, products such as Google Brain, Siri, Facebook photo search and IBM Watson have all been created using AI. These advancements are changing the way we interact, share resources and knowledge, and provide life-changing healthcare solutions.

Big data and the brain

Professor Sean Hill, co-Director of the Blue Brain Project at the École Polytechnique Fédérale de Lausanne in Switzerland, expresses his views on disentangling the complexities of the human brain by identifying disease signatures and through international knowledge exchange

Representing the simulation core of the Human Brain Project (HBP), the Blue Brain Project (BBP) was set up to build biologically detailed reconstructions of the rodent brain and, eventually, the human brain. Can you explain how enhanced mapping will help scientists to better understand neurodegenerative and cognitive diseases?

The Medical Informatics subproject of the HBP is focused on identifying the signatures of brain diseases and disorders from clinical data. By better defining and diagnosing diseases from specific measures (brain imaging, biomarkers, genetics, etc.) we will have better hope of identifying the actual causal mechanisms of the disorders. Detailed biophysical modelling provides a way of testing hypotheses of specific disease mechanisms by implementing them *in silico* and evaluating the impact on network structure and function in a simulation.

What inspired the name and concept of the BBP?

The supercomputer that made the first simulations possible was the BlueGene/L from IBM (Big Blue). Thus the 'Blue Brain Project' was appropriate because we started with a technology partnership with IBM using the BlueGene.

The BBP's digital reconstructions are continually being refined and updated. At what stage is the Project at present?

We delivered and published the first major paper about our virtual circuit reconstruction recently. However, we have been developing many of the technologies and workflows for building larger brain regions and initial drafts of the whole brain.

In lay terms, how could this work be applied to develop neurorobotics and neuromorphic technologies?

The principles that we learn about brain functions can be implemented in simpler forms on computer chips to run at real time and using low power. Neurorobotics helps us understand the close interaction of the body and environment with neural activity and brain function.

What was the focus of your presentation at the Pujiang Innovation Forum 2015?

I presented an overview of the HBP with an emphasis on the importance of global collaboration.

There is a tremendous opportunity for international collaboration around the brain. No single country will solve the problem of understanding the brain and each country brings its own strengths. My hope is that we can arrive at high-level commitment to data sharing and collaboration so that the great complexity and mysteries of the brain can be understood even sooner.

Why did you choose to participate in the event? What are the benefits of such a conference?

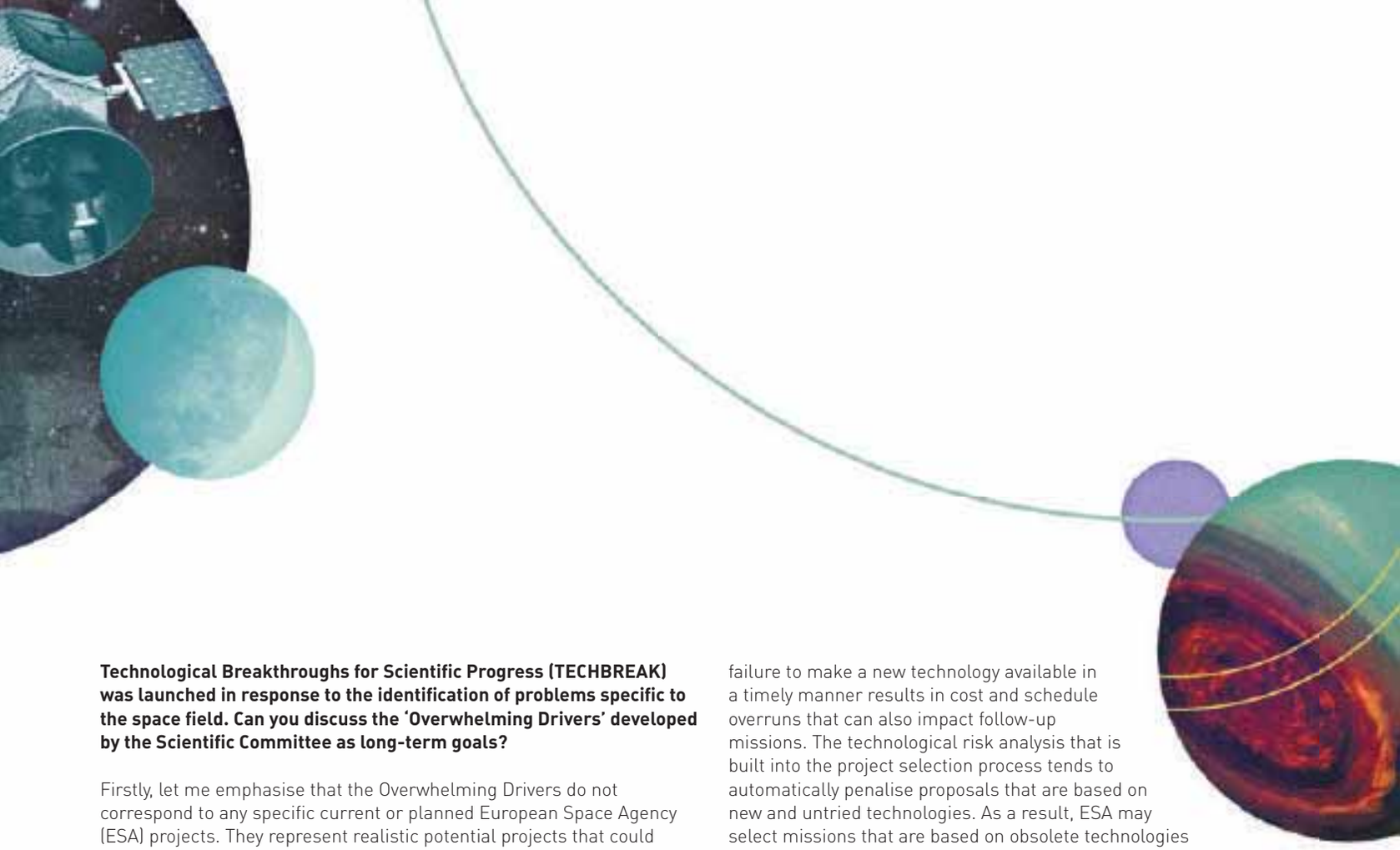
It is important to reach a broad audience, in particular, international leaders and innovators, to ensure awareness of what the project is developing and to identify opportunities for collaboration.

While cementing its place in the global innovation network, China is aiming to develop more open and inclusive policies that involve a plan for technological progress and draw on both valuable domestic and international expertise

TECHBREAK

EUROPEAN SCIENCE FOUNDATION

Researchers worldwide are pioneering techniques for the continued advancement of space exploration. **Dr Martin Cullum**, Chair of the TECHBREAK Scientific Committee at the European Science Foundation, discusses their activities and the development of technologies to enable new missions



Technological Breakthroughs for Scientific Progress (TECHBREAK) was launched in response to the identification of problems specific to the space field. Can you discuss the 'Overwhelming Drivers' developed by the Scientific Committee as long-term goals?

Firstly, let me emphasise that the Overwhelming Drivers do not correspond to any specific current or planned European Space Agency (ESA) projects. They represent realistic potential projects that could be undertaken in the coming 10-25 years, and illustrate the technical challenges many future space projects will face. The TECHBREAK Scientific Committee realised early on in the study that it was important for researchers outside the space industry to relate to the goals of the study in order to be able to assess the potential relevance of their own research to future space projects. The Overwhelming Drivers were primarily aimed at helping this dialogue by describing specific realistic examples rather than simply listing technical requirements for currently initiated or planned ESA projects.

The objective of Overwhelming Driver 5 is to enable humans to stay in space for more than two years. How close are scientists to making this a reality?

The background of the two-year space mission was the often discussed idea of a manned round trip to Mars. In the last 10 years, much experience has been gained – for example, through the International Space Station – on the effects of long-duration spaceflight on humans. However, there is a big difference between being in a close orbit around the Earth, where rescue and/or repair missions are realistic, and an autonomous trip into deep space. For a Mars trip, there are still many challenges to be overcome before such a trip would be technically, economically and even politically feasible. A number of these challenges have indeed been identified in the TECHBREAK Report. However, my personal guess is that a round trip to Mars could not feasibly take place before 2040.

Self-censorship due to the fear of adopting technologies that are not fully proven is one of the challenges inhibiting progress in the field. How is TECHBREAK encouraging departure from these traditional approaches?

It was not the purpose of TECHBREAK to challenge the way the ESA runs its programmes. What we did, however, is draw attention to the problem that ESA itself has also recognised. When missions are selected, the failure to make a new technology available in a timely manner results in cost and schedule overruns that can also impact follow-up missions. The technological risk analysis that is built into the project selection process tends to automatically penalise proposals that are based on new and untried technologies. As a result, ESA may select missions that are based on obsolete technologies in a fast developing field, thereby losing competitiveness and leadership.

There are ways in which ESA might address the risk of self-censorship. For example, instead of requesting a single competitive call for science proposals, it calls for a number of parallel study proposals to enable a better evaluation of the benefits and risks of new technologies before the final project is selected. What is important here is that ESA defines a transparent selection process in which the bidding firms and institutions do not feel that they will be prematurely disadvantaged by proposing avant-garde solutions.

What do Key Enabling Technologies (KETs) mean in the context of TECHBREAK?

KETs are technologies that are multidisciplinary in their nature and cut across many technology areas. They are seen by the European Commission (EC) as the route to new products, processes and services capable of generating economic growth and employment within Europe as well as contributing to strengthening and/or rejuvenating existing European sectors and improving competitiveness. KETs were therefore a useful starting point for defining the scope of the study. However, the EC KETs are quite broadly defined and, to be useful for TECHBREAK, they had to be refined and the granularity improved. In the end, a selection was made by the Scientific Committee of those technologies that seem most appropriate for future space projects, which were not already well known to ESA, and which could be realised within the planned time scale and with the resources available.

Could you outline the process involved in forecasting the development of technologies for the achievement of scientific breakthroughs that enable novel space missions in the 2030-50 timeframe?

The process was somewhat eclectic and evolved through the duration of the study. TECHBREAK initially obtained input from a study by the

European Science Policy Institute and then elaborated a foresight strategy and methodology for the project. The basis for the technologies investigated in the study were aligned to the EC's KETs. A bibliographic study was carried out to identify key researchers and institutions within Europe and a meeting was held with the ESA Advanced Concepts Team (ACT) to clarify ESA requirements and boundary conditions.

Within ESA, the ACT has a somewhat similar function as TECHBREAK, but its approach is more mission orientated (technology pull) whereas TECHBREAK was specifically looking outside mainstream space science, and was therefore more orientated towards technology push. Some specific areas, such as lasers, propulsions systems and energy storage were excluded from the TECHBREAK study because ESA already had considerable experience in these fields. The KETs reviewed by the study comprised nanotechnology, advanced materials, photonics and metamaterials, micro and nano electronics, and biotechnology and medicine. Following these meetings, a series of multi-thematic workshops with invited experts were arranged. These were followed up towards the end of the study by interviews with selected key researchers and visits to various laboratories. For the final report, assessments were made for the various fields on technological readiness, likely timescales to reach maturity, level of research interest and funding as well as, of course, potential relevance to future space science missions.

Have you identified any fruitful partnerships with space and non-space specialists?

Yes, we have collaborated with a number of experts and institutions. One example is in the field of biomimetics. The Alfred Wegener Institute (AWI) in Bremerhaven has developed a mechanical design process based on plankton. These creatures have evolved into a vast array of different structural forms, but with the general criteria that they must be extremely robust to withstand the environment in the oceans, but also be light so they can float near the water surface. Unlike computer-aided designed structures, which are often based on cut-and-paste designs, natural structures are usually highly irregular. Selecting and adapting them has been shown to lead to considerable reduction in structural mass, higher stiffness and better damping. For example, an AWI design for an off-shore wind turbine base resulted in a weight reduction of almost 50 per cent without changing the construction material. Other examples of biomimetic design have been applied in the auto industry as well as in medicine. This technology is at a Technology Readiness Level (TRL) that could be readily applied to space and other projects.

Inventing and demonstrating an idea in a laboratory is a far cry from developing a technology mature enough to work reliably in a space environment

TECHBREAK identified a range of technologies that are of potential interest to future space projects. One should bear in mind, though, that the scope of the TECHBREAK study did not allow for establishing partnerships. Rather, the purpose was to identify and to flag up promising technologies to ESA that could have potential application for future space missions. To this end, key European experts and institutions were identified in the final report, but the follow-up and establishing of partnerships is a matter for ESA itself.

'OVERWHELMING DRIVERS' FOR SPACE RESEARCH AND EXPLORATION

1. **Reduce mass, maintain stiffness**
2. **Build a spacecraft and space missions that can last 50 years**
3. **Deploy a 30m+ telescope into space**
4. **Autonomous geophysical survey of planets**
5. **Enable humans to stay in space for more than two years**

THE DEMANDS OF MODERN SCIENCE

Thomas Edison is quoted as to have said: "To invent, you need a good imagination and a pile of junk". Dr Martin Cullum explains to what extent he agrees with this statement

I would not disagree with the first statement, but the 'pile of junk' really refers to a bygone age. Today, competition in science is so intense that even the smallest academic department has to operate in a highly professional way in order to survive. Moreover, inventing and demonstrating an idea in a laboratory is a far cry from developing a technology mature enough to work reliably in a space environment. Over the past 30 years, the concept of TRL, originally developed by NASA in the 1980s, has been an important tool for managing high tech development projects. A new technology not only has to be at the right stage of technological maturity, it also has to be available at the right time for a mission. There is no point in spending manifold resources to bring an interesting technology to a stage at which it can be deployed, if it arrives too late to be useful for the intended mission. In this sense, invention and development are far more goal orientated and less serendipitous than in the past. Nevertheless, over a longer time scale, such as that of TECHBREAK, we also had room for considering some more quirky long-shot ideas.

Are there any successes to date that you would like to highlight?

It depends on what you mean by 'successes'! In the TECHBREAK report, there are a number of cases where technologies – or, in several cases, a combination of technologies – under development outside the space sector, would appear highly interesting for future space missions. To give but one example: large telescopes, both ground-based and in space, have revolutionised our understanding of the universe in the last 20-30 years. However, it is a fact of life that the more we discover about the universe, the more questions are raised, and that usually means requiring even larger telescopes to provide the answers.

The reason for proposing a 30m space telescope as an Overwhelming Driver, was based on this premise. All current space telescopes have rigid mirrors – either monolithic or segmented – that can fit into a rocket fairing. As this will no longer be true for a 30m telescope, we need to adopt new approaches. Another challenge is that such mirrors not only need to be extremely smooth to reduce scattering, but also be diffraction limited. This becomes increasingly difficult with very large mirrors. The Hubble and James Webb Telescopes, along with all ground-based telescopes, have a mechanical structure to hold the telescope mirrors and instruments in strict alignment. This constraint leads to the requirement for a very fast primary focal ratio, which is not only difficult to manufacture, but could not simply be 'rolled up' for transport.

ESA has been intensively studying formation-flying concepts for space probes during the last few years. This would seem a highly attractive solution for the 30m telescope because it could release these constraints. A very large free-flying primary mirror can have a very long focal length, which would therefore be much easier to transport or even manufacture *in situ*, and much simpler to correct the optical aberration. The main disadvantage is that the optical field would be small, but nevertheless ideal for research into many hot topics in astronomy, such as extra-terrestrial planets. A further advantage of this concept is that instruments could be exchanged or juxtaposed relatively easily rather than with the complex manned repair missions required to exchange, for example, Hubble Space Telescope instruments.

WWW.ESF.ORG

Problem solved: using computerised methods to advance quantum many-body physics

Dr Joaquín Drut sheds light on his work in the area of computational lattice quantum field theory, discusses the influences that brought him to this discipline and shares his thoughts on the state of scientific progress as a whole

Could you first introduce us to your background and talk a little about how you came to work in your present field?

I was born and raised in La Plata, Argentina. There is a big university there, and both of my parents are medical doctors, so it was natural for me to develop an interest in science at a very young age, and to decide to go to college there. My choosing to study physics was somewhat unexpected for everyone, though. As an undergraduate physics student, I quickly leaned towards theory , and I was always interested in using computers to solve problems – I think I started programming computers around the age of 11 – especially problems involving phase transitions and quantum mechanics, and those where conventional methods fail or have no access. I remember being in an advanced quantum mechanics class and thinking: 'OK, so why don't we just put all this on a computer and solve it?' As it turns out, it's not that simple! I started to understand that when I took a computational physics class in one of my last years in college. It was not until my time in graduate school at the University of Washington, however, that I began to learn in earnest about computational lattice field theory and its wide applicability.

What is it that inspires and motivates you to pursue your research?

My main drive and inspiration come from a conviction that we can solve many of the problems in front of us, and moreover that we can do so efficiently – so that we could obtain more results in less time and learn faster. I often tell my students that we live in a time that is in some ways both primitive and extremely advanced. We have amazing amounts of ingenuity (some of it still untapped due to socioeconomic reasons), mind-boggling computer power and superb automation capabilities, yet there is still too much that we do 'by hand', there is still too much that we live with that is an unnecessary relic from a time when we were less capable. But that is certainly changing and I guess one of my main drives is wanting to be among the people that implement that change and bring the future closer.

What do you find most exciting about physics and astronomy and do you have any advice for students considering a career in these fields?

When I was growing up, people back in Argentina used to say: 'in this modern world, you'll absolutely need to know two things: English and computers'. I think they were quite right. In that spirit, my advice to students is that they learn as much Mathematics as possible. This is the language of science. (I'm assuming you already speak English, and if so, then today you'll find it hard not to learn about computers, coding, etc). I find that across all levels, from non-physics (or astronomy) majors to undergraduates and graduates, the main hindrance in learning advanced physics is that students think they know enough math, or that they've had enough practice with it; this is usually not the case. This is very important for students outside physics and astronomy as well, as disciplines like biology are becoming increasingly quantitative and computational.

A quantum of solace

A team of physicists based at the **University of North Carolina at Chapel Hill** has been pursuing a varied programme of research within the field of quantum mechanics, borrowing tools from other areas and creating its own methods in order to succeed

THE STUDY OF quantum systems can often seem an impenetrable topic to the layman. Though its subject matter is dense, the motivation of the physicists pursuing research in this area is very simple. Quantum mechanics is the theory of how things that are extremely small behave, and its complexity arises from the fact that such tiny bodies behave in ways that we would never expect from larger bodies: they become entangled, stop moving when observed, and sometimes exist in two places at once. In recent decades, physicists have been concerned with bridging the gap between small and large systems, ie. trying to explain the behavior that emerges when many interacting particles are present – and this is one motivation that drives the study of many-body quantum systems.

One research group expressly concerned with going from 'micro' to 'macro' in every quantum problem that it tackles is that led by Dr Joaquín Drut at the University of North Carolina at Chapel Hill. As part of his role as Assistant Professor, Drut leads his lab in the investigation of quantum matter under extreme conditions using a variety of approaches, but relying primarily on lattice quantum field theory. As part of this work, the group also adapts known methods and develops its own novel approaches to quantum matter research and its own tools – a good example of this being their 'Scimitar' app, which helps to coordinate thousands of simultaneous runs submitted to a central computer cluster.

A LATTICE OF LEARNING

Lattice quantum field theory is appealing to physicists because it allows them to study the effects of interactions in quantum systems *in silica*; the lattice element simply refers to a convenient way of representing the space and time on which the system lives. Take Drut's recent work with 2D Fermi gases – large collections of fermions that take the form of a cloud, and are limited to two spatial dimensions. Even though these are comparatively simple systems, they have only been realised experimentally very recently using ultracold atoms in conditions where they can be studied in detail. Drut and his team have carried out some of the first lattice calculations for the thermodynamics of these systems, and the use of lattice methods has allowed them to draw a more complete physical picture of them.

So how does the North Carolina group go about defining quantum problems? "Our research programme involves going from 'micro' to 'macro' in every problem we encounter," Drut explains. "'Micro' refers to defining a problem by spelling out what particles are involved and what their interactions are (eg. bosons or fermions; relativistic or non-relativistic; point-like or long-range interactions; etc.)". The 'macro' part, however, is a little more difficult, and refers to answering questions about what properties emerge when the system is composed of many particles, and trying to understand how such systems respond to external probes, the state of matter they are in, and where the phase transitions are. To quote P W Anderson in this regard: "More is different."

STERLING ACHIEVEMENTS

Another recent achievement by the group has been the development of a novel lattice method that is adapted for dealing with the entanglement properties of quantum many-particle systems. A previous method for computing entanglement entropy had been proposed, but it fell short in that it was not apt for dealing with realistic calculations – although the method worked fine in small systems. Inspired by the importance of entanglement to quantum information aspects of condensed matter, Drut and a student in his lab proposed two novel solutions that could get around the problems of the previous model, and demonstrated that they worked.

"At the moment, we are finalising multiple projects," Drut enthuses, referring to three particular endeavours which his lab is now drawing to their individual conclusions. The first is focused on the creation of software that automates analytic techniques in lattice quantum field theory, the second centres on calculating the entanglement properties of strongly coupled non-relativistic particles using the novel method Drut and his student devised, and the final project looks at ultracold atomic fermions in external trapping potentials that closely mimic experimental conditions. In the longer-term, the lab will continue to characterise these systems and borrow techniques from other fields – as well as expanding into nonequilibrium statistical mechanics.

UNRAVELLING QUANTUM SYSTEMS

OBJECTIVES

- To go from 'micro' to 'macro' in every quantum problem encountered
- To develop novel methods to enhance that capability

KEY COLLABORATORS

Dr Jens Braun, Institut fuer Kernphysik, Technische Universitaet Darmstadt, Germany

FUNDING

National Science Foundation

CONTACT

Dr Joaquín Drut

Assistant Professor & Melchor Fellow

Department of Physics and Astronomy
University of North Carolina
120 E. Cameron Ave.
Chapel Hill, North Carolina
27599-3255, USA

T +1 919 962 4732
E drut@email.unc.edu

http://user.physics.unc.edu/~drut

DR JOAQUÍN DRUT was born and raised in La Plata, Argentina. He moved to Seattle in September 2003 to attend the physics PhD program at the University of Washington. Soon after my graduation, in March of 2008, I became a Postdoctoral Researcher in the Nuclear Theory group at The Ohio State University, in Columbus, Ohio. From October 2010 to June 2012, he worked in the Theoretical Division at Los Alamos National Laboratory, in Los Alamos, New Mexico, as Director's Postdoctoral Fellow. As of July 2012 he has occupied the role of the Assistant Professor and Melchor Fellow in the Department of Physics and Astronomy of the University of North Carolina at Chapel Hill.

Redefining what is possible through quantum imaging

QuantIC is the UK Quantum Technology Hub in Quantum Enhanced Imaging. Led by the **University of Glasgow** and involving seven academic institutions and over 30 industrial partners, QuantIC's aim is to translate quantum science into new technological applications in imaging across the industrial, scientific, security, healthcare and consumer markets

WHILE CLASSICAL PHYSICS is a means of explaining matter and energy on a scale that human beings find relatively familiar, quantum physics is the science of the very small. Indeed, the word 'quantum' is the absolute minimum amount of any physical entity involved in an interaction. A photon is the quantum of all forms of electromagnetic radiation, including light and, like all elementary particles, is best explained by quantum physics.

Quantum physics is often thought of as something that belongs to the realm of science fiction, not least because many aspects of quantum physics can produce results that are counterintuitive or contradictory, owing to the fact that the behaviours they describe are often completely different to those observed at larger scales of length.

However, despite these popular misconceptions, there is an abundance of technological products already around us that make use of quantum physics. For instance, the Global Positioning Systems (GPS) technology that enables us to navigate our ways around the cities of the world is based on the timing technology used in atomic clocks – the most accurate clocks on Earth. Moreover, without quantum mechanics, there would not be lasers or semiconductors, which power modern electronics.

HARNESSING QUANTUM MECHANICS FOR THE FUTURE

In recognition of the growing importance of quantum science and the ways it could positively impact the UK, the Government has invested £270 million in the UK National Quantum Technologies Programme. As part of this significant investment, £120 million has been used to establish a national network of Quantum Technology Hubs that seeks to explore the properties of quantum mechanics and how they can be harnessed for use in technology.

QuantIC is the UK's centre of excellence for the research, development and innovation in quantum enhanced imaging. The Hub's vision is to pioneer a family of multidimensional cameras operating across a range of wavelengths, timescales and length scales to create a new landscape for imaging systems and their applications in the UK.

LEADING THE WAY FOR INNOVATIVE IMAGING SOLUTIONS

The team at QuantIC comprises world-leading quantum technologists from the universities of Glasgow, Bristol, Edinburgh, Heriot-Watt, Strathclyde, Warwick and Oxford who are working closely with industrial partners to exploit the potential for quantum imaging. Examples of the Hub's cutting-edge research include the use of ultrasensitive cameras to see round corners, producing cameras that can see through smoke and tree canopies, and enhancing imaging through turbid media and sensing gravity.

The potential applications for these new technologies are still being discovered; for instance, a camera that can see around corners might be a useful safety enhancement for cars, while a camera that can see through smoke would benefit the security and defence industry, as well as enhance the work of the emergency services. The same technology can even be used to detect methane leaks. Moreover, gravity imaging boasts tremendous potential for assisting in environmental monitoring situations, such as observing volcanoes, but can also be used to scan for tunnels under the ground.

The QuantiCam™ can film light in flight.

Credit: Dan Tsantilis and EPSRC.

WELCOMING THE FUTURE THROUGH DISCUSSION

Innovation requires the ability to collaborate and share ideas, and QuantIC invites participation and engagement with all stakeholders – including the public – that could lead to further discussion on how the Hub's work will benefit society. Indeed, QuantIC is keen to hear from anyone – irrespective of whether they have a scientific background or not – with suggestions on new applications and where they think quantum imaging technology could lead to in the future.

QuantIC's Principal Investigator, Professor Miles Padgett is committed to responsible research and innovation: "We are always interested in discovering new applications for our research, and we can only do that through ongoing dialogue. If reading this article sparks an idea about how our technology could be used, why not get in touch?"

He also acknowledged the potential for discussions regarding ethical and moral dilemmas some of the technology development might present and added: "Innovation is an exchange of ideas. Exploring the concerns and benefits is part of the innovation process, and it will help develop and determine the impact of new technology on society".

As part of QuantIC's commitment to responsible research and innovation, the Hub has a public engagement strategy to facilitate ongoing dialogue of its research and to increase understanding of quantum physics. This has included attending public events, a permanent exhibition at the Glasgow Science Centre, running physics teachers' workshops and a pilot Quantum Buddies outreach programme.

QuantIC's Single Pixel Camera offers infrared imaging at low cost.

Credit: Dan Tsantilis and EPSRC.

As understanding of the complex world of quantum physics has improved, so too has the potential for technologies that make use of it. What once would have been beyond our imagination is now becoming a reality. The science might be small, but the possibilities are endless.

NEW TECHNOLOGIES TO SHAPE THE FUTURE OF IMAGING

Over the course of its ongoing research, QuantIC has developed several technological innovations that rethink imaging and what is possible. What would you use them for?

QuantiCam™ is a camera system that can detect a single photon at the same time as noting when it arrived. This incredible level of sensitivity and performance has enabled the team to film light in flight. In further developing and modifying this technology, it could soon be possible to monitor the ripeness and health of fruit and vegetables to determine the best time to harvest them; detect cancer using non-invasive medical imaging; and perform remote 3D imaging.

Single Pixel Camera is a means of using infrared imaging at low cost. By developing cameras that have only one pixel, QuantIC can combine it with technology to make it possible to produce real-time video for a fraction of the price of using a multimillion infrared pixel array. With further development, these cameras could deliver competitive advantages in areas such as security and defence, emergency services and environmental monitoring.

Wee-g™ is an ultrasensitive gravity imager that is the most sensitive Micro Electro Mechanical Sensor (MEMS) device ever developed. With a target sensitivity of 10ng/√HZ, it will be able to measure acceleration variances in all three directions. In addition, it is fabricated as a single component from solid silicon and offers the best cost to performance ratio in the marketplace.

To find out more about QuantIC you can visit **www.quantic.ac.uk**, follow the Hub on Twitter (**@QuantIC_QTHub**) and tweet to let its members know what you think by using the hashtag **#askQuantIC**.

QUANTIC

OBJECTIVE

To translate fundamental research in quantum imaging into new technological applications in imaging across industrial, scientific, security, healthcare and consumer markets.

FUNDING

Engineering and Physical Sciences Research Council (EPSRC) • Scottish Funding Council (SFC)

CONTACT

Sara Diegoli
QuantIC Programme Manager

QuantIC Innovation Space
James Watt South
University of Glasgow
G12 8QQ

T +44 141 330 2338
E sara.diegoli@glasgow.ac.uk

www.quantic.ac.uk

http://bit.ly/QuantIC_LinkedIn

https://twitter.com/quantic_qthub

QUANTIC
The UK Quantum Technology Hub in Quantum Enhanced Imaging

An image of success

Expert engineer and interdisciplinary researcher **Professor Frederik Maes** presents a snapshot of his work to develop new ways for clinicians to amalgamate the information from disparate imaging methods into one comprehensive overview

Could you provide insight into your academic background, and explain what attracted you to your present work?

I was lucky to have a very passionate and inspiring mathematics teacher in high school. He motivated me to take the university entrance exam for engineering studies. I passed, and it was obvious that engineering was the right choice for me. The medical sciences also interested me, but professionally I didn't see myself as a medical doctor.

After obtaining a Master's degree in Electrical Engineering from KU Leuven, Belgium, I broadened my perspective by going to the US and obtaining a Master of Science in Electrical Engineering at Stanford University. I also passed the qualifying exams for a PhD programme at Stanford, but decided to return to Belgium for family reasons. Professor Paul Suetens offered me a PhD position in his research group on medical image computing, and I was appointed as faculty member a few years later.

How does your research group bring about benefits for patients and professionals in the clinic?

Our group is housed within the Medical Imaging Research Center, occupying a central location inside the University Hospital of KU Leuven. This facilitates intensive interdisciplinary collaboration between engineers and clinicians and assures that our research stays relevant and up to date in view of continuous technological advances and novel clinical applications.

Medicine today strives towards a new paradigm of personalised therapeutic approaches. Medical imaging data, together with other sources of data, play an essential role in this development. As an engineer, I cannot help the patient directly. Instead, my aim is to help the doctor by providing solutions that facilitate a more effective use of the available data. An academic hospital setting in which clinicians and engineers work together on common research projects, each from their own perspective and expertise, provides an ideal environment for my work.

What approach do you take towards commercialising the outcomes of your research?

Usability and valorisation potential are nowadays essential elements in almost every funding application, even for long-term fundamental research. As I like working in an academic environment – in which one strives for an optimal solution that is not necessarily the most cost effective or profitable one – I prefer to bring my work into the public domain through peer-reviewed publications that have an impact on the field and leave it to others to further develop these ideas into marketable products or services and bring them to the market.

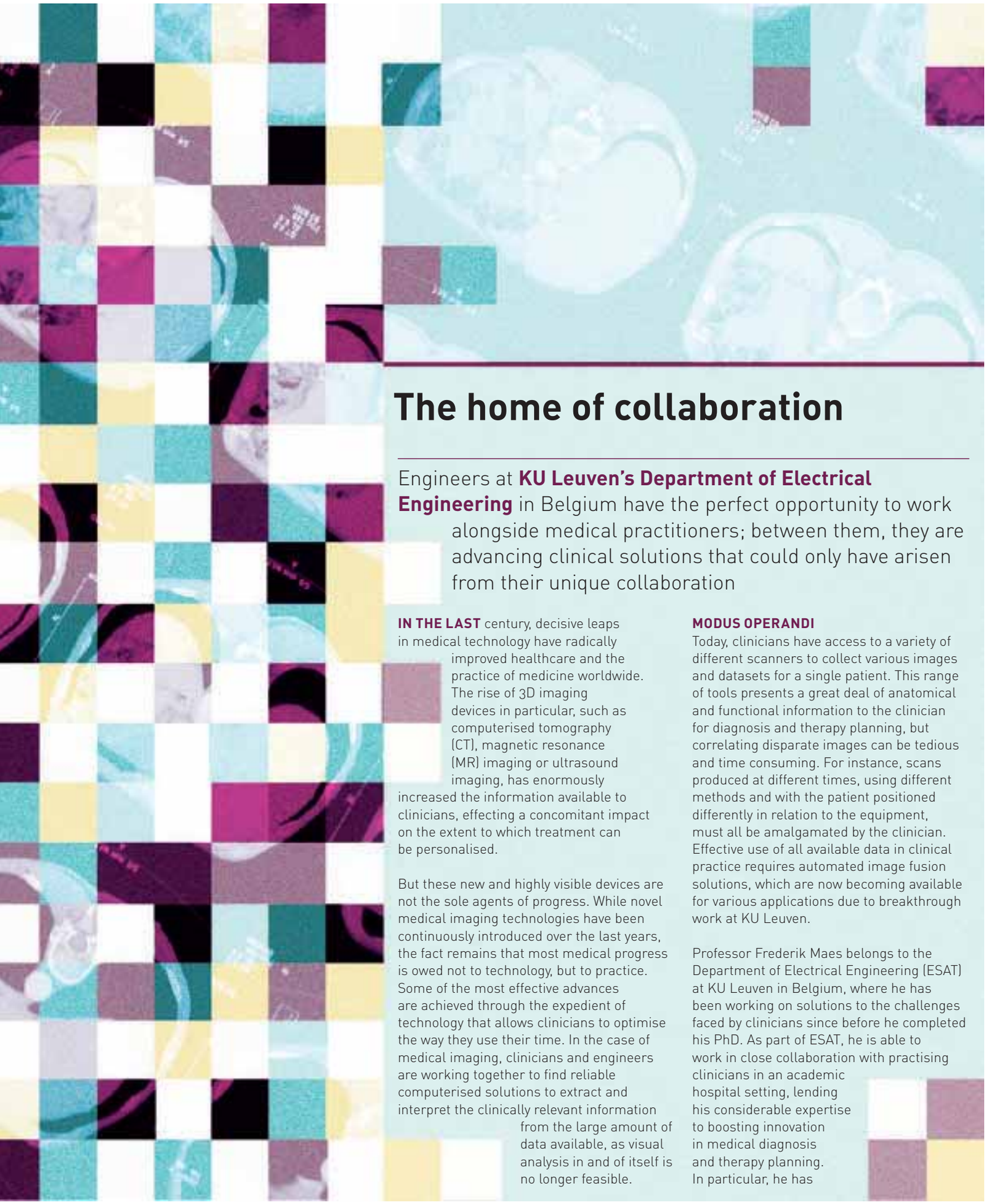
Can you give examples of how your research has been further developed into medical innovations?

My invention of mutual information-based image registration was commercialised for clinical medical applications through a licensing agreement with Radionics Inc., now part of Integra, a company active in the field of image-guided neurosurgery. This happened largely by coincidence. One day, the Head of Radiology of our hospital brought some representatives of the company to our lab for a demonstration of our new registration software. They were impressed, and because we had published the method already, we had no objection to sharing the software with them, as we had already done with many other labs.

They went home with the software, a short manual and a one-page ad hoc drafted agreement stating that the software could be used for experimentation only and that any plans for commercial use would require our explicit approval. This visit eventually led to a formal contract. I later went to Boston, where I had the opportunity to speak with a developer who had integrated my code into Integra's 'image fusion' product. Knowing that the software resulting from my PhD research was actually being used in the clinic to assist in neurosurgical procedures was quite rewarding.

Which other aspects of medical diagnostics do you think could benefit from the application of engineering research?

My research focuses on medical imaging data. However, the current trend towards more personalised medicine involves a large variety of patient data derived from genetic profiles, molecular and cellular analysis, histopathology, physiological recordings such as electrocardiograms and electroencephalograms, biosensors and monitoring devices, and personalised health apps. In all these developments, breakthrough advances rely on interdisciplinary collaboration between medicine and engineering. Several of my colleagues at the Department of Electrical Engineering of KU Leuven are contributing towards this end.



The home of collaboration

Engineers at **KU Leuven's Department of Electrical Engineering** in Belgium have the perfect opportunity to work alongside medical practitioners; between them, they are advancing clinical solutions that could only have arisen from their unique collaboration

IN THE LAST century, decisive leaps in medical technology have radically improved healthcare and the practice of medicine worldwide. The rise of 3D imaging devices in particular, such as computerised tomography (CT), magnetic resonance (MR) imaging or ultrasound imaging, has enormously increased the information available to clinicians, effecting a concomitant impact on the extent to which treatment can be personalised.

But these new and highly visible devices are not the sole agents of progress. While novel medical imaging technologies have been continuously introduced over the last years, the fact remains that most medical progress is owed not to technology, but to practice. Some of the most effective advances are achieved through the expedient of technology that allows clinicians to optimise the way they use their time. In the case of medical imaging, clinicians and engineers are working together to find reliable computerised solutions to extract and interpret the clinically relevant information from the large amount of data available, as visual analysis in and of itself is no longer feasible.

MODUS OPERANDI

Today, clinicians have access to a variety of different scanners to collect various images and datasets for a single patient. This range of tools presents a great deal of anatomical and functional information to the clinician for diagnosis and therapy planning, but correlating disparate images can be tedious and time consuming. For instance, scans produced at different times, using different methods and with the patient positioned differently in relation to the equipment, must all be amalgamated by the clinician. Effective use of all available data in clinical practice requires automated image fusion solutions, which are now becoming available for various applications due to breakthrough work at KU Leuven.

Professor Frederik Maes belongs to the Department of Electrical Engineering (ESAT) at KU Leuven in Belgium, where he has been working on solutions to the challenges faced by clinicians since before he completed his PhD. As part of ESAT, he is able to work in close collaboration with practising clinicians in an academic hospital setting, lending his considerable expertise to boosting innovation in medical diagnosis and therapy planning. In particular, he has

IMPROVED MEDICAL IMAGE ANALYSIS

OBJECTIVE

To improve the medical outcomes of a range of applications, such as brain surgery or radiotherapy, by optimising image registration – the geometric alignment or fusion of images acquired with different scanners or at different time points.

KEY COLLABORATORS

Professor Paul Suetens; **Professor Dirk Vandermeulen**; **Professor Raymond Oyen**; **Professor Karin Haustermans**; **Professor Uwe Himmelreich**; **Professor Wim Van Paesschen**, KU Leuven, Belgium

PARTNERS

Leuven Medical Technology Centre

KU Leuven Research & Development

iMinds

DR THERAPAT consortium

FUNDING

Flanders Research Foundation (FWO)

Agency for Innovation by Science and Technology (IWT)

EU Seventh Framework Programme (FP7)

CONTACT

Professor Frederik Maes

KU Leuven, Faculty of Engineering Science
Electrical Engineering (ESAT) Department
Center for Processing Speech and Images (PSI)
Medical Imaging Research Center
UZ Herestraat 49 – Box 7003
3000 Leuven, Belgium

T +32 16 349025
E frederik.maes@esat.kuleuven.be

www.icometrix.com

www.medicim.com

DR FREDERIK MAES is Professor of Medical Image Computing at the ESAT Department of KU Leuven. His main research interest is computational strategies for medical image analysis, particularly focusing on fundamental problems with image registration and segmentation and their applications within a clinical setting, through collaboration with biomedical researchers. He has co-authored more than 200 peer-reviewed journal and conference publications and has supervised 12 completed PhD projects.

spearheaded the development of a number of techniques that assist in the collation and amalgamation of distinct images of the same patient. "It is the doctor and not me, the engineer, who decides which information is relevant – so interdisciplinary collaboration is fundamental in this field," he explains.

SHARING AND CARING

Maes' research is primarily concerned with overcoming the fundamental challenges facing medical image computing – the process of extracting quantitative data from images and applying them to therapy, diagnosis and research. One of the most pressing is that of image registration, the problem of developing mathematical procedures or algorithms to establish the anatomical correspondence between images. Maes' solution, which he first reached during his PhD work, is based on the concept of maximisation of mutual information. Unlike other approaches, it has the advantages of coping well with noisy signals, responding flexibly to different imaging modalities and managing images captured at different points in time; the method is particularly attractive to clinicians because it does not require preprocessing of images.

Since its invention, the technology has been in a state of constant refinement. Maes first presented his method at the International Conference of Information Processing in Medical Imaging in 1995, where it was well-received; he then published it in *IEEE Transactions on Medical Imaging* two years later, without being covered by patent, making the software freely available to researchers hoping to develop the tool in their own ways. Because of this, Maes' method was popularly employed and became an industry standard – and his IEEE paper became one of the most-cited engineering studies of the last decade. Since the 1990s, the method has been extended from rigid body registration in the brain to both rigid and soft tissues everywhere in the body. One of the most successful applications is the fusion of multi-parametric images for radiotherapy planning, as investigated by the EU Seventh Framework Programme (FP7) DR THERAPAT project in which Maes participates.

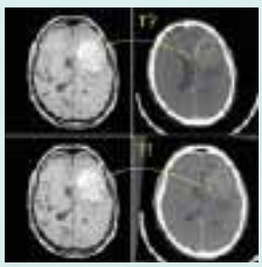
COMMERCIAL BREAK

Bringing a method to the clinic takes more than just successful collaboration between academics. As Maes puts it: "From our side, we focus more on the R of R&D than the D" – the development side is handled by commercial companies interested in using the work. To this end, his team collaborates with innovation actors within its home institution and beyond. These partners include the KU Leuven Research & Development office and iMinds, Flanders' digital research and entrepreneurship hub.

A MATHEMATICAL FOUNDATION

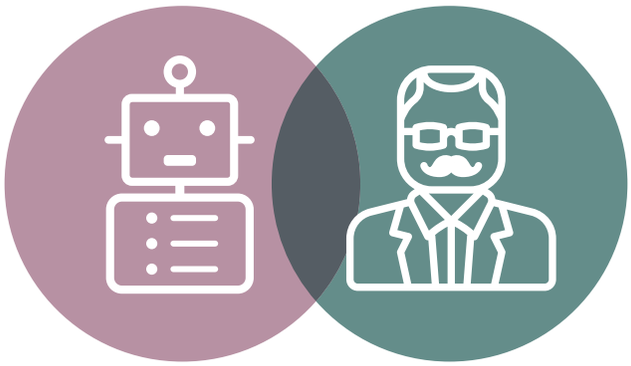
The method for automated image registration developed by Professor Frederik Maes is based on the maximisation of mutual information – a fundamental concept of information theory that measures the amount of dependence between two random variables. Given two images A and B of the same subject acquired with different scanners (eg. CT and MR scanners), the image intensities of anatomically corresponding points in both images can be considered as dependent random variables, as they are different measurements of the same (unknown) tissues. Maes' method maps 3D coordinates from A onto corresponding 3D coordinates in B. This transformation aligns structures in both images where the information between the intensities is most similar.

When the images are properly aligned, their joint histogram appears more clustered since similar intensities in both images are paired. Mutual information measures the dispersion of the histogram in a generic way, without making assumptions about the specific relationship between the intensities in A and B, which makes the method applicable to a large range of applications.



The method developed by Professor Frederik Maes allows the coordinate transformation T – which maps corresponding anatomical points in two images – to be determined from the image content itself.

To date, two spin-off companies have been launched by former PhD researchers in Maes' group: Medicim, established in 2002, focuses on dental implant planning, while icoMetrix, started in 2009, focuses on brain image quantification in multiple sclerosis. External companies like Radionics Inc., who commercialised Maes' registration software in 2000, have also played a vital part in bringing this innovation to the clinic.



Humans and robots working in harmony, safely

Ilari Marstio has expertise in both industrial and manufacturing engineering. He forms part of a team working on ways to facilitate improved human-robot interaction. Below, he discusses his background, the new safety technologies he is enabling and his hopes for the future

Could you begin by telling us how you became interested in human-robot cooperation?

I have been working with industrial robots and production development for a long time. During that time, I have seen the struggle in industry for flexibility and customised products with traditional robotics. I realised there was great potential of utilising the flexibility and decision making capability of humans, and combining that with the strength and precision of robots.

Are humans and robots going to be cooperating with each other in an industry setting more in the future than they already do?

Until artificial intelligence in robots improves and becomes more reliable, effective employment of robots will always necessitate humans working alongside them. Robots can help humans in performing tedious tasks, and in the future, they will have capabilities that are closer to those of humans, and before long they will be an integral part of the workforce.

Can you discuss the safety challenges that human-robot interactions currently pose to both the humans and the robots, and how we might overcome these challenges?

Safety has the utmost importance in all industrial activities. Traditional robots are large and powerful and may really harm humans by hitting them or squeezing them if there is not a proper safety system present. Traditionally, in the industry setting robots have been isolated by large cages and kept far away from humans. We want to bring down that barrier and help humans work in closer proximity to robots, thus enabling true interaction between them.

In order for this vision to become a reality, robots will need to be able to know where humans are at all times and make decisions with that information. We will also have to limit robots' velocity and movements safely. Current sensor technology and new safety technologies are making this possible.

A major topic you cover in your research is user friendliness. How are you working to make robots less complicated to use?

Many companies around the world feel that robots are too complicated to use. Robots should certainly be more intuitive and easy to programme, especially since manufactured products change so rapidly.

We have been studying new technologies that would enable easy – or even zero – programming. These technologies would also enable methods for easy calibration, easier ways to use different peripherals and more intuitive user interfaces. In addition to this, we have done some real case studies regarding how workers feel using the robots, and we have discovered some improvements to facilitate their work and interactions.

How else are you trying to make robots more user friendly?

We are studying the human and user experiences to find out all the laborious and cumbersome points in the human-robot interaction process. We have created new working methods and solutions to overcome these problems. For example, with the new technology force control, we are enabling people to move a robot simply by touching it and nudging it in the direction they want the robot to go.

What has been the biggest challenge you have come up against in your work, and how have you overcome it?

It has been a challenge to get our safety system bulletproof. We are using non-safe sensors to control the system and the safety system only works in backup. If the non-safe system fails in any situation, the safety system has to take over. Making sure that it will be safe in all situations is really complex. However, our configuring software has the ability to calculate everything punctually.

How would you like to see your research evolve in the future?

I would like to see our research results utilised by industry and see new, innovative solutions using human-robot collaboration. In future research endeavours, we will focus on calculating actual robot stopping distances instead of following our current method, which relies on using the worst case scenario stopping distance required by the standard.

Are there any other human-robot interaction activities that you are involved in?

Besides large industrial robots, we will be focusing on developing lightweight, collaborative robots, called 'cobots'. Many robot manufacturers have brought a safe robot to the market, but companies – especially small ones – have difficulties knowing what the robots are capable of and what can they do with these new and inexpensive robots. Our mission is to clarify this by our research, tests and demonstrations.

A completely new way of working with robots

Developments in safety technology have paved the way for new possibilities involving human and robot cooperation. With that in mind, researchers in the **Productivity by User Friendly Human Robot Collaboration** project are investigating advanced safety solutions to solve the challenges the technology brings

IN MARCH 2016, when Google's artificially intelligent computer system AlphaGo defeated the Korean grandmaster Lee Sedol 4-1 at the game Go, it represented a huge step forward for machine learning technologies. For, while IBM's Deep Blue computer had defeated world chess champion Garry Kasparov almost 20 years before, the defeat of Sedol was both impressive and significant, as the possibilities within Go far exceed chess. Indeed, there are more possible Go games than there are atoms in the universe, and creating a machine that can beat a human at something so complex was an astonishing achievement, far exceeding anything that had gone before.

However, while both AlphaGo and Deep Blue demonstrated their abilities when pitted against a human, modern safety technological developments are opening up new and exciting possibilities for humans and robots to work together. Robots and machines have been used within various industries for years. One only has to look at the automobile industry, with its plethora of helpful robots, to see the impact robots have had on the industrial sector.

Unfortunately, limits in safety technologies have limited the application of robots. For instance, while robots are easily employed within companies to perform menial tasks, more complicated tasks often require large, bulky and powerful robots that represent a genuine safety threat to human workers – getting in the way of one of these robots could easily lead to accidents and injuries. Thus, robots have traditionally been kept away from people in the workforce, isolated in cages where they cannot come into contact with humans.

Excitingly, advances in modern safety technologies open up a completely new way of working with robots, one that researchers in Finland are attempting to facilitate through their investigations into new safety systems for industrial robots.

MAN WORKING ALONGSIDE MACHINE

Ilari Marstio is an expert in industrial and manufacturing engineering with a deep interest in finding new ways to facilitate human-robot interaction within industry. As part of the Productivity by User Friendly Human Robot Collaboration (TuoHIRo) project, he has sought to create new and novel safety systems for industrial robots.

The benefits of encouraging people to work with and alongside robots are numerous. "Manual labour is expensive," explains Marstio. "But with the aid of robotics, we can enhance productivity and ensure collaborative solutions are profitable."

Manufacturing in high-cost labour countries relies upon automating processes through the use of robots, but automation technologies cannot solve all the problems with manufacturing and while remaining financially

> With the modern safety technologies comes a completely new way of working with robots, one that researchers in Finland are attempting to facilitate through their investigations into new safety systems for industrial robots

viable. Because of this, it is not sensible to rely purely on robots – human workers must be kept in the loop. "Combining the two is key," explains Marstio. "Facilitating this through our research will also enable small and medium size businesses to enter the world of robotics."

DEVELOPING A DYNAMIC SAFETY SYSTEM

Marstio and his team have been working on the development of a novel, certifiable system that maintains the safety of people at all times. A key consideration of any system that facilitates human-robot interaction must be on enabling the robot to understand where the human is at all times. Thus, their Dynamic Safety System (DSS) makes use of 3D sensors to detect where the human is moving. Importantly, the position of the human directly affects the maximum speed of the robot and the limits of its working area.

Current industrial standards state that humans cannot touch large industrial robots when they are moving, so the DSS ensures that the robot stops when a human is close to it. However, this alone is not good enough for the system to be certifiable, so Marstio and his team have included other features. "We have safety sensors and a safety controller as a backup if the non-safe system fails," explains Marstio. "The safety controller and sensors are directly connected and synchronised so that the limited speed leads to small monitored areas and vice versa."

In addition to this, the team has employed safety configuring software that is able to determine the exact size that the safety areas need to be as well as configurations relating to the specific robot model, its working speed and the area it occupies.

MEETING THE NEEDS OF THE FUTURE

As technology develops faster and faster, so too do the opportunities that arise as a result. While there are legitimate safety concerns regarding implementing workforce policies centred on human-robot cooperation, new technologies are making many of these concerns redundant. However, though new safety technologies are solving problems, they bring about a unique set of challenges, especially when we consider the larger, heavier robots.

Marstio and his team's research is significantly contributing to solving these challenges, resulting in new industrial applications for robots and a far more adaptive and flexible human-robot cooperation. In a world that seems to be changing more and more rapidly, the findings from Marstio's investigations will help industries stay ahead of the curve and meet the demands of the workplace, but also, importantly, encourage other industries to employ robots by demonstrating the benefits of doing so without negating the safety of their human workforce. Man and machine can work in harmony, safely.

"I encourage companies to invest more bravely in new technologies and robotics! It will help to ensure competitiveness long into the future," concludes Marstio.

SYMBIOSIS OF MAN AND MACHINE

In addition to Marstio and his team's work developing their DSS, they are also involved in the Horizon 2020 SYMBIO-TIC project. Beginning in April 2015, the project is set to last for a period of four years, and it will address important issues to ensure a safe, dynamic, intuitive and cost-effective working environment. The project is aimed at developing a novel hybrid assembly and packaging ecosystem in a dynamic factory environment that is based on human and robot collaboration. Within the project, there are five specific objectives:

1. Develop an active collision avoidance subsystem to safeguard human workers
2. Generate adaptive task plans appropriate to both robots and human workers
3. Adapt to dynamic changes with intuitive and multimodal programming
4. Provide human workers with in-situ assistance on what to do and how to do it
5. Demonstrate and validate the project concepts and solutions

You can find out more about the SYMBIO-TIC project by visiting: **www.symbio-tic.eu**

HUMAN-ROBOT INTERACTION

OBJECTIVE

To enable humans to interact with robots in a cooperative, adaptive and flexible way that opens up new types of possibilities for robot applications within the industrial sector.

KEY COLLABORATORS

Mr Timo Salmi; Mr Timo Malm; Mr Jari Montonen, VTT Technical Research Centre of Finland Ltd, Finland

FUNDING

VTT Technical Research Centre of Finland

Finnish Funding Agency for Innovation

CONTACT

Ilari Marstio
Senior Scientist, MSc (Tech)

Production Processes, Robotics
VTT Technical Research Centre of Finland
Vuorimiehentie 3, Espoo
Finland

T +358 40 724 7285
E ilari.marstio@vtt.fi

http://bit.ly/IlariMarstio

www.linkedin.com/in/ilari-marstio-7587227

www.facebook.com/VTTFinland

https://twitter.com/VTTFinland

ILARI MARSTIO is a senior scientist in VTT Technical Research Centre of Finland, where he has been working since 2007, after receiving his Master's degree from the Automation Department of Helsinki University of Technology. He has experience in the automation industry. He has been developing robotised assembly lines for ABB. At VTT, he is a member of the production development team. His research interests include production concepts and advanced robot applications. He was developing a novel, self-configuring modular assembly system concept, which has been published in ISAM 2009 in Seoul. Marstio has been also researching human-robot cooperation and 3D-sensing robots in several projects. He has been developing a safety certified dynamic safety system for large industrial robots.

Predicting how people think and behave

Dr Victor Joo Chuan Tong discusses two innovative social intelligence systems that can precisely forecast the attitudes and responses of individuals or groups from social media data

To begin, can you outline the chief goals of your current study?

Social media and platforms are highly transformative, already disrupting industries and creating new economic sectors and opportunities. We feel that social computing is the next big thing for enterprises in the evolution of big data analytics. Our primary goal is to develop new research capabilities to address the challenges of this new 'social era'. I also hope that we can apply our work in social innovation to build a more sustainable and inclusive world, in particular in Singapore, our home country.

Our scientific programme is structured into three inter-related research thrusts: Psychometrics and Decision Science, Consumer and Social Intelligence, and Cognitive and Social Systems Modelling. We fuse capabilities and know-how from multiple disciplines in computing, engineering and social-behavioural sciences. It is critical to properly fuse these elements to avoid the 'garbage in, garbage out' scenarios common to poorly managed multidisciplinary programmes.

Could you talk us through your role in the Social and Cognitive Computing Department at the Agency for Science, Technology and Research's Institute of High Performance Computing?

Social computing refers to the study of social behaviour and social context using computational systems. Cognitive computing deals with intelligent computing methodologies and systems that mimic natural intelligence behaviours of the brain such as thinking, inference, learning and perceptions. We believe that both fields are converging.

My task is to look at how to best fuse these elements by emphasising the interdisciplinary aspects. We combine advanced data-driven analyses with theory- and hypothesis-driven approaches in social behavioural sciences. Thus, we deal with both hard and soft science. We now hope to nurture more researchers with a good knowledge of these disciplines, who can communicate well and have a good appreciation of what their colleagues are doing.

What are People Analytics (PA) and Sentiment Analytics (SentiMo)?

PA is a suite of technologies we are developing. It is capable of inferring individuals' personalities, values and behavioural dispositions, given a small set of observed characteristics. Our modelling framework is based on localist-connectionist networks in which these integrated representations comprise generalised, de-individualised associative relationships (as heterogeneous links) between various attributes or dimensions (as nodes) and their idiosyncratic variations across individuals, such as personalities, attitudes, beliefs, preferences, interests, temperament and behavioural tendencies. The main psychographic inference algorithm has been validated on a set of human subject data collected about people's perceptions of other people based on a few facts.

SentiMo is a psychographics-enhanced sentiment and emotion classification engine we are developing using fuzzy inference methods. The system is capable of fine grain sentiment and emotion analysis of social media data, able to recognise varying degrees of positive and negative sentiments, without the need for training datasets. This last feature is of particular importance for analysing unconstrained real-world data.

In which areas can PA and SentiMo be used?

PA has applications in finance and wealth management, consumer profiling, market segmentation, branding and human capital management. For example, it could be used for screening job candidates, making creditworthiness assessments and profiling consumers for product ranges.

SentiMo has applications in marketing, product innovation, customer relationship management and public relations. It could be used in competitor analysis, branding or policy formulation and understanding consumer preferences for different product features. Moreover, it can generate understanding of the attitudes and emotions of customers in real time and sense public sentiments for marketing campaigns.

Why are social computing and cognitive computing such useful tools?

Big data involving people can be used to generate insights of critical value for society. Social and cognitive computing tools put a human face on big data and enable innovations for better outcomes in everyday life.

Harnessing the power of big data in social networks

Multidisciplinary research at Singapore's **Agency for Science, Technology and Research** develops next-generation social informatics and computing systems that can rapidly make sense of internet-enabled human interactions for a wide range of applications

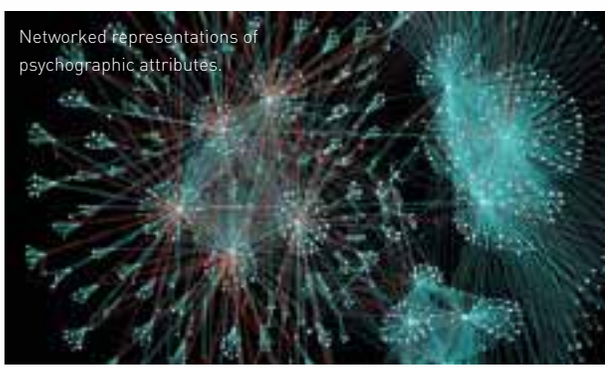
USERS OF SOCIAL media platforms, such as Facebook and Twitter, are able to constantly communicate personal news, as well as their likes and dislikes, to circles of friends, family and followers. As a result, a large industry has sprung up around this behaviour that attempts to mine information about potential consumer preferences and sell it to anyone interested in using it – for targeting advertisements or selling luxury products, for example.

As the internet becomes more open, the wealth of available data will grow. However, current data mining tools are relatively unsophisticated: "Organisations face a common challenge in unlocking the value of social data, interpreting the results reliably, and translating them into actionable insights to enhance operational efficiency," states Dr Victor Joo Chuan Tong, Director of the Social and Cognitive Computing Department at the Institute of High Performance Computing (IHPC), Agency for Science, Technology and Research (A*STAR) Singapore.

Blending expertise in social and consumer psychology, behavioural analysis and economics, linguistics, intelligent systems, and social and cognitive science, Tong is developing two applications for mining big data to predict personal or social behaviour with high accuracy: People Analytics (PA) and Sentiment Analytics (SentiMo).

PREDICTING THE PERSONAL

PA is a modelling and inference suite that can be used to predict a person's preferences, purchasing decision-making patterns and even job fit and performance from only a few known attributes. Integrating research findings on measures of human personality, behaviour and cognition, PA can report on the unobserved – and, most importantly, unobservable – character traits that drive a person's motivations, values and tastes from very limited information.



Networked representations of psychographic attributes.

Based on fuzzy logic and linguistic processing engines, SentiMo, on the other hand, can harness insights about people's attitudes and emotions even when they use very different ways to express their thoughts on Twitter: "SentiMo is capable of fine-grained sentiment classification, and trend, influencer and geospatial analysis," Tong explains.

SentiMo collects and classifies tweets – in different languages, topics and social contexts – as positive, negative, neutral or mixed. It then filters them by the dominant emotion they express, ranging from anger to anxiety and satisfaction. The results are displayed in near-real time in a descriptive graphical dashboard that reveals emerging trends: "Organisations can pick up changes in patterns or behaviour on the ground early, anticipate and respond to the consequences of change faster, better understand and respond to customer needs and thus enhance their marketing and public engagement capabilities," Tong enthuses.

FAST TREND MONITORING

IHPC recently tested SentiMo as a means of leveraging the power of social networking systems to calibrate response measures and communicate risk during an outbreak of a communicable disease.

The trial analysed avian influenza A (H7N9)-related content shared on the popular Chinese Sina Weibo social networking and microblogging site during the 2013 outbreak in China, to determine how SentiMo might have helped with epidemiological monitoring. References to H7N9 were collected and compared against information obtained from public health reporting and information sites and news media at the time. SentiMo reported new cases of H7N9 significantly faster than the conventional channels and also provided richer information about the outbreak.

Tong has now validated the potential of SentiMo and PA with several organisations to better understand consumer behaviour and sentiments, and plans to upgrade their capabilities for more unconstrained analyses. He hopes to attract talented researchers to help with this, and new partners to participate in their productisation for market readiness.

UNDERSTANDING HUMAN BEHAVIOUR USING ADVANCED SOCIAL & COGNITIVE ANALYTICS

OBJECTIVE

To leverage advances in social computing for the development of more advanced big data analytical tools.

FUNDING

Agency for Science, Technology and Research (A*STAR) Joint Council

CONTACT

Dr Victor Joo Chuan Tong
Department Director

Institute of High Performance Computing
1 Fusionopolis Way
#16-16 Connexis North Tower
138632, Singapore

T +65 6419 1570
E tongjc@ihpc.a-star.edu.sg

http://bit.ly/A_STAR

http://bit.ly/LinkedInChuanTong

DR VICTOR JOO CHUAN TONG heads up the Social & Cognitive Computing Department at A*STAR's Institute of High Performance Computing, Singapore. He holds a BSc in Computer Science and a PhD in Biochemistry, both from the National University of Singapore. His research interests include social computing, social innovation, biomedical informatics, data mining and urban systems. Tong has received over 20 professional awards for his work, including the MIT TR35 Award, World Economic Forum Young Scientist, World Economic Forum Young Global Leader and the Singapore Youth Award for Science & Technology.

Institute of High Performance Computing
A*STAR

Going beyond the literal to mine the conceptual

Researchers from the **Université du Québec à Montréal** have come up with a new way of mining repositories of information for concepts, moving away from a reliance on words confined to specific parameters. Their findings could change the way researchers and professionals discover new information

IN OUR DIGITISED world, experts such as academics, journalists, lawyers and doctors are becoming increasingly reliant on computers to research ideas and concepts. Yet, while the internet is an extremely useful tool for gathering research information, it has limitations. For instance, search engines like Google are unable to perform particularly 'deep' searches. Even Web 3.0, although sensitive to semantic information, may not meet the requirments of expert readers. When an individual uses a search engine, they type in a set of words relating to their query – and the system works by pulling up pages that contain these text segments. Sometimes, the so-called answer to their query might be contained in over 100,000 pages.

Expert readers desire to analyse content more deeply, exploring the ideas and concepts underpinning our use of certain words

But expert readers are often interested in more than simply matching their search terms to text within web pages. They desire to analyse content more deeply, exploring the ideas and concepts underpinning our use of certain words. Examples might include wanting to understand the attitudes of a particular author or the unconscious motives behind a certain policy.

CONCEPTUAL MINING

A researcher based at the Université du Québec à Montréal is therefore leading an innovative computer information retrieval project. Dr Jean-Guy Meunier has established the Computer assisted conceptual analysis of text (CACAT) project, with the aim of helping expert readers with conceptual mining. "The term conceptual mining is a metaphor for exploring the complexity of the conceptualisations underlying a text," explains Meunier. "It can be compared to the complexity of exploring valuable minerals underground."

The team is building and testing a set of algorithms with a capacity to conceptually mine digital texts for relevant information. Through looking at mathematical structures and creating prototypes, Meunier hopes to ascertain the extent to which these algorithms assist the expert reader, ultimately improving computer-assisted conceptual analysis. This could influence the ways in which expert readers in the future conduct research and discover new information.

DR JEAN-GUY MEUNIER has expertise in information science, computational linguistics and semantics. He is based in the Department of Philosophy at the Université du Québec à Montréal.

Technology-enhanced research

Dr Sandra Gesing develops computational tools that enable scientific researchers to analyse big data via high-performance computing more simply, efficiently and sustainably

Could you start by explaining how you developed an interest in computer science, and what motivates you in your research?

Computer science was offered as a class at my high school. Besides software and hardware theory, we were taught programming, which became one of my hobbies. I decided to make my hobby my career and completed an apprenticeship in computer science. While I enjoyed working in industry as an administrator, system developer and head of a systems programming group over the following 12 years, I realised early on that I would like to delve deeper into computer science and I did my German diploma (equivalent to a Master's degree) via extramural studies.

I then became especially interested in the important and challenging topics that bioinformatics supports, such as drug design and eradicating diseases, and I started to work in academia in a bioinformatics group. My PhD was focused on science gateways for molecular simulations. From this, I developed a primary interest in science gateways, workflows and distributed computing. While I know that I won't find cures for diseases or eradicate them, my skills enable me to contribute to projects with these goals.

Can you explain why science gateways are so important for advancing scientific discoveries?

Science gateways are software solutions – now often accessible via a web browser – tailored to the requirements of a specific community while hiding complex underlying infrastructures. They are important for enhancing science, since researchers are experts in their disciplines but not necessarily information technology specialists.

What are some of the biggest achievements of your research career to date?

Because of the interdisciplinary nature of my research, a large network of collaborators is essential for gathering ideas and understanding the pain points of researchers using complex computing infrastructures. The three biggest achievements in my research career are the successful MoSGrid science gateway (an intuitive portal for the molecular simulation community), a large international network of interdisciplinary collaborators and the European International Workshop on Science Gateways (IWSG) I founded in 2009 and have guided since.

Successful collaboration in MoSGrid is reflected in over 20 scientific publications. I led the design and implementation as work package leader of the project. IWSG is the partner workshop series of the US science gateway workshop series, as well as the Australasian science gateway series. Each year, IWSG attracts 30-60 participants, and it has an active community and enjoys strong support from collaborators.

You are particularly interested in science gateways for bioinformatics applications. Why is this an exciting area?

Bioinformatics is an exciting area for me for two reasons. First is the wide range of important applications in health and life sciences. The second is its novel technologies, such as next-generation sequencing, which allow data creation in exascale dimensions with relatively minor effort and monetary resources compared to only a decade ago. We are able to find answers for research that would not have been feasible before – maybe the questions were not feasible to ask before. But the amount of data creates new challenges, which obviously need new software solutions.

Have you faced any major challenges?

The major challenge is the breadth of topics associated with science gateways and workflows. While my field is exciting for this reason, the challenges are manifold, from intuitive user interfaces and security features to efficient data and workflow management, and parallelisation of applications employing parallel and distributed computing architectures. I overcome these challenges by becoming acquainted with the target domain and applying novel solutions. Close collaboration with researchers from the target domain and calling on experts for specific aspects, such as librarianship, statistics and machine learning, are essential, since it is not practicable to become an expert in every aspect of a science gateway.

Why are you so passionate about enhancing the reproducibility of science?

Reproducibility is a cornerstone in science for validating results. Research applying computational simulations and methods is predestined to support reproducibility in an easy way. Science gateways and workflow systems are promising vehicles to achieve this goal.

Could you outline some solutions that you have been working on recently?

One current solution is a prototype for easing the use of a software for calculating the dynamics of mosquito populations by exploiting graphical processing units. This software could be used for malaria research, for example. Another solution we are working on is concerned with combining two workflow systems to make use of the strengths of each and increase computational efficiency.

Gateways to advancing science

The Center for Research Computing at the **University of Notre Dame**, USA, is developing computational tools that enable the creation, distribution and widespread use of vital scientific knowledge

AS SCIENTIFIC KNOWLEDGE has developed, so have the complexities of the problems researchers seek to solve. Discovery and innovation in science increasingly depend on multidisciplinary knowledge. Computation has therefore become a fundamental tool, not only for developing and testing hypotheses but also for streamlining collaboration across disciplinary, organisational and geographic boundaries.

Leveraging the massive data processing capabilities offered by parallel, grid and distributed computing, as well as internet services, is essential for harnessing the power of big data generated by scientific research projects. Dr Sandra Gesing, who is based at the University of Notre Dame in Indiana and is the founder of the European Science Gateways International Workshop series, is confronting these challenges head on. Her research predominantly serves the bioinformatics domain, and recent projects have addressed a variety of technical and logistical issues, such as improving both computational performance and user access to accelerated architectures.

"Gesing draws on her experience in developing quality software and her deep understanding of computational strategies to open up new opportunities; working with experts in other disciplines, she advances computational technology until it meets the challenges posed," states Professor Malcolm Atkinson of the University of Edinburgh, who is one of Gesing's collaborators.

SCIENCE GATEWAYS

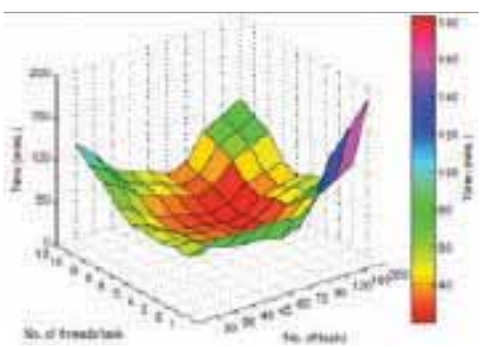
For scientists without extensive knowledge of information technology, it can be difficult to use a portal involving terabytes or petabytes of data and teraflop or petaflop computing power to obtain results, especially when time is of the essence. A science gateway is a system designed to make the task easier, based on a distributed computing infrastructure and delivering integrated access to specific sets of data and accompanying analysis and modelling tools, via a web portal or desktop computer application.

"Gesing's science gateway research aims at designing efficient methods for connecting scientific applications to cyber infrastructure, in the end making scientific discoveries faster and easier," points out Jarek Nabrzyski, Director of the Center for Research Computing. Key to this is delivering a seamless, intuitive user experience, making it feasible for any scientist to extract information, run workflows, execute simulations and develop complex algorithms without the need for a deep understanding of the underlying computing infrastructure.

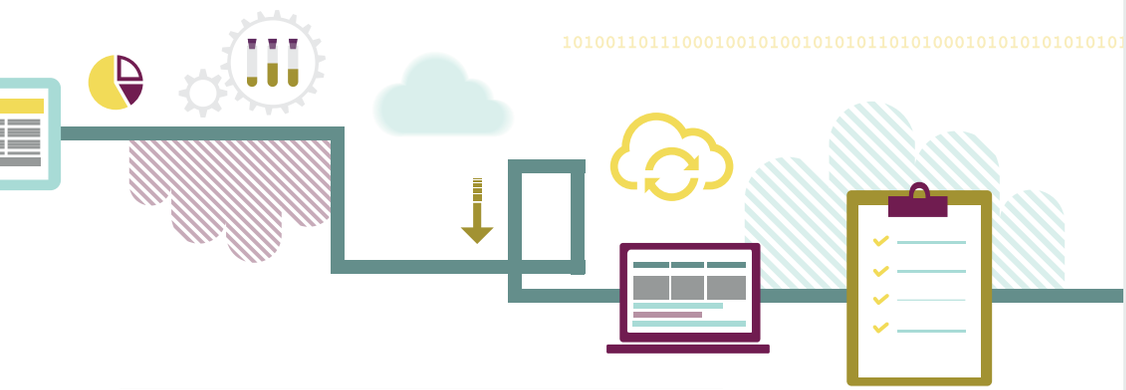
EASY-TO-USE COMPLEX RESOURCES

Workflow software products are useful to scientists for analysing observational and experimental data, and for running models and simulations. However, their effective use requires knowledge of their underlying technologies, so the learning curve is steep. In addition, support for the whole workflow lifecycle and adaptability tends to be poor. Thus, in recent projects, Gesing has developed frameworks to help scientists manage workflows from end to end while making optimal use of massive data mining and computing resources.

Where possible, Gesing's frameworks reuse existing software and procedures. She then enhances them by applying agile web methods, state-of-the-art infrastructure design and deep knowledge of the abilities and attributes of existing science gateway technologies that exploit research infrastructures such as the US Extreme Science and Engineering Discovery Environment (XSEDE) and the Partnership for Advanced Computing in Europe (PRACE). A central feature is the use of application programming interfaces (APIs) to enable rapid tailoring of the system to the end user's data, task and/or workflow requirements. APIs enable information technology developers to create a solution without needing to start from scratch. For users, APIs enable access to workflow systems through a single graphical user interface, allowing them to easily edit and



Impact of multilevel concurrency (thread-level parallelism) and distributed computing (task-level parallelism) on the execution time of a data-intensive workload. Selecting a good runtime configuration can optimise resource utilisation. (O. Choudhury, et al. 2015. *Cluster Computing (CLUSTER), 2015 IEEE International Conference on.* p390-393.)



Gesing anticipates that improving the usability and sustainability of science gateways will enhance the reusability and reproducibility of scientific research

monitor workflows and simultaneously optimise their usage of data from one screen.

Gesing developed her graphical user interface design through close collaboration with scientists. It is based on a web browser 'dashboard' concept, which connects seamlessly to both the workflow system and external resources like Cloud infrastructures, meaning the user does not need to become acquainted with diverse interface layouts. The dashboard can be tailored to each user, allowing researchers to focus on their own research topics instead of trying to familiarise themselves with a complex data and computing infrastructure.

IMPROVING ACCESS TO RESEARCH DATA AND PUBLICATIONS

Gesing anticipates that improving the usability and sustainability of science gateways will enhance the reusability and reproducibility of scientific research. Unfortunately, despite living in a digitally connected world, access to research data and publications remains difficult, and is often restricted by local copyright and funding policies. If the results of prior research projects were made more readily available, this would allow other researchers to build on them rather than simply reinventing the wheel.

Using the German Molecular Simulation Grid science gateway as a case study, Gesing recently examined the possibilities of integrating different research infrastructures. This has led her to advocate for the examination of policies governing each research infrastructure. Only when policies are aligned can technical integration follow.

DRIVING OUTREACH, ENGAGEMENT AND EXPERTISE

Gesing places strong emphasis on collaboration and she works closely with a number of international researchers. Dr Michelle Barker, Deputy Director of National eResearch Collaboration Tools and Resources and founder and co-chair of the International Workshops on Science Gateways – Australia, speaks warmly of their cooperative efforts: "My collaboration with Gesing has expanded my vision of what is possible in my research programme, as her

The concept of the Science Gateway Institute.

suggestions on alternative approaches and practices have helped elevate the programme to one that provides leadership in this field," she says.

Gesing is also heavily involved in a proposed US Science Gateway Community Institute, where her role focuses on outreach and community engagement. "Our proposal for the National Science Foundation (NSF)'s software institute programme will help advance both science gateways research and outreach to diverse research communities. We envision the Institute will help the research community by providing a range of services to help them develop science gateways," said Nancy Wilkins-Diehr, Associate Director at the San Diego Supercomputer Center, lead Principal Investigator of the SGCI – and one of Gesing's key collaborators. "One important part of this is carving out career paths for gateway developers and economies of scale for academic institutions achievable by creating gateway expertise groups on campuses."

For the foreseeable future, Gesing has her work cut out for her. She is now producing a guide to best practice in science gateway development and is lead editor for a forthcoming book about bioinformatics and big data. She is also participating in an ambitious worldwide project – the International Consortium for Technology in Biomedicine – with partners in the US, Europe and India, which is designing science gateways for biomedical applications. Moreover, together with Barker and Wilkins-Diehr, she is also planning to establish a global coalition on science gateways.

SCIENCE GATEWAYS, WORKFLOWS AND DISTRIBUTED COMPUTING

OBJECTIVE

To develop computational strategies that efficiently connect scientific applications to cyber infrastructure in order to accelerate scientific discoveries.

KEY COLLABORATORS

Jarek Nabrzyski; **Scott Emrich**; **Douglas Thain**; **Natalie Meyers**; **Ian Taylor**, University of Notre Dame, USA • **Thomas Connor**, Cardiff University, UK • **Malcolm Atkinson**, University of Edinburgh, UK • **Rizos Sakellariou**, University of Manchester, UK • **Michelle Barker**, Nectar, Australia • **Nancy Wilkins-Diehr**, University of California, San Diego, USA • **Maytal Dahan**, The University of Texas at Austin, USA • **Katherine Lawrence**, University of Michigan, USA • **Marlon Pierce**; **Suresh Marru**; **Sudhakar Pamidighantam**, Indiana University, USA • **Michael Zentner**, Purdue University, USA • **Linda B Hayden**, Elizabeth City State University, USA • **Jens Krüger**, University of Tübingen, Germany • **Peter Kacsuk**, MTA SZTAKI, Hungary • **Tamas Kiss**; **Gabor Terstyanszky**, University of Westminster, UK • **Richard Grunzke**, Technische Universität Dresden, Germany • **Sonja Herres-Pawlis**, RWTH Aachen University, Germany • **Johan Montagnat**, CNRS, France • **Horacio Perez Sanchez**, University of Murcia, Spain • **Jesus Carretero**, Universidad Carlos III de Madrid, Spain • **Gabriele Pierantoni**, Trinity College Dublin, Ireland • **Ivan Merreli**, CNR-ITB, Italy • **Cezary Mazurek**, Poznan Supercomputing and Networking Center (PSNC), Poland

PARTNERS

IEEE Technical Committee on Scalable Computing

FUNDING

National Science Foundation (NSF) • National Institutes of Health (NIH) – no current funding but past fundng and a grant under review • Bill & Melinda Gates Foundation – past funding

CONTACT

Dr Sandra Gesing
Research Assistant Professor

Center for Research Computing
PO Box 539, Notre Dame, Indiana 46556, USA

T +1 574 631 2400
E sandra.gesing@nd.edu

https://engineering.nd.edu/profiles/sgesing

http://sandra-gesing.com

www.researchgate.net/profile/Sandra_Gesing

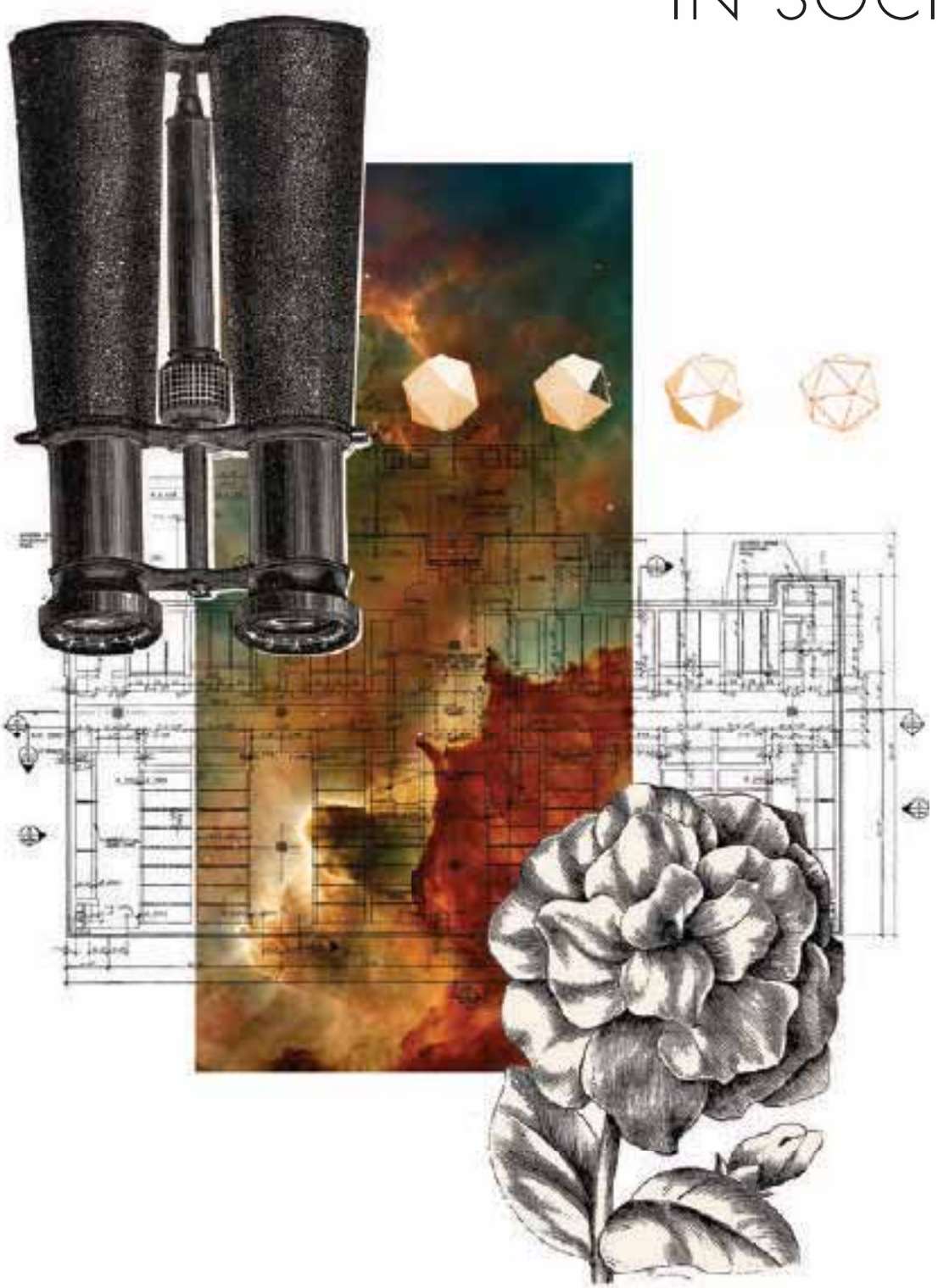
www.linkedin.com/in/sandragesing

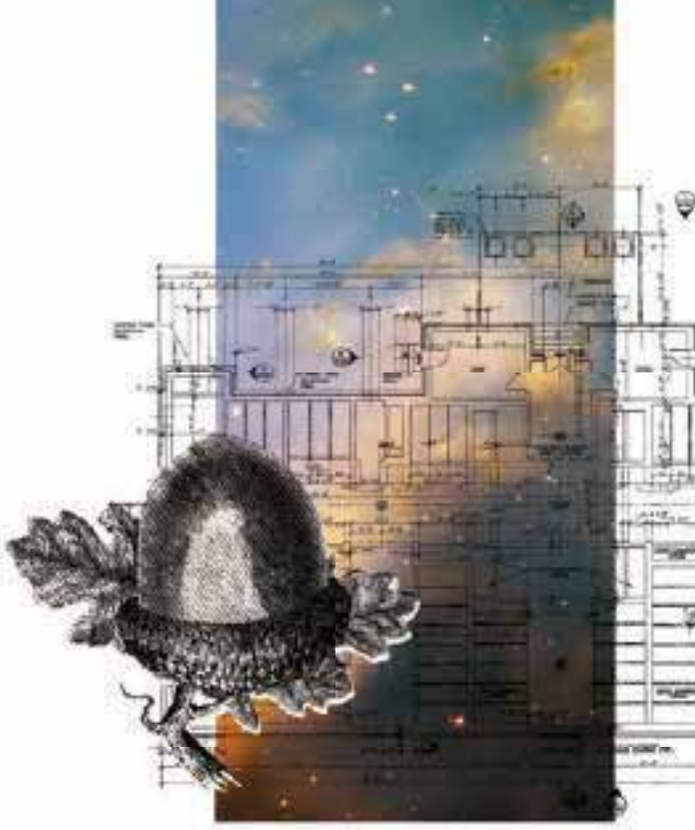
@sandragesing

SANDRA GESING is a research assistant professor and computational scientist at the University of Notre Dame, USA. Previously, she worked as a research associate at the University of Edinburgh, UK, and at the University of Tübingen, Germany, where she also received her PhD. Additionally, she has extensive experience working as a project manager and developer in industry.

CRC CENTER FOR RESEARCH COMPUTING

SCHOOL FOR THE FUTURE OF INNOVATION IN SOCIETY





What does the future hold? **David Guston**, Founding Director of SFIS, encourages scientists and citizens alike to shape a desirable tomorrow. How? Through the development of innovative ideas that address both existing and foreseeable real-world problems

As Founding Director, what motivated you to establish the School for the Future of Innovation in Society (SFIS) at Arizona State University (ASU), USA?

My ASU colleagues and I have been working on the societal aspects of science, technology and innovation since the Consortium for Science, Policy and Outcomes (CSPO) moved here in 2004. CSPO was initially created by Michael Crow, when he was Executive Vice Provost for Research at Columbia University, to be Columbia's science policy think tank in Washington, DC. After Michael became President of ASU in 2002, he made CSPO Director Dan Sarewitz an offer he couldn't refuse to recreate the centre at ASU – and then Dan made me an offer I couldn't refuse to join him.

So, in one sense, the founding of SFIS is the culmination of activities that we've been engaged in for more than a decade at ASU – just formalised in an organisation that is more recognisable as an academic unit than CSPO was. Over the years, we've hired new faculty, instigated the creation of new graduate programmes – namely, a doctoral programme in Human and Social Dimensions of Science and Technology and the Master of Science and Technology Policy – and generated a lot of new research, especially in the Center for Nanotechnology in Society at ASU, which the US National Science Foundation funded with an initial $6.2 million, five-year award in 2005 and renewed for $6.7 million in 2010.

But in another sense, SFIS is a brand new beginning because, first, as an academic unit reporting to the Provost, we are in greater control of our own destiny and, second, as a school embracing ASU's particular mission of access, excellence and impact, we are taking on new challenges like creating an undergraduate major and minor. Like ASU's School of Sustainability, SFIS is a school created from a problem in the world, rather than from a centuries-old tradition of scholarship or the coalescing of a professional community. For us, that problem is the complex and sometimes ambiguous role of innovation in society, and the role that we all have in making our own futures.

How is SFIS preparing students to build upon the incredible accomplishments of science and technology in years to come?

Our students pay a lot of attention to the so-called emerging technologies – like nanotechnology, synthetic biology, artificial intelligence and so forth – that are characterised by high stakes, high uncertainty and what I like to call a 'politics of novelty', in which it is essentially impossible to say whether synthetic biology, for example, is not novel because it merely extends a millennia-old practice of husbandry and agriculture, or that it is novel because it introduces species that not only have not been, but could not have been, crafted by evolution.

With emerging technologies, we're operating without much data and with multiple kinds of uncertainty, so the risk paradigm really falls apart. We're teaching our students to pursue a vision of what we call 'anticipatory governance', in which they work toward three capacities. The first is understanding or generating anticipatory knowledge of plausible futures with an eye toward what can be done today to help better establish the path toward more desirable futures. We're teaching them about upstream public engagement, in which substantive, two-way dialogues can be created between lay and expert communities at a point in time at which the differences between the two are minimised due to those great uncertainties. And we're teaching them how to integrate knowledge across the traditional two-cultures divide, and not just work in, but lead, cross-disciplinary teams aimed at real-world problem solving.

But our students are also interested in legacy technologies – think in particular about large-scale systems like energy, water and food – in which contemporary innovation certainly plays a role, but the key factor is the interaction of numerous social and technical subsystems that have evolved over decades in complex ways. At SFIS, we challenge our students to think about how social change (like behaviour

with respect to energy use) and technological change (such as smart metering of affordable roof-top solar panels) interact such that it makes little sense to speak of one without the other. In other words, we teach them to analyse socio-technical systems. We also focus on knowledge systems; that is, the connections among the various ways in which knowledge is produced, validated, disseminated and consumed across society. And we teach them in both national and international contexts, such as through our Master of Science in Global Technology and Development.

To what extent is SFIS addressing existing issues or 'gaps' within society?

I've mentioned three of the four graduate degrees that SFIS already offers. The fourth is the Master of Arts in Applied Ethics and the Professions. The idea that knowledge-based innovations are not simple, neutral tools but parts of complex systems that have different outcomes for different kinds of people (and for non-humans, too!) is a fundamental ethical concept for us. The distribution of the risks and benefits of innovation, the divides between the haves and the have nots, the 'gaps' between what we want out of our innovation system and what we ultimately get or will settle for are of central concern. There are a host of skills important for the future of innovation in society, and most of them are socio-technical in nature. So one of the gaps that we're addressing is the training of professionals who have those synthetic, cross- or interdisciplinary skills and can deploy them in problem-orientated ways.

This concern meshes well with ASU's own emphasis, expressed in its recently adopted charter, to pursue access, excellence and impact. In the view of SFIS, the future is for everybody. We all have a role in future-making; it should not be left only to the tech-savvy, quant-heavy code writers. But saying that the future, and more directly, future-making, is for everybody is different from saying that everyone should code. Professionals with social and socio-technical expertise have important roles to play, as do ordinary people who can and should be engaged with the future of innovation in their roles as citizens, family members, workers, etc. SFIS wants to help such people to be more effective actors in bringing about more desirable futures.

Do you have any specific goals for the School in the next five years?

We held a retreat for our faculty, students and staff at the beginning of our first semester in August. One of the small-group activities was a 'future visioning' in which we asked participants to write magazine headlines from the future (say 10 years) relevant to the School. According to those headlines, we educated a lot of students – including some heads of state and some who led the transformation of global organisations and massive infrastructures – many universities in the US and abroad emulated our ambitions and created their own cognate schools, and, apparently, IBM's Watson will join our faculty.

In reality, SFIS has ambitious enrolment goals, as well as goals for the scale of its research enterprise as constructed through a new, companion Institute for the Future of Innovation in Society. The enrolment goals will be pursued not only through expanding our current graduate degrees, but also by creating a new undergraduate degree that we anticipate will be offered by the start of the 2016 academic year, as well as the creation of new graduate degrees and certificates. We also hope to deliver these degrees and their classes in some innovative ways. And as a new academic unit, we're at work designing an institutional culture, policies and procedures to overcome some of the hidebound ways in which universities, even ASU, can reflexively devalue innovative, integrative, interdisciplinary and impact-orientated scholarship.

KNOWLEDGE-DRIVEN CHANGE

Universities prepare students for the future; at SFIS we make the future an explicit focus of our activities. We are planning now for the kinds of futures that we will want to inhabit. Universities are at the forefront of innovation, generating and applying knowledge to improve our lives. At SFIS, we make innovation the object of systematic study and informed critique. Universities serve society by producing knowledge and facilitating opportunity. They educate new generations of informed citizens and skilled, productive workers. At SFIS, we see our efforts as part of a larger social fabric – local, regional, national, global – that informs our wants and needs about the future.

ASU was recently named the number one most innovative college or university in the US by a US News and World Reports survey. I want SFIS to be at the vanguard of keeping ASU in that position.

A BROADER LOOK AT REAL-WORLD SCIENCE

David Guston shares his expertise and outlook by addressing three topical questions around the realities of implementing research at the societal level

SCI-COMM

Why is science communication becoming an increasingly important component of research dissemination and impact?

There are a number of reasons: one is that innovations in information and communication technology have allowed content producers to engage in better narrowcasting and broadcasting, and so scientists and engineers can reach more appropriate and wider audiences more directly than ever before – if they have the skills to do so. But another, I like to think, is that by engaging in communication with lay publics, scientists and engineers learn a lot more about the societal aspects of their research and might generate some new ideas from such interactions about what kind of innovation the public would really like to see. Sometimes, this latter reason is cast as an unfortunate necessity, an obligation of public patronage in a democracy. I prefer to think of it as a virtue in the system.

FROM RESEARCH TO POLICY

Can you explain the relationship between research and policy in the context of societal outcomes and progress?

Explaining that is essentially a career! There is a classic argument, closely associated with the great chemist and philosopher of science Michael Polanyi, that because you cannot predict where research is going to take you, and thus cannot predict what its societal consequences will be, science is thus essentially ungovernable and you have to leave it to its own devices. It's a powerful defence of scientific autonomy, written in a very popular essay called 'The Republic of Science' just over 50 years ago. But it's wrong. And what's wrong is not that you can predict where research will go – Polanyi's dead right about that; it is rather his assertion that prediction is essential to governing. Indeed, if prediction were possible, it might be that governance would not be necessary, because we'd all know the outcomes in advance and plan accordingly. But anticipation – that is, considering alternative, plausible futures and making decisions about their desirability and how to pursue them in the here and now – is possible, and necessary. Anticipatory governance can allow us to find a path between a passivity that is the equivalent of technological determinism and an activism that suggests the ability to control all aspects of the application of our knowledge. Anticipatory governance can help us to make social and technical progress, hand in hand, better than we have been doing.

RESPONSIBLE INNOVATION

You are also the Founding Editor-in-Chief of the *Journal of Responsible Innovation*. What is responsible innovation?

Well, I haven't fallen into defining responsible innovation elsewhere, and I won't here. Responsible innovation is several things – a movement, a process, an aspiration – based on the indisputable observation that while innovation does much good in the world, it also does harm, and on the very human (and humane) hope that the balance of good and harm can be shifted toward the former. In the contemporary environment, I think that responsible innovation can get a lot of leverage, because while everyone wants to innovate, no one wants to be irresponsible about it.

What would it mean to innovate responsibly? Presumably it goes beyond making something marketable and not killing anyone in the process. There have been many impulses similar to responsible innovation historically. Indeed, the scientific humanists, who were opponents of Polanyi in his own time, had similar things to say. One of them, the Nobel laureate radiochemist Frederick Soddy, believed as early as the beginning of World War I that the energy held in atomic nuclei might be liberated for use in wartime. H G Wells dedicated his novel, *The World Set Free*, which imagines the atomic bombing of cities, to Soddy and his troubling anticipation. Soddy launched something of a one-man campaign against the atom bomb before the fact, and turned his whole scientific career toward investigating what he thought would be the causes of the next war – one that might use atomic weapons – so that war might be prevented. In the process, Soddy essentially wrote himself out of science, and he died in relative obscurity for such a marvellous talent.

Now, I'm not advocating that scientists who realise that there may be negative or inhumane uses of their research immediately reorientate the entirety of their work to prevent such use. But one needs to be much more active than Polanyi's fatalism allows in order to be responsible.

ASU SCHOOL FOR THE FUTURE of Innovation in Society
ARIZONA STATE UNIVERSITY

sfis.asu.edu

Prometheus: stealing the sun is no myth

Dr Daniele M Trucchi is the coordinator of a project that seeks to create, validate and implement a highly efficient means of converting solar energy into electric energy. Below, he discusses challenges his team has overcome and the impact he hopes the project will have

What are the key goals of the Production Method of Electrical Energy by Enhanced Thermal Electron Emission by the Use of Superior Semiconductors project (ProME^{3}ThE^{2}US^2)?

The main goal of ProME^{3}ThE^{2}US^2 is the development of high temperature solar cells that can provide high efficiency in solar concentrating systems. Standard solar cells have a low efficiency and, when operating at higher temperatures, can experience a further significant reduction in efficiency. What we are proposing with ProME^{3}ThE^{2}US^2 is a completely new concept for a solar cell.

What inspired the name of the project?

I have always liked the idea of linking my interests in classic literature (spanning from the ancient Greek and Roman period through to 19th Century Russian novelists) to my passion for photoelectronic devices. I achieved this combination by applying acronyms to two European projects – one entitled Ephestus (a reference to Hephaestus, the Greek God of fire and technology), and another Prometheus. Both represent a particular attitude pertaining to the proposed innovation.

As Project Coordinator, can you explain what your key responsibilities are?

My duties include controlling the ongoing activities and the quality of results – smoothing every possible technical, scientific and management issue and providing a longer-term scientific vision to the consortium. As the Project Coordinator, I consider it a priority to personally communicate with the people working in my group and other organisations in the consortium. It is not always a simple task. Sharing information with all the collaborators quickly, convincing them about certain strategies, putting negative events into a positive light and, when necessary, being intransigent are all vital actions and attitudes for obtaining credibility. Another important consideration is finding a compromise between possible activities and the available budget.

How have you surmounted the challenges you face in your work?

The challenges in my work are continuous and sometimes insidious. Indeed, in R&D, a very fine line separates an excellent result from a technical or scientific defeat. Being devoted to the project and combining good methodology with creativity are essential in overcoming the challenges. I genuinely believe creativity is an important added value to the success of this project.

One challenge in ProME^{3}ThE^{2}US^2 was to create a material able to withstand high temperatures, emit electrons efficiently and interact with sunlight. While both synthetic and natural diamonds are excellent at satisfying the first two conditions, they are transparent and so cannot be considered a useful material for converting sunlight. Nevertheless, with a sagacious use of nanotechnology, we developed black diamond – an incredible material capable of absorbing the solar radiation by maintaining the same physical properties of diamonds.

What do you hope the impact of your research will be?

My hope is to demonstrate that high-temperature solar cells are feasible and possible, thereby encouraging more and more companies to join forces with us to facilitate the realisation of their potential. I think that in ProME^{3}ThE^{2}US^2 we have achieved several important results that should be adequately disseminated to attract the attention of stakeholders and investors.

The myth of Prometheus still radiates inspiration

ProME³ThE²US² is a three-year project that aims to develop novel solar energy conversion technology. The team behind it is laying the foundations for future high-temperature solar cells that can operate efficiently and overcome the limitations of current technologies

IN GREEK MYTHOLOGY, Prometheus is a Titan who stole fire from Mount Olympus then handed it over to mankind. The figure and myth of Prometheus has proved inspirational for many creations over time; a poem by Goethe, a lyrical drama by Shelley, even a short story by Kafka. This great protector and benefactor of mankind has proven grist to the mill of artistic endeavour and continues to be a source of inspiration for other fields.

CONVERTING CONCENTRATED SOLAR RADIATION

The Production Method of Electrical Energy by Enhanced Thermal Electron Emission by the Use of Superior Semiconductors project (ProME³ThE²US²), was established in May 2013, with the aim of developing improved systems to convert solar energy into electric energy. The functions of modern society increasingly necessitate more and more energy consumption, but as this increased need develops, so too does mankind's responsibility to ensure sustainability. Indeed, the negative impact consumption of non-renewable energy sources has is well documented, so a move towards greater use of renewable sources is necessary.

Solar radiation provides an important means of satisfying the energy demands of Earth, though capturing it effectively and efficiently has proved beyond the scope of technology for a number of years. The ProME³ThE²US² project has been established to develop greater methods and materials for converting concentrated solar radiation into electrical energy.

(BLACK) DIAMONDS ARE FOREVER

Project Coordinator Dr Daniele M Trucchi is acutely aware of the problems ProME³ThE²US² will provide solutions to. "Solar radiation is the largest energy source we have on Earth. Its more efficient and diffused exploitation means a higher energy availability with a minimal contribution to CO_2 formation," Trucchi explains. "Nevertheless, high efficiency is not enough – materials composing the converters cannot be toxic to humans and have to be simply and economically recoverable at the end of their lifetime."

Thus, the team has pursued several different routes. One branch of their research has investigated the development of semiconductors, made from the most advanced traditional solar cells, to provide an innovative conversion mechanism. However, perhaps the most exciting and notable project output has been their development of synthetic diamond technologies. Indeed, their creation of a brand new material – the black diamond – boasts all the properties of real diamonds conducive to solar radiation capture, but where diamonds are usually transparent (making them unsuitable for converting sunlight), the team's black diamonds are, as the name suggests, not. Thus, the team is able to harness the absorption of solar radiation efficiently and at high temperatures. Importantly, their black diamond is exploitable for other electronic applications.

CAPTURING ATTENTION AS THEY HAVE THE SUN

Armed with this important, potentially revolutionary technology, the consortiums aim to build upon its solid foundations until its maturity in the next few years. The hope is that by demonstrating the technology's effectiveness and feasibility for solar radiation absorption, industrial partnerships will be formed to realise the potential of these exciting developments. "Novel technologies for energy conversion are not acquiring the adequate attention by investors," explains Trucchi. "The low price of petroleum and other hydrocarbon sources influences attention on economically safer, but far more polluting, investments in the energy market."

However, the consortium is confident that, once the hydrocarbon prices increase, as they inevitably will, interest in their technologies will significantly increase. Ultimately, the ProME³ThE²US² project has already stolen the fire – it just needs investors to help them hand it over to mankind.

ProME³ThE²US²

OBJECTIVE

To develop improved systems to convert solar energy into electric energy.

KEY COLLABORATORS

Professor Abraham Kribus, Tel Aviv University, Israel

Professor Alon Hoffman, Technion Institute of Technology, Israel

Dr Frank Dimroth, Fraunhofer Institute for Solar Energy, Germany

Mr Aniello Vitulano, Ionvac Process Srl, Italy

Dr Fernando Centeno, Exergy Ltd, UK

Dr Arnaldo Galbiati, Solaris Photonics Ltd, UK

Dr Veronica Carcelen, Abengoa Research SL, Spain

FUNDING

EU Seventh Framework Programme (FP7)

Future and Emerging Technologies (FET) Programme

CONTACT

Dr Daniele M Trucchi

CNR-ISM
Via Salaria
Monterotondo Scalo
00015
Rome, Italy

T +39 0690 672 558
E daniele.trucchi@ism.cnr.it

www.ism.cnr.it/it/staff/daniele-trucchi

www.prometheus-energy.eu

bit.ly/RGDanieleTrucchi

http://bit.ly/LinkedInDT

DANIELE M TRUCCHI has a PhD in Electronic Engineering. Since 2002, he has organised the technical-scientific activity of the EU project 'Diamond' for Consiglio Nazionale delle Ricerche (CNR), with activities focused on the design and development of electronic devices and energy converters. Since 2010, he has been managed the CNR DiaC2 Lab, where he coordinated the activities of the FP7 project E²PHEST²US, focused on the development of innovative conversion modules for solar concentrating systems. He was then Coordinator of the FET project ProME³ThE²US² and of several industrial, Italian and European R&D projects.

Seeing the wood for the trees

Professor Alexander Petutschnigg and colleagues are working to optimise efficiency at every stage of the wood supply chain, developing inspired methods of engineering and biomaterials science to make each log go a little further

How did your academic background lead you to specialise in the holistic usage of natural resources, and what motivates you in your work?

My career began as a forester. I then decided to study forest products technology and timber construction, and following this, mathematics in Salzburg. For my PhD, I studied at the University of Agricultural Sciences in Vienna and the Technical University of Graz, where I finished my research on the simulation of production processes in forest products industries. Importantly, I gained insight into different scientific disciplines on the topic of materials and production processes. Thanks to these experiences, I realised that the real potential of development in the 'old-fashioned' forest products technology field lies in holistic developments rather than partial solutions.

To what extent is intelligent resource utilisation important for addressing resource shortages in the future?

With our use of available resources continually increasing, it seems more likely that we are going to experience resource shortages in the near future. In my opinion, survival of the fittest will become the survival of the most intelligent rather than the victory of the strongest. We must therefore increase the intelligence behind our actions.

If we look at the usage of trees, for example, the current focus is on the production of sawn timber, which is less than 50 per cent of the total resource; indeed, in the conversion chain of roundwood to timber, the yields of the production processes are less than 65 per cent. If we can reduce the dissipation of resources in our modern product development and production processes, this could lead to the avoidance of resource shortages.

What are the benefits of using wood materials to address resource shortages?

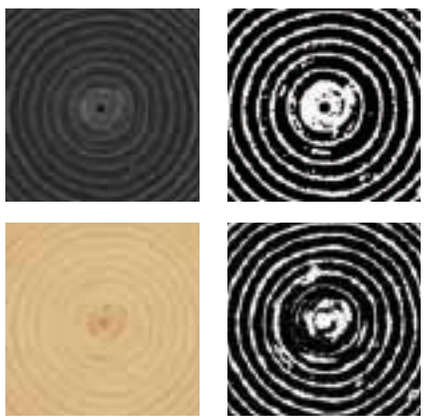
From our perspective, benefits can be derived from using all resources associated with trees, including wood, bark, leaves, needles and seeds, among others. The greater use of these materials will increase the amount of resource output without increasing the quantity of felled trees. As wood is a renewable material, in the long term, no shortages will occur if the principles of sustainable management are upheld and respected.

Biomaterials research surely calls on a number of disciplines; how do you approach such a multifaceted field?

In our team, breadth of knowledge is essential to solving our multidisciplinary research questions. Depending on the research question, technologists must be supported by mathematicians, chemists, biologists, economists and other scientists.

How important is collaboration with other universities?

The development of new products and processes in the supply chain, from the forest to the end consumer, involves knowledge from different fields and, therefore, collaboration with other universities all over the world is essential. We have strong scientific and student exchange links with universities in Europe, North and South America, Africa and Asia. Our partner institutions do not only support us with specific expertise in their focus fields, but they also provide laboratory equipment, allowing us to make use of machines we could never afford in Salzburg.



FINDING FINGERPRINTS
To combat the illegal felling of trees, Petutschnigg and his team are devising a database of 'fingerprints' for trees by obtaining crosscut images of logs from forests across the world. This enables the optimisation of the whole supply chain and the secure identification of illegally felled trees.

DRIVING DURABILITY
The team at Kuchl are impregnating wood with bark extractives to prevent quick biodegradation. Not only does this technique increase the durability of exterior applications of wood and enhance fire resistance, but its ability to change the colour and odour of wood means that it can also be used in the creation of aesthetic products.

Transforming waste from wood

An interdisciplinary team of researchers at **Salzburg University of Applied Sciences**, Austria, is finding new uses for one of humanity's oldest resources – and their work is contributing to a more sustainable future for all

THE IMPORTANCE OF wood cannot be overemphasised. Historically, it served as humanity's primary source of heating fuel and building material – and it is still used today as a major material in houses, furniture, decorative artefacts and pulp-based products, including paper. Yet, the continuing demand for wood materials coincides with diminishing resources and a burgeoning global population.

Professor Alexander Petutschnigg and his colleagues at Kuchl campus of Salzburg University of Applied Sciences (SUAS), Austria, propose a two-pronged approach to transforming the wood supply chain. With the ultimate goal of minimising wastage at every stage, from felling to final product, Petutschnigg's research is inherently multidisciplinary. Together with his team and collaborators, he is pioneering a holistic approach to the usage of wood resources by promoting higher efficiency in existing processes and the upcycling of residues.

OPTIMISING EFFICIENCY

Wood may be the principal tree-derived material, but it is certainly not the only one. Trees also produce so-called 'extractives', solutions that protect the tree from bacteria, fungi and insects. The antimicrobial and insecticidal tannins that confer these properties are of potential benefit to humans; however, when wood is dried prior to being used as a building material, these extractives evaporate into the atmosphere.

In response, Petutschnigg's group suggests the use of a purpose-built vacuum chamber to isolate these extractives by steam distillation, the process through which perfumes and other organic compounds are isolated. The group's latest publication details the antimicrobial efficacy of larch- and pine-derived extractives, which effectively inhibited the growth of gram-positive bacteria such as *Staphylococcus aureus*.

Additionally, due to increases in both material costs and production processes in the construction industry, the Kuchl researchers are simulating and developing new joints and constructions based on the framework of the human skeleton. "These constructions are optimised for dynamic loads and the results are implemented in a range of applications, such as new ski cores for ultra-light skis," Petutschnigg outlines.

UPCYCLING RESIDUALS

As the process of re-purposing or transforming by-products or waste materials into objects of superior value, upcycling has become extremely popular in recent years – and Petutschnigg and his team are applying this procedure to the transformation of wood residues.

For instance, the researchers are using tannins, as an extractive of bark processing, to produce natural foams – that is, renewable insulation materials that could replace synthetic foams such as polystyrene. In addition to being effective thermal insulators, tannin foams are also fire-resistant, unlike the highly flammable polystyrene.

Moreover, the team also demonstrates that residual bark – produced during the conversion of roundwood from trees to timber boards – can be used as a construction material. Its low thermal conductivity and high specific heat capacity make it an excellent heat buffer; indeed, a building insulated with bark experiences minimal heat loss.

Petutschnigg's upcycling endeavours also include the development of a new material based on a combination of wood residuals and leather waste from homogenisation processes. Interestingly, the two component parts of this innovative material compensate for the physical limitations of the other. For instance, the leather waste endows the composite with fire resistance, while the wood residuals provide mechanical stability and prevent the leather from melting. The resultant material is therefore durable, renewable and safe.

Ultimately, the R&D innovations in the Kuchl lab are testaments to the power of interdisciplinary collaboration. Continuing with their holistic approach, Petutschnigg and his team are planning to seek sustainable solutions to global problems, focusing on improving efficiency and upcycling residues.

DISCOVERING THE HIDDEN QUALITIES OF WOOD

OBJECTIVES

- To overcome resource shortages in the future by identifying intelligent means of resource utilisation
- To both improve and develop new products and processes in the field of biogenic resources

KEY COLLABORATORS

Professor Timothy M Young, University of Tennessee, USA

Professor Alfred Teischinger, University of Natural Resources and Life Sciences, Vienna, Austria

Professor Klaus Richter, Technical University of Munich, Germany

PARTNERS

University of Natural Resources and Life Sciences, Austria

Technical University of Munich, Germany

University of Tennessee Knoxville, USA

University of Stellenbosch, South Africa

FUNDING

FWF Austrian Science Fund

Austrian Research Promotion Agency (FFG)

CONTACT

Alexander Petutschnigg
Professor and Head of Department

Salzburg University of Applied Sciences
Holztechnologie und Holzbau
Markt 136a
5431 Kuchl
Austria

T +43 50 2211 2011
E alexander.petutschnigg@fh-salzburg.ac.at

http://bit.ly/1RoqBEa

www.researchgate.net/profile/A_Petutschnigg

ALEXANDER PETUTSCHNIGG is Professor at the University of Applied Sciences in Salzburg, Adjunct Professor at the University of Tennessee and a lecturer at the University of Natural Resources and Life Sciences in Vienna. His academic background lies in forest products technology, timber construction and mathematics.

Inspired by nature: exploiting the beauty of biominerals

Nanomaterials expert and enthusiast **Dr Siddharth Patwardhan** provides an insight into the inner workings of his lab, and explains why his team's bioinspired research is so innovative

Why did you choose to pursue research in the field of bioinspired green nanomaterials? What fascinates you about this area of study?

Biology has mastered the art of producing sophisticated and ornate nanomaterials through a process called biomineralisation. Well-known examples include bones and teeth. The precision and beauty of biominerals is unique and admirable. Seeking inspiration from biominerals and learning how biology orchestrates the formation of such high-quality nanomaterials is fascinating, as is discovering the formation mechanisms and utilising them to develop new technologies. The potential impact of bioinspired technologies is huge, especially given the opportunity to reduce environmental damage caused by current processes.

What have been the biggest advances made by scientists with regard to silica-based materials using bioinspired approaches? How do these correlate with your research?

There are four main areas wherein scientists have made the biggest advances pertaining to bioinspired silica. The first of these is the identification of biological mechanisms that control the formation of biominerals. These include cellular processes as well as the isolation of specific biomolecules responsible for biomineral formation. Secondly, there is the translation of these mechanisms into the non-biological synthesis (fully synthetic in the lab) of biominerals by gaining understanding at the molecular level. The third area is the utilisation of the underpinning molecular-level science in producing a wide variety of silicas with varying properties. Finally, there is the translation of this knowledge into developing applications and manufacturing technologies. My group has contributed significantly in the last three areas, while recently, we have focused more closely on the applications and manufacturing.

Nanomaterials are used across a range of applications, from sensors and coatings to hybrid materials, catalysis and drug delivery systems (DDS). In what ways have you applied knowledge of the latter in your studies, given the ability of silica to control drug loading and delivery?

Many nanomaterials have been investigated for use as DDS, and silica has been proposed as a promising candidate. Although, over the past 15 years, silica has been tested with various drugs (ranging from anti-inflammatory to antibiotics and anticancer drugs), there are currently no silica-based drug delivery systems on the market. We identified the problems with the existing silica technologies, which include laborious synthesis, the use of hazardous chemicals and harsh conditions (extremes of temperatures and pH). We then utilised our knowledge of bioinspired silica to overcome these issues and design novel DDS. One radically new approach we have taken is direct loading of drugs into silica when silica is produced, as opposed to loading drugs after the silica powder has been produced. This approach reduces the production steps, and hence also cost and waste.

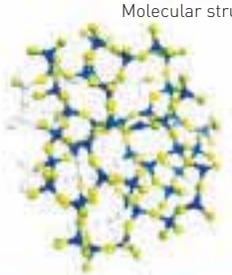
The industrial-scale design you proposed in your feasibility study is economically competitive, requires no heat and reduces carbon dioxide emissions in comparison to traditional methods. What further conclusions were you able to draw and how have you developed this research since?

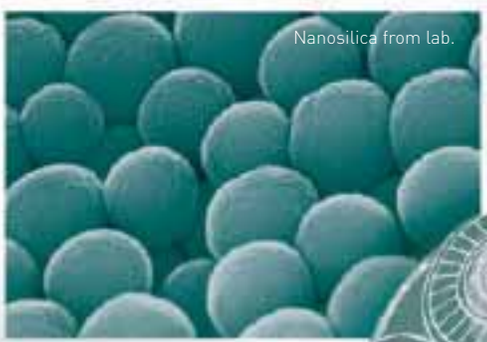
Since the publication of that feasibility (theoretical) study, we have put the outcomes into practice and we are now able to produce large amounts of silica (hundreds of grams to kilogram quantities compared to hundreds of milligrams, which anyone could produce beforehand). We have also developed greener ways for downstream processing (purification), which makes the entire process truly green and sustainable. These developments are under intellectual property protection and are at the commercialisation stages.

Why does the silica obtained via the bioinspired process result in a more diverse range of properties that can be controlled? What new applications could silica have?

Biology is able to offer superior control, hence bioinspired silica is also highly controllable and can be 'moulded' to generate a wide range of properties. We use specific molecules (called additives) that are inspired by biomolecules and help control the process. We have developed a vast amount of knowledge pertaining to the use of these additives in silica formation. We are constantly exploring new and exciting applications for bioinspired silica and recent avenues include treating waste water and capturing CO_2 from power plants (these are being developed in collaboration with other colleagues).

Molecular structure of silica.





Nanosilica from lab.

The significance of silica

A system designed at the **University of Sheffield**, UK, could revolutionise the way nanoparticles are produced, with associated benefits for medicine

SINCE TIME IMMEMORIAL, humans have drawn inspiration from the natural world around them when attempting to overcome technological challenges. This process of biomimesis, the imitation of life, is evident in the works of Leonardo Da Vinci and the Wright brothers, ancient architecture, and even in everyday inventions like Velcro. And this is more than just a preoccupation with the organic; because of the refining effect that evolutionary processes can have, many of the forms observed in the natural world have close to optimal configurations to fulfil their various purposes. The curve of a sycamore leaf and the clinging pad of a gecko's foot may have arisen by chance – but they persist because they are effective.

One compound often found both in nature and in the lab is silicone dioxide, also known as silica. Silica is used in various applications – commonly in the packets of silica gel that reduce humidity in an environment, but also in synthetic products such as crystal and fused quartz. In nature, silica is an important component of many microalgae, plants and sponges; in the case of sponges, it often forms a delicate 'crystal' skeleton that supports the organism, and in plants too it can play a role in reinforcing the structure of the body. So strong of a scaffold is silica, that it gives strength to blades of grass – and, through these leaves, has influenced the evolution of grazing animals around the world.

DRUG DELIVERY

This begs the question: how effective could silicone dioxide be in human technology? Many scientists have worked towards answering this question. In particular, attempts have been made to use silica nanoparticles in drug delivery systems. Silica is an extremely attractive candidate for this application because its surface chemistry and porosity are easily controlled, its drug loading can be varied, it has been approved as safe in the EU and USA, and it has excellent biodegradation properties. It has even been suggested as a beneficial chemical for bone growth.

Highly sophisticated silica produced by microalgae.

But there are two problems: firstly, silica nanoparticles have to be synthesised under harsh conditions that are demanding in energy and not environmentally friendly. Secondly, questions remain regarding their toxicity and biocompatibility – scientists are not sure how cells react to them. Dr Siddharth Patwardhan is Senior Lecturer in the University of Sheffield's Department of Chemical and Biological Engineering and leader of the Green Nanomaterials Research Group. His aim is to solve these issues with the help of his dedicated team. Patwardhan's theory is that learning from nature, the synthesis of these nanoparticles may yield materials of greater use at a lower environmental cost.

THE LIVING END

Patwardhan's work centres on investigating living biosilicifying systems, which naturally operate at near-neutral pH, in aqueous environments and at ambient temperature, to see how they can inspire approaches to accomplishing the same in a lab. Towards this goal, 2011 saw the group publish a comprehensive and widely-read review of applications that had come out of this field of research, examining the potential for scaling up such measures in the future.

Much of the group's work has focused on the use of additives to enable and accelerate silica formation under diverse conditions – and, recently, the Sheffield scientists have been preparing for the publication of a very important study. The article will describe a new green process to facilitate rapid silica formation in less than five minutes and under ambient conditions. Their method, they say, is not only economically comparable to current industrial approaches, but also yields silica samples with superior properties to those created using other methods. By adopting this innovative green process, which can easily be incorporated in existing manufacturing without significant capital investment, industry will be able to create and adapt silica for current and new applications – a very exciting prospect indeed.

BIOINSPIRED GREEN NANOMATERIALS

OBJECTIVE

To discover, design and manufacture nanomaterials using sustainable processes for engineering, environmental and biomedical applications.

FUNDING

Engineering and Physical Sciences Research Council (EPSRC)

The Royal Society

Nuffield Foundation

CONTACT

Dr Siddharth Patwardhan
Senior Lecturer; Leader of the Green Nanomaterials Research Group

Department of Chemical and Biological Engineering
University of Sheffield
Sir Robert Hadfield Building, Mappin Street
Sheffield
S1 3JD
UK

T +44 114 222 7593
E s.patwardhan@sheffield.ac.uk

www.svplab.com

DR SIDDHARTH PATWARDHAN obtained a first degree in Petrochemical Engineering from the University of Pune, India. This was followed by an MS and PhD in Materials Science and Engineering from the University of Cincinnati, USA. Subsequently, he gained postdoctoral experience from the University of Delaware and Nottingham Trent University. In 2010, Patwardhan became a lecturer in Chemical and Process Engineering at the University of Strathclyde. In 2016, he moved to the University of Sheffield to take up the position of Senior Lecturer in Chemical and Biological Engineering, where he leads the Green Nanomaterials Research Group. Patwardhan's research has produced 65 peer-reviewed articles, over 40 conference presentations and intellectual properties. Patwardhan is Associate Editor of *SILICON*, an elected member of the Royal Society of Chemistry's Materials Chemistry Division Council and EPSRC's Early Career Forum for Manufacturing Research. He has held visiting positions in Japan, India and the US. Patwardhan has also organised and served in scientific committees of national and international conferences.

The University Of Sheffield.

Field controllable polymer hybrids in action

Drs Marina Saphiannikova-Grenzer, **Olga Guskova**, **Vladimir Toshchevikov** and **Dmytro Ivaneyko** from the Material Theory and Modelling group research functional polymer materials for a wide range of applications. Here, they expand on their activities

Can you begin by describing the work your group does and the foci of your research?

MG: Our group has complementary scientific backgrounds in the fields of theoretical chemistry, theoretical physics and material engineering, with an emphasis on small organic molecules and polymers. However, our current research interests are not limited to pure organic materials. In recent years, our research into polymer hybrids has increased; they have gained tremendous scientific and industrial attention owing to their unique properties. These materials synergistically combine the best features from inorganic, organic and even biological worlds.

Importantly, the behaviour of polymer hybrids can be remotely controlled by the light and magnetic fields, which makes them especially attractive for a modern society. Our target is to understand and predict how the structure of these field controllable hybrids defines their macroscopic properties. Our dream is to be able to assist the manufacture of diverse polymer hybrids according to customer specifications and the needs of society.

What kinds of applications does your research on functional polymer materials have?

VT&OG: The fields of our scientific interests include hybrid materials of various structures, whose components define their physical properties and specific applications. One of our research activities is devoted to magneto-sensitive elastomers. These have found practical applications in controllable membranes, rapid-response interfaces designed to optimise mechanical systems, and in automobile applications, such as adaptive-tuned vibration absorbers, stiffness tuneable mounts and bushings, and automobile suspensions.

Other scientific activities are devoted to azobenzene-containing polymer hybrids, which have fascinating potential for applications as sensors, actuators, microrobots, micropumps, artificial muscles for exoskeletons and robots. Last but not least, we predict the behaviour of polymers for organic electronics when they are in contact with another material or interface. This topic is of particular interest for further development of energy-efficient devices.

Can you tell us what you find most interesting about magneto-sensitive elastomers (MSEs)?

DI: MSEs are viscoelastic polymer composites with inclusions of ferromagnetic particles. They exhibit unique mechanical properties under external magnetic fields that are the result of a synergy between elastic and magnetic components. One of the most fascinating features of MSEs is the change of the mechanical moduli under an applied magnetic field, as well as the ability to generate magnetically induced deformations and actuation stresses. The mechanical properties of MSEs strongly depend on the elasticity of the polymer matrix, volume concentration of the particles, and their shape, size and spatial distribution. Because of their unique properties, MSEs are of strong commercial interest in numerous fields, from automotive to medicine to soft robotics. Several industrial groups already incorporate MSEs into their devices.

How do you overcome the particular challenges you face in your research?

VT&MG: The theoretical description of the structure and dynamics of polymer hybrids inside a broad range of time and length scales is an extremely challenging task. It would be impossible to solve it if all the details and processes were simultaneously taken into account. We use our expertise to identify key details that influence the macroscopic properties of interest and issue appropriate material models. In particular, we use the powerful tools of coarse-graining and renormalisation to describe the physical properties of the materials on specific scales, ranging from nanometres to centimetres. Unifying all key physical processes into one picture, we obtain a multiscale approach that is able to describe physical properties of the material in a broad range of time and length scales.

Could you reveal any future plans for the group?

MG: In its present state, our international group consists mainly of early- and mid-career researchers whose primary ambition is to become leading experts on the scientific market in the aforementioned fields of research. This demands stable income from funding agencies, so the nearest future plans presume securing of long-term financial support by getting prestigious research grants in close collaboration with experimentalists and industrial firms.

This will allow us to employ additional personnel and strengthen our efforts to meet research goals. The personal strategic plans include acquisition of the next scientific and academic degrees by the group members, as well as the department status of the group. For strategic research initiatives, we would like to build and maintain a successful research network with industrial partners in areas alluded to above.

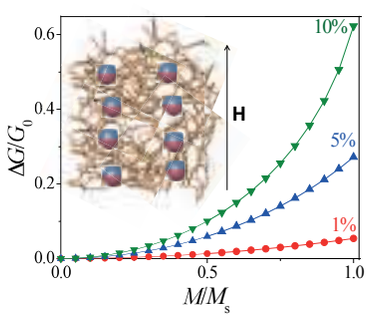
From fundamental science through to R&D

Researchers at the **Leibniz Institute of Polymer Research Dresden** are working to advance knowledge regarding the development of field controllable polymer hybrids with new and improved characteristics. Their findings will enable the production of new materials with diverse practical applications

Drs Vladimir Toshchevikov, Olga Guskova, Marina Grenzer and Dmytro Ivaneyko

FIELD CONTROLLABLE POLYMER hybrids are multicomponent materials made up of a polymer matrix with organic or inorganic additives. The polymer component, as German chemist Hermann Staudinger understood back in 1920, is represented by giant chain-like macromolecules built from repeating chemical units bonded together. Polymers boast a wide range of mechanical and physical properties, but as such lack sensitivity to external electric, magnetic and light fields. This can be outsmarted in polymer hybrids by incorporating light-sensitive moieties or iron particles in otherwise non-conductive and non-magnetic polymers. The resulting polymer hybrids show a strong response to external fields and can be controlled by the latter.

The breadth of potential for the polymer hybrids is such that they present a fascinating and exciting field of enquiry in both science and technology. Indeed, field controllable polymers are one example of polymers that have been created with an extraordinary amount of advanced magnetic, optic and electronic properties. The benefits of research into this specific type of polymer includes the fact that it is possible to tweak the properties of it without exorbitant cost. Material usage is also often low which, given the ever-increasing environmental concerns, is a particularly attractive perspective.



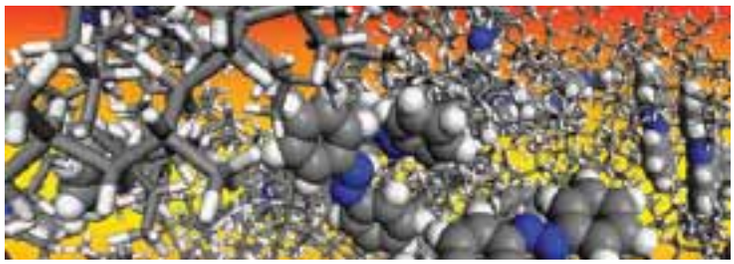
Relative change of the shear modulus of MSEs as a function of the relative magnetisation for different volume fractions of particles: 1%, 5% and 10%.

The 'Material Theory and Modelling' (MTM) group focuses on developing understanding of functional polymer materials that is orientated around practical applications. Together, Drs Marina Grenzer, Olga Guskova, Vladimir Toshchevikov and Dmytro Ivaneyko perform research into field controllable polymer hybrids. Their work represents the potential for imbuing materials with new field controllable functions that meet the demands of industry. The MTM group also researches mechanical behaviour of polymer networks reinforced with rigid particles, which is important for the development of tyres.

APPRECIATING REPRESENTATIONS FROM DIFFERENT SCALES

Theoretical studies on field controllable polymer hybrids is a rapidly growing field of polymer science that has been developing over the past few decades. Nowadays, it incorporates a number of novel theories and computer simulations to enable molecular and morphological designs, and predictions of macroscopic properties. As such, the MTM group performs computer simulations alongside analytical studies to generate deeper understanding of the molecular processes that occur in functional polymer hybrids under external fields.

"For our research, we apply a number of methods and approaches, including analytical models of statistical physics based on the



Polymer macromolecules with azobenzene chromophores (moieties with two aromatic rings) in side chains.

MATERIAL THEORY AND MODELLING (MTM) GROUP

OBJECTIVE

To develop an understanding of functional polymer materials that is orientated around practical applications.

KEY COLLABORATORS

Professor Svetlana Santer, University Potsdam, Germany

Professor Jaroslav Ilnytskyi, Institute for Condensed Matter Physics, Ukraine

Dr -Ing habil Markus Kästner, Technische Universität Dresden, Germany

FUNDING

German Research Foundation (DFG)

CONTACT

PD Dr habil Marina Grenzer

Institute Theory of Polymers
Leibniz Institute of Polymer Research Dresden
Hohe Str 6, 01069 Dresden, Germany

T +49 351 4658 597
E grenzer@ipfdd.de

http://www.ipfdd.de/2749.0.html

PD DR HABIL MARINA GRENZER graduated from St Petersburg State University (SPBU). In 1995, she received her PhD from the Institute of Macromolecular Compounds St Petersburg, IMC, and completed her habilitation in 2007 at the University of Potsdam. She currently leads the MTM group at IPF and is Associate Professor at TU Dresden.

OLGA GUSKOVA received her PhD from Ulm University, Germany, in 2008. She was a postdoc at the Max-Planck Institute of Colloids and Interfaces, Potsdam, Germany. In 2011, she joined IPF as research associate and, since 2015, has been a Junior Group Leader of Material Properties of Semi-Conducting Polymers.

DR VLADIMIR TOSHCHEVIKOV received his Master Degree in physics from SPBU in 1998 and, in 2002, defended his PhD thesis at IMC. At IMC, he had a longstanding collaboration with the Physical Institute, University of Freiburg, Germany. Presently he is research associate at IPF.

analysis of free energy and the dynamic Langevin equation," explains Grenzer. "We also take quantum chemical approaches and particle-based computer simulation techniques, like coarse-grained and full-atomistic molecular dynamics." The team's unique combination of expertise across the theoretical materials science field enables them to understand the structure and dynamics of field controllable materials on different time and length scales. "It is similar to making a film about the Black Forest," she says. "You need to use quite a number of different magnifiers to admire the forest in all its complexity. Similarly, we construct a multiscale picture of a particular field controllable material from representations of the material structure and physical processes taken across different scales."

Importantly, the multiscale approach developed by the team provides a deep understanding of the molecular processes and their relation with macro-properties of functional materials. The high predictive power of the team's multiscale approach can be used to guide the manufacturing of field controllable polymer materials for target practical applications.

MANY PARTS MAKE LIGHT WORK

Throughout the course of their studies, the team has developed further understanding of several field controllable polymers. Azobenzene-based hybrid materials have unique physical properties, can change their shape under illumination, and have been the subject of intense study for a number of years. The MTM group has developed an analytical theory to describe the photomechanical properties of these azobenzene polymers as a function of their chemical architecture. "The established structure-property relationships can be used by engineers of specific photo-deformable materials for specific applications," explains Toshchevikov.

ELASTIC POLYMER AND MAGNETIC PARTICLES: A PERFECT MARRIAGE

Another notable achievement of the MTM group is their work on magneto-sensitive elastomers (MSEs). These polymers are able to change their shape and mechanical behaviour under external magnetic fields. The team's unique theoretical approach not only describes the deformation and static moduli of MSEs, but also the dynamic moduli of these materials. As it stands, there are no other theoretical works to describe the field controllable dynamic moduli of MSEs. "The dynamic moduli characterise mechanical response of materials on oscillating mechanical stress and are important characteristics for design of elements affected by external oscillating loadings in practical applications," explains Ivaneyko. The approach the team has developed is particularly useful for those in the automobile industry who produce materials with field controllable stiffness for movable elements.

POLYMER HYBRIDS FOR AN ELECTRONIC WORLD

In today's world, in which every aspect of life is impacted by electronic technology, the development of required materials begins with computational design. New chemical structures, component combinations, and even the morphology of working units of devices like smartphone displays (based on polymer light-emitting diodes), photovoltaic cells and polymer field effect transistors can be predicted theoretically. "For instance, our simulations shed light on the controlled self-assembly of organic electronic molecules into arranged carpets at different interfaces, whose structure finally defines the performance of handheld or household gadgets," explains Guskova.

PERSPECTIVES: A LEAP FROM THEORY TO MANUFACTURING

The work of the MTM team is increasingly necessary to effectively guide the manufacturing of functional polymer materials with tailored properties. Their advanced research into field controllable hybrids gains rapidly in importance; as the structure of these fascinating materials can be smartly manipulated to perform a near-limitless amount of functions. This boasts huge potential for incorporating theoretical studies into the development of new products for a diverse range of practical applications.

There is a natural process to the research of the MTM team; their findings must take a leap from the theory and modelling stage through to manufacturing. As such, the members of MTM are keen to work with R&D professionals around the world to make the best use of their work on field controllable polymer hybrids. Similar to how there are multiple components to a successful marriage, the manufacturing of beneficial polymer hybrids will not be realised without the cooperation of partners from across academia and industry. The MTM team believes that one important component of this 'acting together' is a theoretical prediction of a field controlled response.

Organic electronic carpet on graphite solid surface

RESEARCHER PROFILE

A NEW BIOLOGICAL PESTICIDE FOR AGRICULTURE

SVEIN LILLEENGEN

RESEARCH GOALS

Farmers and gardeners in Europe, the US and Russia have a problem, and its name is *Delia radicum* – commonly known as the cabbage fly. *D. radicum* is a seemingly innocuous little insect similar in appearance to the common house fly. Unlike its domestic relative, however, it has an insatiable appetite for plants in the genus *Brassica*, including cauliflower, broccoli, cabbage and rutabaga. The fly lays its eggs in close proximity to these plants and, when they hatch, the larvae migrate to the roots of the vegetables to feed and grow for around three weeks before pupating. The process destroys these often economically valuable plants, with gardeners and farmers losing more than half of their *Brassica* crops this way if left untreated.

Agricultural researcher Svein Lilleengen has witnessed this problem firsthand. With more than 30 years of experience as a farmer, much of which has been spent collaborating with others in the industry, he has gained an insight into the impact of *D. radicum* and the most popular ways to negate it. Organic farmers use various kinds of nets to keep the flies away, a labour-intensive and costly solution that is not always effective. Conventional farmers, on the other hand, use pesticides – but because of concerns over food safety, there is currently no pesticide fully approved for use on these farms in Scandinavia. The negative health effects of these endocrine-disrupting chemicals are estimated to cost over €150 billion a year in Europe. "New ways of protecting the crops without harming the environment or people's health had to be developed," Lilleengen explains.

METHOD

Lilleengen's research career began in the 1990s. At that time, he began to run a biogas plant to look for ways of using the resultant fibrous byproducts. In 1991, he patented the Bioskiva – a disc, 12 cm in diameter, made from the fibrous remnants of cow dung. The Bioskiva was designed to be placed around the stalk of the Brassica plant, preventing weeds from growing up in close proximity to the crop. This invention was soon followed, in 2002, by an odourless, pelletised fertiliser derived, similarly, from cow manure.

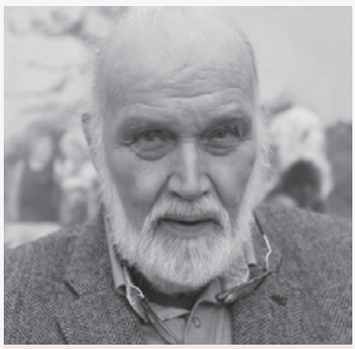
FertiBug, successfully patented in 2014 based on research funded by the EU´s Seventh Framework Programme (FP7), is the most innovative of Lilleengen's environmentally friendly inventions. Designed to repel cabbage flies without killing them or using toxic chemicals, FertiBug combines solid fertiliser based on the fibrous byproducts of biogas production with a certain algae that the flies cannot stand – resulting in a product that nourishes *Brassica* plants at the same time as protecting them. "The very first inspiration was an academic article saying algae could be used much more in agriculture," the Norwegian farmer recalls.

IMPACT

FertiBug has already attracted attention from the public at large. Lilleengen has been approached by newspapers and broadcasters from around the world – to date, he has taken part in five TV programmes in Norway, one in Spain and one in the UK. He has also been visited by the Norwegian Government's Committee for Energy and the Environment, and invited to tea by Harald V – the king of Norway.

The efficacy of FertiBug as a product has also been dramatic. Greenhouse tests of the repellent-cum-fertiliser showed that it discouraged around seven in every 10 flies from laying their eggs on plants to which it had been applied, but field trials in Spain and Hungary conducted in 2011 were even more positive, demonstrating a 100 per cent repellent effect. Consequently, Spanish crops of Savoy cabbage saw a 50 per cent increase in yield per hectare, and the Hungarian fields were between 20 and 80 per cent more productive.

These statistics back up the attributes that make FertiBug so appealing to farmers; quite simply, it is sustainably produced, environmentally friendly and very effective. As one of the farmers involved in Lilleengen's tests remarked: "I've never had a crop of cabbages so beautiful as the plot treated with FertiBug pellets". New EU rules coming into effect in the coming years will ban the use of around 20 different pesticides – and the arrival of FertiBug on the market will no doubt have a big impact. Always ready to add to the product's green credentials, Lilleengen plans to produce only the algae for FertiBug on site at Bioskiva AS; the raw materials, he says, will be sourced at biogasplants for local use in Europe, reducing emissions and improving sustainability.



CONTACT

Svein Lilleengen
Agricultural researcher

Bioskiva AS
Vestråtveien 161
7140 Opphaug
Norway

T +47 915 151 07
E svein@bioskiva.no

www.fertibug.eu

SVEIN LILLEENGEN has been a farmer in organic, dairy and vegetables for the past 30 years. His research career began in the 1990s upon developing Bioskiva, a disc that prevents weeds from growing close to *Brassica* plants. This disc was awarded a patent in 1991, and Lilleengen subsequently went on to establish Bioskiva AS in 1997. He has also worked within electronics and marketing for 12 years and completed three years of Engineering studies at the Malmø Tekniska Institute.

Fertibug

Organic insect repellent

The hugely inspiring nature of nature

Dr Tak-Sing Wong heads a team investigating a range of plants and animals to aid the development of technologies with broad industrial and medical applications

Your work at The Pennsylvania State University focuses on how droplets of liquid move and how this can be applied to industry. What initially drew you to this area of study?

Water droplets are commonly found in our natural environments, from rain droplets to fog and cloud formations. Understanding the interactions between water droplets and engineering surfaces has a wide range of applications for many industrial processes and applications, including heat transfer condensation, fog harvesting, water desalination, anti-icing and anti-frosting.

Because of these important applications, my group is interested in developing engineering surfaces that can facilitate droplet movement under a variety of environmental conditions. One effective way of doing this is to study nature to understand how natural surfaces can manipulate tiny water droplets, as these surfaces are perfectly evolved to deal with water in their everyday lives.

In lay terms, can you introduce the difference between liquid drops when they are in their Cassie and Wenzel states? Is it true that droplets in their Wenzel state cannot be mobile?

A droplet sitting on a rough surface is said to be in the Cassie state when the droplet is sitting on the tips of the surface textures with a thin layer of air trapped in between the textures. A droplet is said to be in the Wenzel state when the droplet completely impregnates into the surface textures. For over a decade, Wenzel-state droplets have been known to be immobile on rough surfaces.

Often, your work takes inspiration from natural phenomena. Could you explain some particular types you are looking at and the discoveries you have made so far?

We are interested in a broad range of natural phenomena. Over the past few years, we have become very interested in the multifunctional nature of various biological surfaces, including lotus leaves, pitcher plants, butterflies, the Tokay gecko and cuttlefish. The discoveries that I am most excited about are the development of slippery liquid infused porous surfaces (SLIPS) and slippery rough surfaces (SRS). SLIPS is a highly slippery surface modelled after the slick rim of the Nepenthes pitcher plant and SRS is a cross-species material that is modelled after the unique surface architectures of the pitcher plant and lotus leaves.

You are working on materials capable of repelling water and dirt on rough surfaces. To which industries could this be beneficial and can you describe in what ways?

There are many industries that need to deal with unwanted liquid-surface interactions on a daily basis, including – but not limited to – energy, water, aerospace, automotive, marine and medical industries. For example, surfaces that prevent super-cooled water droplets to condense on them in the first place will prevent the formation of both frost and ice, which are of extreme importance for both the aerospace and automotive industries. Furthermore, surfaces that can prevent fouling from marine creatures, such as barnacles on a ship's hull, will reduce the surface drag, and thereby greatly lower the fuel consumption needed to propel the ship across the ocean.

What impact do you see your research having for scientific studies related to wetting, nucleation and transport phenomena?

This is the first time we have been able to engineer a rough surface that can significantly reduce the pinning of droplets, regardless of how these droplets wet the surface. This surface will allow us to validate some of the

In 2012, Wong received the R&D 100 Award from *R&D Magazine* for his invention of SLIPS. The annual awards are only given to the 100 most technologically significant products of the previous year. And, in 2014, Wong was named as one of the world's top 35 Innovators Under 35 by *MIT Technology Review*

classical relationships in wetting and transport phenomena at the highest precision, something that has not been previously achievable using conventional rough surfaces.

Finally, how would you like to see your research advance in the future?

Our group will continue to explore the novel industrial and medical applications of SLIPS and SRS. Our ultimate goal is to solve the 'sticky' problems that occur in daily life. In addition, we are interested in developing new classes of bioinspired materials with unusual properties, in order to solve the key challenges in water, energy, health and sustainability applications.

Engineering an escape from sticky situations

The Pennsylvania State University is home to a laboratory that is interested in translating the inspirations it finds in nature into technological applications. The researchers' findings benefit deeper scientific understanding and have the potential to improve all of our lives

THE ENGLISH ROMANTIC poet William Wordsworth once penned a verse that said "Come forth into the light of things / Let nature be your teacher". The notion that nature is something that can teach us important things is not merely one that benefits the scribe; time and again the fields of science and engineering have made use of certain principles found in nature.

As far back as the 15th Century, Leonardo da Vinci studied birds to aid the development of his plans for a 'flying machine'; the Eastgate Shopping Center in Zimbabwe was developed by an architect who studied the structure of termite mounds to help facilitate energy savings. Engineers have incorporated the structural design of trees and bones into software design programmes, and researchers in Japan have developed a less painful needle that was based on a mosquito's proboscis.

FINDING INNOVATIONS IN THE NATURAL WORLD

Now, a team of researchers from the Department of Mechanical and Nuclear Engineering at The Pennsylvania State University is investigating various life forms found in nature to help translate their incredible abilities into technological innovations. With a specific focus on utilising biologically inspired concepts to design functional and adaptive interfacial materials, the team's ultimate goal is to improve the quality of human life.

The team is led by Dr Tak-Sing Wong, who has established a laboratory called the Laboratory for Nature Inspired Engineering. The researchers are composed of scientists and engineers who provide solutions to critical engineering challenges that have been brought about through inspiration provided by nature. One of their specific focuses is on designing and developing super liquid-repellent surfaces that could have significant benefits for a wide range of industries related to energy, water and health.

THE SCIENCE AND ENGINEERING OF PLANTS

One of their recent developments is Slippery Liquid-Infused Porous Surfaces (SLIPS), which was modelled on the carnivorous Nepenthes pitcher plant. Insects are attracted to the plant by its smell, but when they try to land or walk on it they find it impossible to get a grip and so slide into the throat of the plant, where they are consumed by the plant's digestive juices.

Inspired by the slippery surface of the pitcher plant, Wong and his former colleagues at Harvard University have created a novel coating that is capable of repelling almost every type of liquid and solid, including blood, crude oil

and ice. "SLIPS exhibits many features that outperform state-of-the-art liquid-repellent materials, such as negligible adhesion when in contact with various pure liquids, rapid and repeatable self-healing, extreme pressure stability, low adhesion to ice, insects, bacterial biofilms and synthetic adhesives," explains Wong.

Inspired by the slippery surface of the pitcher plant, Wong and his team have created a novel coating that is capable of repelling almost every type of liquid and solid

Because of the material's abundance of exceptional properties, the SLIPS technology can be developed into a wide range of applications in areas such as energy, biomedicine and beyond. "For example, super water-repellent coatings will allow the heat exchanger to run more efficiently by rapidly removing the condensed water droplets," Wong shares. "Moreover, anti-fouling coatings on medical devices such as catheters and implants will be extremely important for their normal operations – something that is necessary for maximising the patients' safety during medical procedures."

Fascinatingly, SLIPS boasts another curious property – it is able to repair itself, so that when the porous, solid material contained within SLIPS becomes damaged, the lubricant fills in the gaps created by the damage, restoring its function as a self-lubricating and self-cleaning material.

CROSS-SPECIES INSPIRATION OF LOTUS LEAVES AND PITCHER PLANTS

The lotus effect has been observed for centuries; the Bhagavad Gita – a 700-verse Hindu scripture written in Sanskrit – refers to the self-cleaning phenomenon of the lotus flower, the plant from which the effect was named.

Specifically, the lotus effect refers to the process by which lotus leaves are able to emerge from muddy water and be clean. Research into this phenomenon, which was first conducted in 1964 using rough hydrophobic surfaces, revealed that the leaves' ability was the result of extremely high water repellence, also known as superhydrophobicity. However, it was not until 1997 that the term 'lotus effect' was first coined.

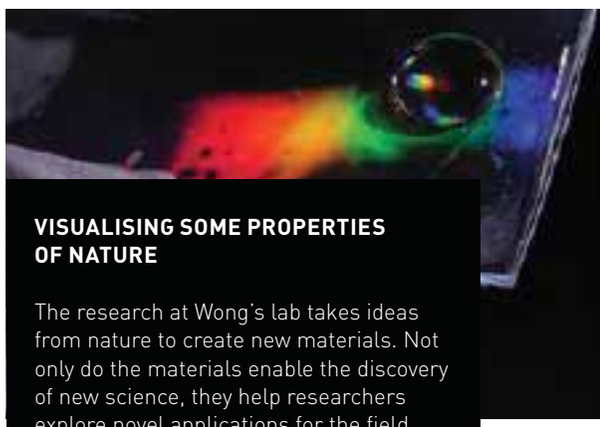
Inspired by the relevant properties of lotus leaves and pitcher plants, Wong and his team have developed a synthetic liquid-repellent surface that they have named slippery rough surfaces (SRS). SRS combines these plants' unique surface architectures in such a way that the surfaces possess both high surface area and a slippery interface. This has the effect of enhancing droplet collection and mobility. "We achieve this by etching micrometre scale pillars into a silicon surface and then creating nanoscale textures on the pillars," explains Wong. "This is followed by infusing the nanostructures with a thin layer of lubricant." Ultimately, this process ensures that the microtextured surface has a conformal lubrication, thereby significantly reducing the pinning of droplets, irrespective of their state of wetness.

The importance of Wong and his team's developments lies in their potential applications for improving understanding. For, although it is known that there is a relationship between the wetness of a material and its transporting properties, SRS will facilitate studies at a precision previously unachievable.

LIFE IMITATING LIFE

Nature refers to an extremely broad realm of natural, physical and material 'things' that we can – and often cannot – see all around us. While nature has often proved the inspiration for Romantic poets such as Wordsworth and Coleridge, it has clearly inspired the research activities of Wong and his team.

It was Oscar Wilde who first asserted the philosophical position that 'life imitates art', but Wong and his team have asserted that science and engineering can imitate nature to improve the lives of all. In this way, life imitates life, creating huge potential for a wide range of industrial applications of significant benefit to life in general.



VISUALISING SOME PROPERTIES OF NATURE

The research at Wong's lab takes ideas from nature to create new materials. Not only do the materials enable the discovery of new science, they help researchers explore novel applications for the field of engineering.

It is one thing to describe nature and its abilities, but another to see it for yourself. With that in mind, here are three videos that demonstrate what Wong and his team have been able to demonstrate:

http://bit.ly/InnovatorsUnder35

www.youtube.com/watch?v=4b-3o6eWE1s

www.youtube.com/watch?v=XA01wKQ6WuA

LABORATORY FOR NATURE INSPIRED ENGINEERING

OBJECTIVES

- To translate concepts from nature into technological innovations, with the goal to improve the quality of human life
- To utilise biologically inspired concepts to design functional and adaptive interfacial materials that not only augment the capabilities of humans to interact with their environments, but will also allow for a broad range of applications related to energy, water, and health – three important elements for sustainability

KEY COLLABORATORS

Professor Joanna Aizenberg, Harvard University, USA • **Professor Alexander Smits**, Princeton University, USA

FUNDING

National Science Foundation (NSF) • Defense Advanced Research Projects Agency (DARPA) • Office of Naval Research (ONR) • Advanced Research Projects Agency – Energy (ARPA-E) • PPG Industries

CONTACT

Dr Tak-Sing Wong
Leader of the Laboratory for Nature Inspired Engineering

Department of Mechanical and Nuclear Engineering
Materials Research Institute
The Pennsylvania State University
University Park, Pennsylvania 16802
USA

T +1 814 865 6122
E tswong@psu.edu

http://bit.ly/WongLab

www.mne.psu.edu/wong

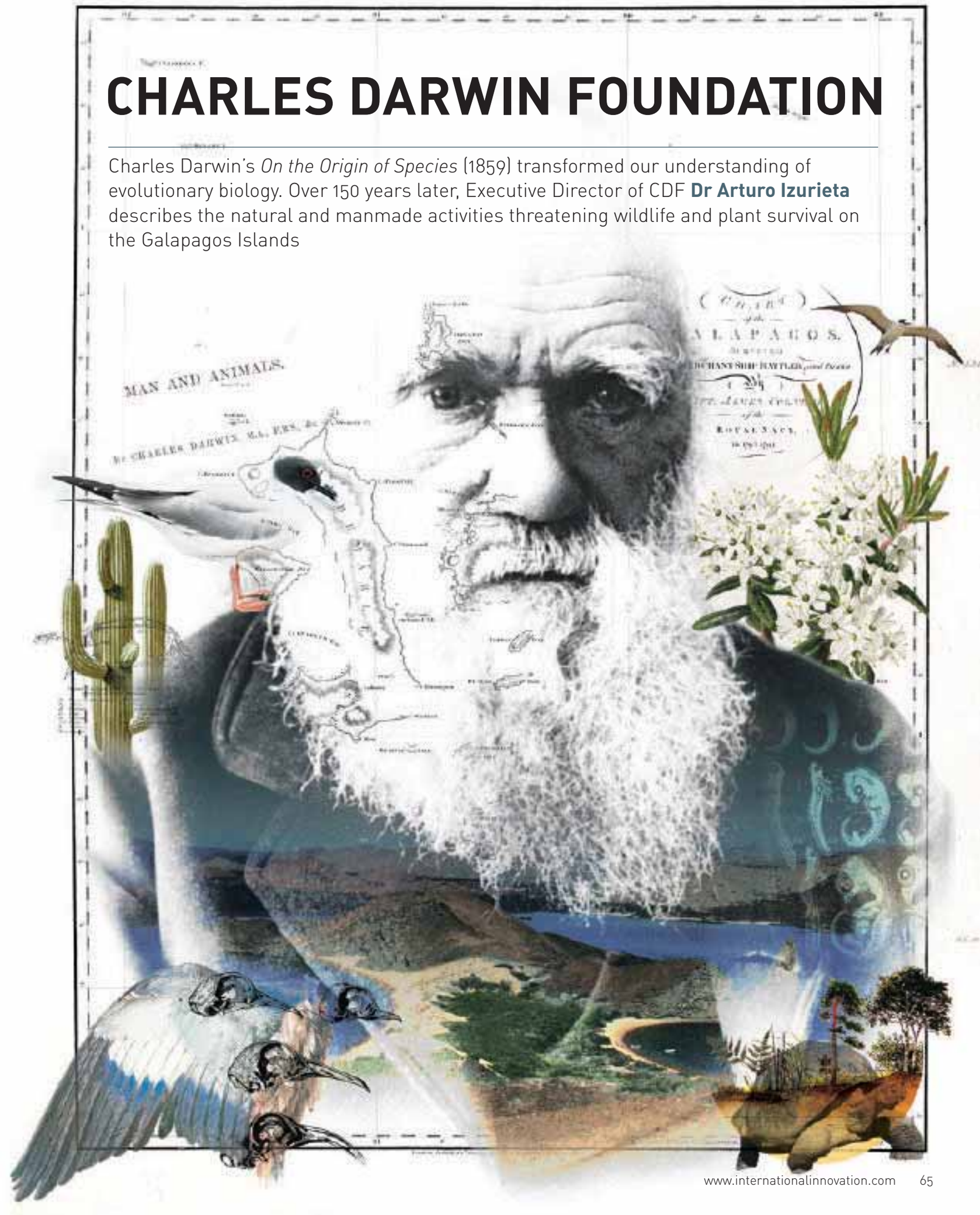
http://bit.ly/TakSingWong_LI

https://twitter.com/taksingwong

DR TAK-SING WONG is currently an Assistant Professor and the holder of a Wormley Family Early Career Professorship in the Department of Mechanical and Nuclear Engineering at The Pennsylvania State University. Wong conducted his postdoctoral research at the Wyss Institute for Biologically Inspired Engineering at Harvard University from 2010-12. He received his PhD degree in the Mechanical and Aerospace Engineering Department at University of California, Los Angeles (ULCA) in 2009, following his BEng degree in Automation and Computer-Aided Engineering from The Chinese University of Hong Kong. Wong's research focuses on micro/nanoengineering, interfacial phenomena and biologically inspired engineering with applications in materials science, water, health and energy.

CHARLES DARWIN FOUNDATION

Charles Darwin's *On the Origin of Species* (1859) transformed our understanding of evolutionary biology. Over 150 years later, Executive Director of CDF **Dr Arturo Izurieta** describes the natural and manmade activities threatening wildlife and plant survival on the Galapagos Islands



THE GALAPAGOS ISLANDS are one of the best preserved island ecosystems in the world. The observations Charles Darwin made when he visited the Islands in 1835 can still be seen and have been studied further by hundreds of scientists around the world. Gaining an understanding of the biological and ecological processes in place has helped Ecuador to implement environmental conservation strategies and policies for the future of the Galapagos.

The Charles Darwin Foundation (CDF) embodies the work and magnificence of Charles Darwin through the generation and sharing of knowledge with the Ecuadorian authorities, local community and institutions around the world.

WILDLIFE ADAPTATION

In the past 50 years, the Galapagos wildlife has had to adapt to changing conditions – the two main drivers of which are natural and anthropogenic. Natural phenomena such al El Niño and La Niña events and, more recently, tsunamis, solar incidences and the natural arrival of species, play a key role in selecting the most adaptable species or individuals on the Islands.

Even though we still have pristine places where natural processes can be studied, enabling us to understand how nature works, the anthropogenic effects on the wildlife are the ones taking up most of our attention nowadays. Human activities since the discovery of the Galapagos in 1535 have increased in various ways, particularly in the past century, when formal colonisation took place.

The introduction of species by man has been the most damaging factor to the fragile and unique Galapagos ecosystems. Competition of invasive species with native and endemic species (plants and animals) has created serious alterations in ecosystem and species composition. These changes have affected the populations and habitat of giant tortoises, land iguanas, Galapagos petrels, endemic *Miconia* (brown tree), and *Scalesia* forests (lechoso or giant sunflower tree). The involuntary introduction of plagues such as the fly *Philornis downsi*, are generating serious threats to the survival of various iconic land birds such as the Darwin finches as the larvae feed on the blood of the recently hatched birds, causing 100 per cent mortality.

NEW AND EXPANDING SPECIES

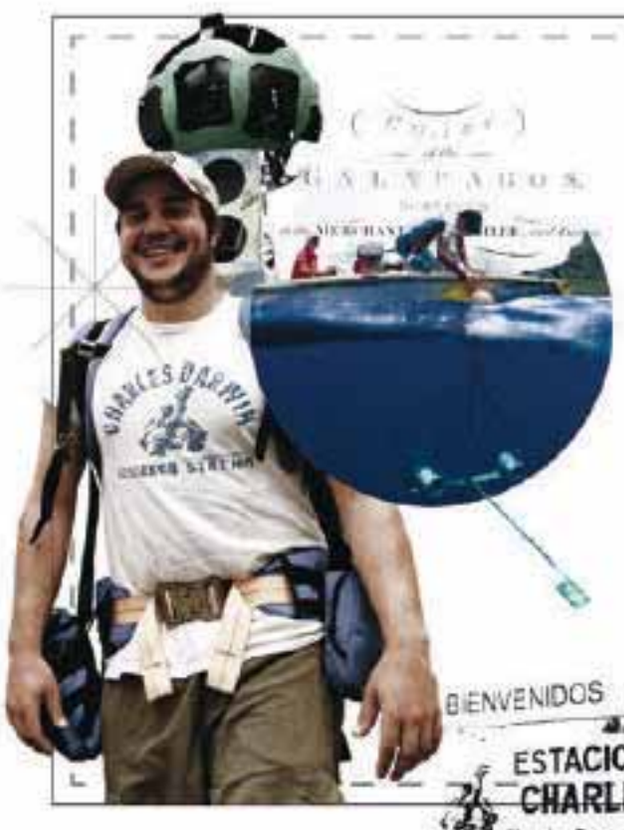
At CDF, we consider the expansion of existing and the arrival of newly introduced species as the greatest threat to the Galapagos ecosystems, both terrestrial and marine. We are continuously monitoring new arrivals of foreign species and studying those that have managed to establish themselves in order to advise the authorities on how to control them and implement management actions. Our goal is to assure the survival of those endemic species and contribute to the stability of Galapagos natural ecosystems.

The arrival of these alien species is directly connected with human activities that sustain a current population of around 28,000 inhabitants, with tourism being the main indirect culprit. Although the Ecuadorian Government has improved its quarantine and biosecurity mechanisms, there are serious limitations, both technical and institutional, for the prevention of such introductions – putting Galapagos at risk on a daily basis.

GALAPAGOS AND BEYOND

Our concerns, however, extend beyond the Galapagos, which is why we work internationally. The Charles Darwin Research Station has hosted scientists from all over the world. This means that CDF is connected with one of the greatest scientific networks, contributing to the global understanding about how nature works and how conservation management can be applied or adapted to other parts of the world.

We are part of international efforts to protect and sustainably manage island systems around the planet. We hosted the International Workshop on Island Sustainability in 2010, which provided us (and international experts), with insights on the difficulties and actions needed to maintain natural and human associations in a sustainable way, and in the context of an increasingly globalised economy and technology. CDF has already inserted in its mission the aspect of contributing internationally by generating alliances with regional conservation initiatives such as the Tropical Eastern Pacific Marine Corridor where four Natural World Heritage Sites are present (Cocos, Malpelo, Coiba and the Galapagos).

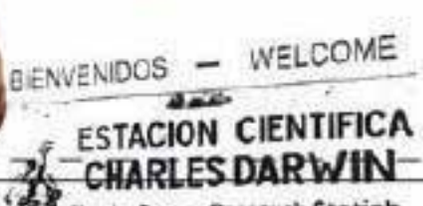


VOLUNTEERING AND SCHOLARSHIPS

The volunteer programme offers the opportunity for individuals to be involved in a variety of projects and experience how our scientists work in extreme and difficult conditions for a great cause. They get what they came for and more! Being in the field or working in our labs or facilities contribute to their professional and personal growth.

The Foundation has provided scholarships and has formed more than 2,000 Ecuadorian professionals, some of whom are now in high-level positions in the Government or environmental and conservation organisations. I am one of them, and I am thankful to CDF for having provided me with such an opportunity. It never crossed my mind that I was going to be directing such an amazing organisation 25 years later!

To know more about CDF and contribute to its work please visit:
www.darwinfoundation.org/en/get-involved/donate



PLANTS

The Galapagos Verde 2050 project has managed to restore the growth of endemic and native plants in islands severely affected by man, such as the Island of Baltra, as well as by rats such as the Island of South Plaza, where an important population of endemic land iguanas live.

Another important innovative study shows that quinine (*Cinchona pubescens*), an invasive plant for the Galapagos but in danger of extinction in the mainland, is enriching the Galapagos soils with phosphorus. This is the first example worldwide of an invasive species enriching the soil with this nutrient.

TECHNOLOGY

There were also some technological gains in 2015 that are proving valuable for research in the Galapagos. The land bird team at CDF helped to launch the application BirdEye Galapagos, which has information about the different birds on the Islands. We expect this will help people record their bird sightings in the 'e-bird', which in turn will increase the data that can be analysed for the protection of the Galapagos birds.

Through our scientific and academic networks we have been able to advance in other technological areas, such as through the donation of high-resolution satellite images of all the inhabited islands. This will be used to better understand the distribution of invasive species.

WORKSHOPS

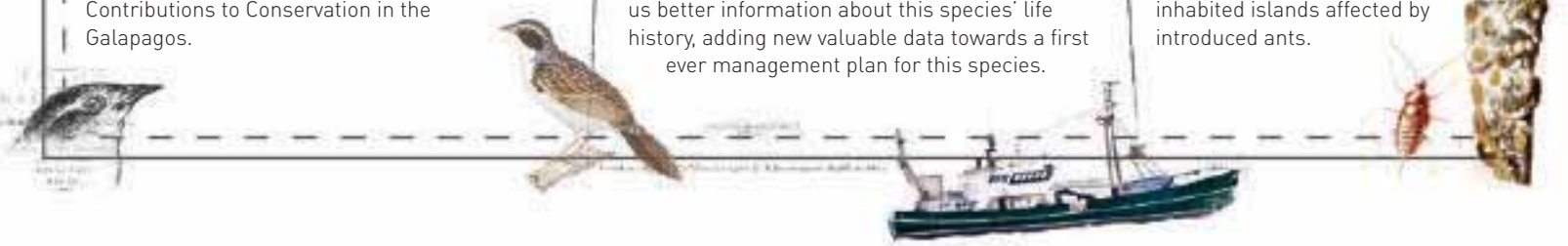
Working with the Ecuadorian Ministry of Environment and the Galapagos Government Council, CDF was key to the organisation of three important international workshops: 1) searching solutions to control the parasitic fly, *Philornis downsi* in the Galapagos; 2) development of the Action Plan 2016-2020 for the Conservation of Critically Endangered Mangrove Finch; and 3) development of the Action Plan for Wildlife Health Contributions to Conservation in the Galapagos.

MARINE BIOLOGY

The CDF marine biology team has worked on the research ship *Nautilus* investigating the unexplored deep waters of the Galapagos. During these studies, they discovered a cat shark that had not been documented before. Together with our collaborators, we recently presented results of their research on the commercially exploited Galapagos sailfin grouper (*Mycteroperca olfax*), which has given us better information about this species' life history, adding new valuable data towards a first ever management plan for this species.

INSECTS

A recent study shows the dominance of invasive ant species compared to native and endemic species, which can help us understand and better manage areas within the agricultural zones of inhabited islands affected by introduced ants.



INVASIVE SPECIES, SUSTAINABILITY AND CONSERVATION MANAGEMENT

Concerning invasive species, we have three different project areas that will continue this year and beyond. The priorities found in a recent 2015 workshop on the introduced fly *Philornis downsi* will be used to find ways of controlling it. Similarly, in early 2015, CDF hosted the International Workshop on Marine Invasive Species. As a result, this year, in collaboration with local authorities and stakeholders, the Foundation will make an action plan to prevent the arrival of non-native marine species. This year, we expect that our scientists at CDF will have the ability to use high-resolution satellite images to understand the distribution of invasive species plants better.

With regard to sustainability, we have three projects that will continue this year to address this complex system: 1) research on the management and sustainability of commercial fisheries such as the Galapagos grouper; 2) a study of submarine seamounts focusing on species dynamics and local and regional connectivity; and 3) the ecosystem restoration Galapagos Verde 2050 project looking into efficient ways to restore degraded terrestrial areas both inside and outside the protected areas space. Hundreds of hectares where native and endemic species are repopulating have benefited from our project, allowing for various associated native species of fauna and flora to regenerate as viable ecosystems.

In the conservation area, CDF has been leading research and advice on the conservation and management of the already fragile and reduced population of the mangrove finch (*Camarhynchus heliobates*), including the generation of the Mangrove Finch Management Plans 2011-2015 and 2016-2020. By the end of 2016, we will have an estimate of the populations of other small land bird groups living in the highlands of inhabited islands, such as yellow warblers, vermillion flycatchers, Galapagos flycatchers and other species of Darwin finches.

Monitoring of the Galapagos penguin (*Spheniscus mendiculus*), flightless cormorant (*Phalacrocorax harrisi*) and the waved albatross (*Phoebastria irrorata*) will continue in 2016 to understand how the species can be better protected. Long-term research on the populations and use of habitats by sharks and rays will be important to determine their distribution and connectivity along the East Tropical Pacific Marine Corridor (CMAR) and improve the regional conservation efforts between Ecuador, Colombia, Panama and Costa Rica.

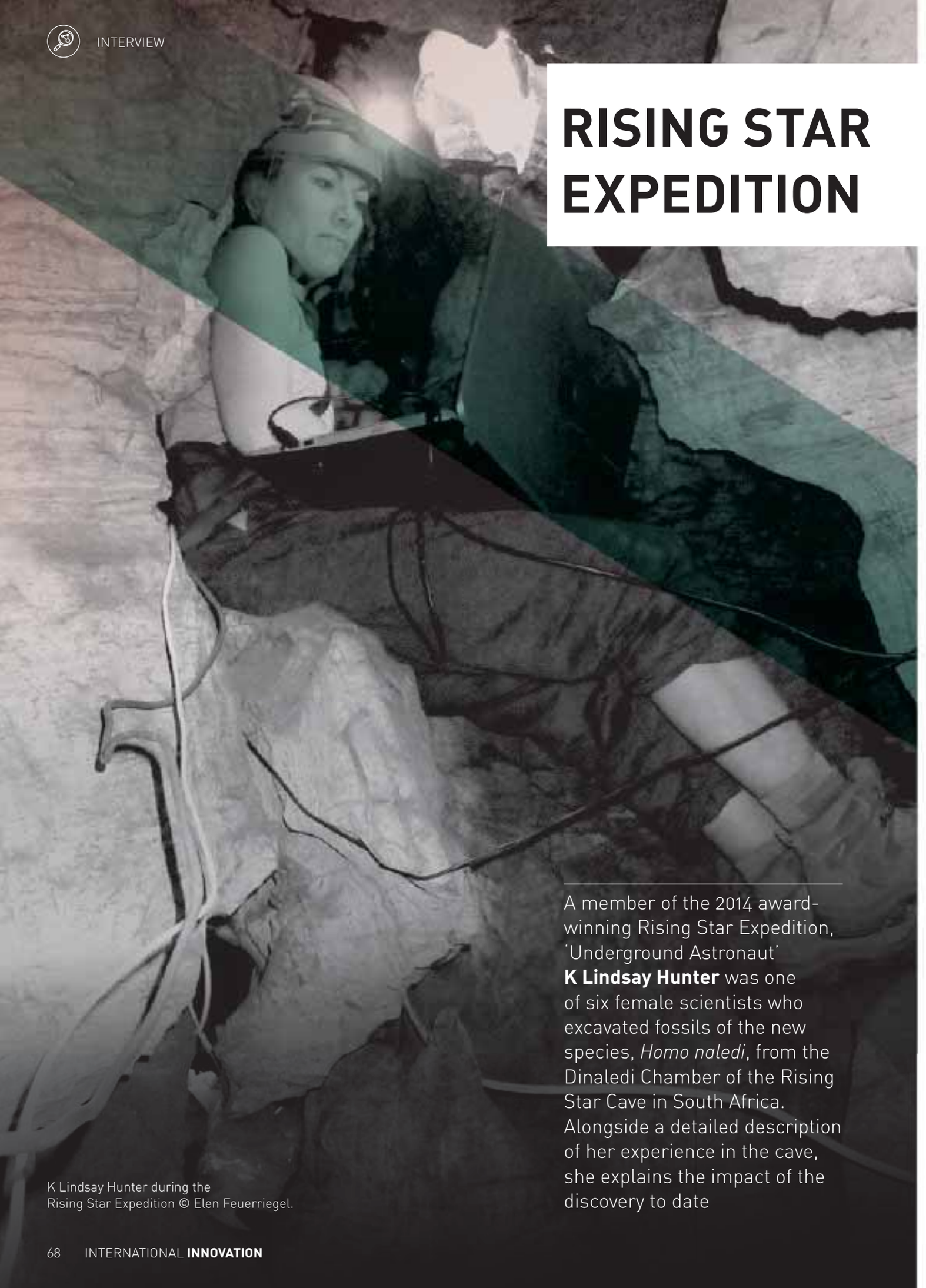
PRESERVING THE ISLANDS

The Galapagos must be preserved as one of the most pristine natural laboratories on Earth. It will depend on how the individuals that live on the islands find the balance between conservation of the natural capital and the sustainability of their ways of living. The international commitment of the Ecuadorian Government as signatory of the UN's World Heritage Convention offers hope for a better future for the Galapagos in this globalised world. We certainly need the international community to help us achieve this goal.

www.darwinfoundation.org

fundación Charles Darwin foundation

RISING STAR EXPEDITION



A member of the 2014 award-winning Rising Star Expedition, 'Underground Astronaut' **K Lindsay Hunter** was one of six female scientists who excavated fossils of the new species, *Homo naledi*, from the Dinaledi Chamber of the Rising Star Cave in South Africa. Alongside a detailed description of her experience in the cave, she explains the impact of the discovery to date

K Lindsay Hunter during the Rising Star Expedition © Elen Feuerriegel.

Congratulations! The discovery of *Homo naledi* is altering our understanding of human ancestry. What can you say, more specifically, about the significance of these findings?

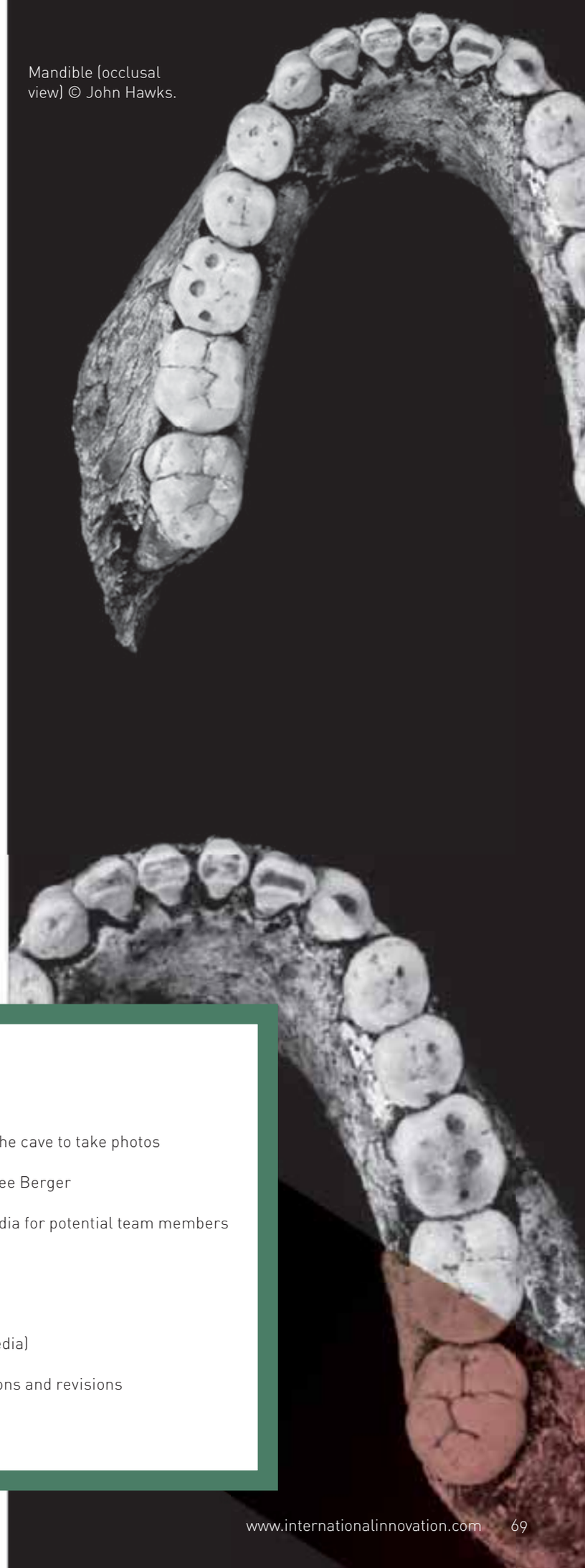
Homo naledi (along with *Homo floresiensis* and the existence of the Denisovans) helps illustrate the diversity of evolutionary experiments our lineage is and was subject to, exposing the hubris of human exceptionalism. Our sole existence at this point in history may be nothing more than a quirk of fate, rather than the steady march of progress even scientists have difficulty thinking past. Rather than abandoning us to nihilism and removing meaning from our existence, it reaffirms our connectedness with the rest of life on this planet. This gives us the opportunity to reassess what we feel sets us apart and be truly exceptional; to actively choose greatness rather than to feel entitled through separate creation or as the winners of some bloody competition. Evolution has meandered and drifted its path one way, but our lives are what we make of them.

What initial conclusions can be drawn from the contrast between the ape- and human-like body parts identified within each skeleton?

The mosaic features (both 'ancestral' and derived features – known technically as plesiomorphies or apomorphies) help us to relatively date the lineage to somewhere in the 2-2.5 million year realm. The uniqueness of this patterning, which is repeated in each of the individuals, instructs us that we are most likely looking at a previously unknown species, hence the designation, *Homo naledi*. The curious morphology of the hands, shoulder and trunk, juxtaposed with relatively long, modern legs and modern feet, indicate both climbing ability on the one hand (perhaps, a more ancestral retention) and long-distance walking on the other – a more derived trait. The coexistence of these two adaptations complicates our view of the behaviour of early *Homo*.

One remarkable finding was that *Homo naledi* deliberately disposed of the dead in a similar manner to human burials. How was this determined? To what extent is this changing the way scientists interpret our ancestors' rituals?

The working hypothesis that *Homo naledi* apparently disposed of its dead in a deliberate manner within the Dinaledi Chamber was reached only after an extensive process of elimination, taking into consideration locally unique features such as deposition in loose, geochemically isolated soil and lack of other contemporary vertebrate fossils. Various depositional scenarios were evaluated in what was deemed reverse order of likelihood: occupation, water transport, predator accumulation,



Mandible (occlusal view) © John Hawks.

A BRIEF *HOMO NALEDI* DISCOVERY TIMELINE

13 SEPTEMBER 2013 – Discovery of fossils

24 SEPTEMBER 2013 – Rick Hunter and Steven Tucker returned to the cave to take photos

1 OCTOBER 2013 – Pedro Boshoff showed the photos to Professor Lee Berger

6 OCTOBER 2013 – Professor Lee Berger posted a call on social media for potential team members

5-26 NOVEMBER 2013 – The initial expedition

MARCH 2015 – The 10-day excavation

MAY 2015 – The Rising Star Workshop (also publicised via social media)

MAY 2015-PRESENT – Analysis, manuscript preparation, submissions and revisions

10 SEPTEMBER 2015 – Announcement of new species discovery

mass fatality or death trap and, finally, deliberate disposal. Each of these schemes was scrutinised and rejected in turn with the exception of deliberate disposal.

We cannot know from the material recovered to date what, if anything, was the intention of these hominins in depositing these bodies within the chamber. There are no cultural or ritual items associated with the assemblage and it is currently unclear whether the bodies were placed or simply posted down the entrance chute into the chamber. There are no marks associated with either cannibalism or mortuary practices.

Depending on the date of the assemblage, this could push the date of known intentional burials back before the time of Neandertals, though the small cranial capacity makes this apparently complex behaviour surprising regardless of the age. This may point to a need to reassess just what we are measuring when we look at cranial capacity – is it really a good indication of cognitive functioning?

The Rising Star Expedition researchers, cavers and explorers successfully identified the species by combining academic knowledge with practical skills. How did this interdisciplinary endeavour work in practice? What role did you play?

I was one of the six advance cave scientists, also known popularly as the 'Underground Astronauts'. For this role, we were required to have 'excellent archaeological/palaeontological and excavations skills', 'be skinny and preferably small', 'not be claustrophobic' and 'be willing to work in cramped quarters, have a good attitude and be a team player,' as requested in the social media post calling for participants written by leader of the Rising Star Expedition, Professor Lee Berger from the Evolutionary Studies Institute at the University of the Witwatersrand, South Africa.

The Rising Star Expedition is a perfect example of the whole being greater than the sum of its parts. While each individual member possessed a multitude of complementary skills and talents, this incredible undertaking could not have been accomplished with such alacrity and proficiency, had we not made use of a large and diverse international team. Not only did each person work competently on their own, as needed, they each contributed to a collegial environment that put the pursuit of human knowledge ahead of individual ego.

Can you provide a visual description of the experience?

This is an edited extract from an audio recording I made during the expedition. To listen to the full recording, visit: **http://bit.ly/AccioSkull**

This is my account of the day the skull came out, which was our day eight on site, 15 November [2013]. [...] It was a Friday, or 'accio skull' day; I wish I'd had a Harry Potter wand to bring it out because it was very, very difficult. [...] The extraction of the skull from the fossil chamber itself was epic. Elen [Feuerrigel], Alia [Gurtov], Hannah [Morris] and I were topside when they finally got ready to send up the precious package. We were all crowded in the command centre around the 'Brady Bunch' cam screen [...] and we all jumped to it when Lee Berger gave the go ahead that we were all going to get to go back in – some of us had just showered and were only wearing sandals – to give the skull a proper reception and to safely pass our precious cargo along our perilous route.

COLLECTIVE IMPACT

The Rising Star Expedition emphasises the need for large, collaborative and open science moving forward. Regardless of background, each uniquely skilled and learned individual played a pivotal role in the exploration, discovery, recovery, analysis and dissemination of *Homo naledi* – but had each worked in isolation, we would have only gone so far. Each person was needed in order to function at peak capacity. Gone are the days of the lonely genius working in isolation; all of us are smarter than any one of us.

Funded by the National Geographic Society, the Rising Star Expedition was organised to excavate and study the most abundant early hominin site in Southern Africa, within the Cradle of Humankind World Heritage Site.

The skull itself was packed first in a plastic baggy, as we do with all our fossils – and then, in this case, in a cereal bowl to give it support. [...] Then this was wrapped in pink bubble wrap and put in a plastic Tupperware. [...] The box had to be handed up the chute – the tight 12 metre vertical bit [that was only 18 cm wide]. [...] I was in the middle of Dragon's Back when I felt slightly nauseated as the box passed from [now my husband] Rick [Hunter]'s hand to mine, and I passed it to Becca [Peixotto] with a 'take' – my heart restarted when I heard a 'thank you'. [...] We were all then greeted by Pedro Boshoff, the cave leader, who greeted the skull in Afrikaans saying: 'Welcome, it's time you came home friend'. We all took a moment underground together as the enormity of this, and every moment of this expedition, sunk in. We'd only met one another less than two weeks before. But the advance scientists and the cavers, and everyone in the camp, fit so quickly to become a family.

@Paleo_Bonegirl

http://voices.nationalgeographic.com/blog/rising-star-expedition

Homo naledi hand © John Hawks.

The curious morphology of the hands, shoulder and trunk, juxtaposed with relatively long, modern legs and modern feet, indicate both climbing ability on the one hand and long-distance walking on the other

Fort Jay Governors Island and Lower Manhattan skyline

The world of STEM subjects is your oyster

Engaging students with STEM subjects tends to be quite challenging. However, **The STEM Collaboratory NYC™** at Pace University in the US is providing a practical solution. **Dr Lauren Birney** leads a city-wide collaboration emphasising the benefits of citizen science within restorative ecology to underrepresented students in the New York City Harbor

THE CONCEPT OF citizen science, defined as the engagement with scientific research by members of the public, is providing an opportunity for concerned citizens to actively participate in real, ongoing scientific research efforts within environmental restoration. With the involvement of New York City public schools, students begin to learn about STEM on a practical level while developing skills, such as water quality monitoring data collection and enquiry-based research techniques.

A key benefit of this particular movement is that citizen science has sparked increased awareness regarding the responsibility we all have to engage in scientific discovery. Indeed, the well-documented impact individual actions continue to have on the environment emphasise how we can all play a part in exacting positive change. Thus, encouraging and facilitating widespread participation in environmental restoration through citizen science has the potential to not only benefit the amateur scientists involved and the scientific field within which the research project falls, but also the entire community and surrounding population as a whole. This particular movement focuses upon the ideas surrounding those of smart and connected communities.

RESTORING NOTIONS OF COMMUNITY RESPONSIBILITY

With this in mind, the Billion Oyster Project (BOP), an ecosystem restoration and education project aimed at restoring one billion live oysters to the New York Harbor was launched by Murray Fisher and Peter Malinowski of the New York Harbor Foundation. Over the course of the last 10 years, more than 100,000 schoolchildren have been engaged through restoration-based STEM education programmes and, thus far, have restored over 11 million oysters to the area.

Where oysters once covered more than 220,000 acres of the Hudson River estuary, providing a variety of valuable ecosystem services, the population has since dwindled through overharvesting, dredging and pollution. BOP will reverse these effects, thereby restoring the local marine ecosystem's natural mechanisms for maintaining itself, providing cleaner water and increased biodiversity. Importantly, by acknowledging the benefits of citizen science projects, the team behind the project engages students and the general public, providing them with an increased understanding of and appreciation for the New York Harbor watershed. In planting the seeds of responsibility now, the future success of the New York Harbor can be secured.

ENVIRONMENTAL RESTORATION THROUGH CITIZEN SCIENCE

In acknowledgment of the broader importance of the project, the National Science Foundation (NSF) recently awarded the team responsible a grant of US $5 million, funding that will enable the project to be extended and expanded. Dr Lauren Birney, Assistant Professor of STEM Education and Director/Founder of The STEM Collaboratory NYC™ – a leading STEM education and engagement scheme at Pace University – is principal investigator for the NSF Curriculum and Community Enterprise for Restoration Science (CCE-RS) project. Results so far have demonstrated several positive developments. "Teachers have displayed a stronger interest in teaching enquiry-based lessons through citizen science and environmental restoration," explains Birney. "Students continue to exhibit excitement through active participation in the field and have taken ownership of the learning process inside the classroom as well in the field – the field being the New York Harbor. This engagement stimulates an interest in the STEM content areas."

The STEM CCE-RS model has been developed with three main goals. First, the team aims to increase the quality and effectiveness of STEM-C teaching and learning; second, it endeavours to enhance the knowledge and instructional skills of teachers; and third, its objective is to develop the knowledge of and interest in STEM-C in students. To achieve these targets, the programme created five interrelated components, or 'pillars'. These are: Teacher Training Curriculum, Student Science Field Research, the Digital Platform, After School and Summer STEM Mentoring, and Community/ Museum Restoration-Based Exhibits. Together, these pillars and the CCE-RS Model will enable both students and teachers to get the most out of the programme through continuous support.

STEM EDUCATION FOR UNDERREPRESENTED STUDENTS

The STEM CCE-RS project specifically targets middle-school students in low-income neighbourhoods and students from groups that are underrepresented in STEM fields and education pathways. To engage with this demographic, the Student Science Field Research arm of the project is developing project-based lesson plans across a full school year relating to harbour restoration activities and monitoring the results in the name of scientific research.

Current project activities for students include teachers implementing lesson plans and taking students to field sites to collect water

© Billion Oysters Project

COLLABORATIVE MODEL WITH TREMENDOUS BENEFITS

The Curriculum and Community Enterprise for Restoration Science project is led by Dr Lauren Birney at Pace University, but the success of its implementation has been aided through extensive collaboration. The consortium of partners with a collective expertise in marine and environmental sciences, STEM education and restoration ecology include:

- Pace University
- The New York Harbor Foundation
- The New York City Department of Education
- Columbia University's Lamont-Doherty Earth Observatory
- The New York Academy of Sciences
- University of Maryland's Center for Environmental Science
- Good Shepherd Services
- The New York Aquarium
- The River Project
- SmartStart ECS

monitoring and observation data – information that will be gathered on a mobile application that has been developed specifically for the project, which will allow students to input data and connect in real time. A process of continued analysis has been emphasised to identify the most effective techniques and strategies for encouraging engagement in the students and, as such, more experienced teachers mentor those less experienced through a process of sharing and discussing lessons.

Ultimately, this will fuel a process of continued refinement and revision of the lessons to maximise their effectiveness. However, the analysis does not cease there: "A quasi-experimental, mixed-methods

© Billion Oysters Project

Five pillars of strength to engage students

THE MISSION OF the Curriculum and Community Enterprise for Restoration Science (CCE-RS) project is to connect teaching and learning to the restoration of the New York Harbor. Ultimately, this will facilitate an enhanced learning experience of STEM subjects for underrepresented students, and present new opportunities and career pathways for those involved in the project.

To achieve these outcomes, an implementation plan has been created that consists of five education-resource pillars. These pillars will work interdependently to support middle school student learning and teacher training, but will also be used in conjunction with five physical project settings – Pace University classrooms for training, the New York City Department of Education, waterfront sites for field research, Good Shepherd Services/New York Academy of Science after school programme sites, and marine science research facilities. Each physical setting has been home to several project accomplishments, and many more project activities have been scheduled for the near future.

RESOURCE PILLARS

While the proposed activities of the project will help the team build upon its already considerable achievements, it is crucial that the project is supported by solid foundations. Each pillar works to achieve a specific target but, importantly, they are all interrelated, where each one complements the others in a highly dynamic arrangement. The proposed activities for each pillar are:

PILLAR ONE

Teacher Training Curriculum

Pillar one will recruit and select 20 new teachers to become Cohort 2 teachers, host monthly fellowship and field days, and implement a curriculum map and performance expectations. Importantly, both institutions will host a STEM symposium in order to disseminate the project details, enabling wider understanding in addition to facilitating a report on the project's progress.

Dr Lauren Birney – Co-Principal Investigator, Pace University

Dr Jonathon Hill – Co-Principal Investigator, Pace University

Sam Janis – Project Manager, New York Harbor Foundation

PILLAR TWO

Student Science Field Research

Pillar two involves Cohort 1 teachers who will implement lesson plans designed to maximise successful involvement of underrepresented students, and will actively engage said students by taking them to field sites. There, they will collect water monitoring and observation data on a specially designed mobile application, providing each individual with a sense of responsibility and ownership. Additionally, Cohort 1 teachers will act as mentors to Cohort 2 teachers, where both will share and discuss lessons, identifying what particular aspects are most effective. In so doing, the curriculum will go through a constant process of refinement and revision, ensuring it is as effective as it can be at all times.

Dr Robert Newton – Co-Principal Investigator, Columbia University

Nancy Woods – Co-Principal Investigator, New York Department of Education

research plan will be used to assess the individual and collective effectiveness of the five project components," explains Birney. "Regression analyses will be used to identify effective programme aspects and assess the individual effectiveness of participation, and social network mapping will be used to further assess the overall 'curriculum plus community' model."

CREATING A SCALABLE AND REPLICABLE MODEL

To ensure that all students have the opportunity to participate in environmental restoration and citizen science, policy changes are needed. This would enable more individuals to have access to environmental science curricula, resources, STEM internship opportunities and projects that allow student participation, creativity and design. This mode of thought is central to the STEM CCE-RS project, with specific focus on giving priority to those students most in need of support, such as underrepresented students, minorities and women. "The project addresses the immediate needs of these students by providing them with the opportunity to be central to the research, design and innovation components of the project," explains Birney. "Student participation in this manner generates ownership in their community, stimulates interest in STEM fields and promotes innovation, creativity and transformation through enquiry and interactive research."

The overarching goal that the model established is fully scalable, transferable and adaptable ensures it can easily be adopted by other school districts outside of New York City – across the US and internationally. Indeed, the intention is to offer the resources to all public schools in New York City across the next decade or so, with a view to expand the model to other geographies, school systems and environmental restoration projects worldwide. We are all citizens of the world and with the success of projects such as STEM CCE-RS, citizen science focused on environmental restoration can demonstrate the enormous positive impacts it has on individuals, STEM-based subjects and the community's environment.

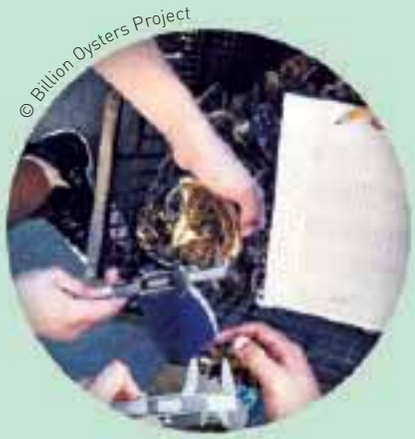
This material is based upon work supported by the National Science Foundation under Grant Number DRL-1440869. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

PILLAR THREE

Digital Platform

The University of Maryland Center for Environmental Science is an integral aspect of pillar three and will be responsible for maintaining and updating the curriculum portal, digital dashboard and mobile application. The team there will also develop a student dashboard – an online resource that will help each individual chart their own progress and encourage continued engagement. Developing additional capacity for citizen scientists is also part of pillar three's remit, which is of benefit to the scientific community, the students and the individual citizens involved.

Dr William Dennison – Senior Personnel, University of Maryland



PILLAR FOUR

After School and Summer Mentoring

Pillar four will include lessons held at Good Shepherd Services after school programme sites, which will also run during the summer. The out-of-school curriculum lessons will engage students in STEM-C concepts with a focus on invertebrate zoology. Importantly, providing students in low-income neighbourhoods with something to do outside of school hours has genuine potential to influence life outcomes in the long term.

Dr Meghan Groome – Co-Principal Investigator, New York Academy of Sciences

PILLAR FIVE

Community/Museum Restoration-Based Exhibits

Pillar five involves The River Project, a marine science field station in New York City, and the New York Aquarium. It will be home to interactive exhibits featuring oysters and showcasing the biodiversity of the New York Harbor. These teams will create and maintain all interactive exhibits to facilitate enhanced learning experiences for both students and the general public. In addition to providing important educational resources, The River Project and the New York Aquarium will also host student field trips throughout the course of the programme.

Jon Dohlin – Director, New York Aquarium

Eli Caref – Coordinator, Education Programs

IMPROVING STEM EDUCATION IN NEW YORK CITY THROUGH ENVIRONMENTAL RESTORATION AND CITIZEN SCIENCE

OBJECTIVES

To create an authentic STEM curriculum that enables New York City (NYC) middle school students to undertake a local species restoration project and conduct environmental field research, resulting in increased engagement in academics; facilitate enhanced performance in STEM-C disciplines; and create an interest toward learning and environmental restoration in the natural environment of New York Harbor.

KEY COLLABORATORS AND PARTNERS

Pace University • NYC Department of Education • New York Harbor School • Columbia Lamont-Doherty Earth Observatory • University of Maryland Center for Environmental Science • New York Harbor Foundation • New York Aquarium • New York Academy of Sciences • Good Shepherd Services • The River Project (Megan Groome, Jonathan Hill, Samuel Janis, Robert Newton, Nancy Woods, Murray Fisher, Peter Malinowski)

FUNDING

National Science Foundation (NSF)

CONTACT

Dr Lauren Birney
Principal Investigator

One Pace Plaza
New York, New York 10038
USA

T +1 212 346 1889
E lbirney@pace.edu

http://ccers.dev.expandtheroom.net/

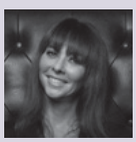
http://bit.ly/LaurenBirney

https://vimeo.com/130355185

www.researchgate.net/profile/Lauren_B_Birney

http://bit.ly/LinkedInLaurenBirney

@LBBirney



DR LAUREN BIRNEY is Assistant Professor of STEM Education at Pace University and Director of the The STEM Collaboratory NYC™. Birney's focus seeks to address the dramatic needs in STEM Education and facilitate interdisciplinary research through the exchange of ideas among students, faculty and industry stakeholders in STEM disciplines nationally and internationally through smart and connected communities.

Soviet women at war

'The Motherland Calls!'

Professor Roger Markwick expounds on the decisive contribution Soviet women on the home front made to the Red Army's victory over Nazism in the Second World War. Here, he explains what motivates his research into an untold story of paradoxical loyalty to Stalin's draconian state, wartime roles that challenged gender norms and the sheer struggle to survive unimaginable hardships

Could you introduce yourself and provide a brief overview of your work?

I have been fascinated by Russian history for as long as I can remember, captivated by its dramatic sweep and why the Soviets' huge social experiment went so badly wrong. I'm also intrigued by the interplay between historical writing (historiography) and the political present – the way in which historical discourse can influence how a society depicts itself. The advent of perestroika under Gorbachev in the 1980s, in which fierce arguments about the Soviet past became intrinsic to its political transformation, and ultimately its demise, enabled me to marry these two passions in my PhD research.

What led you to research Soviet women at war?

In essence, it derives from my PhD research on Soviet historical revisionism in the 1960s Khrushchev era. I was struck by the degree to which the Second World War had shaped a generation of historians who were at once Soviet loyalists and Soviet critics: a 'loyal opposition'. I realised the war was a watershed in Soviet history. My endeavour to answer the question of how, in the face of total war, an overwhelmingly peasant society witnessed women transgressing traditional gender norms by taking up arms is the book co-authored with Dr Euridice Charon Cardona: *Soviet Women on the Frontline in the Second World War*. I'm presently researching the other side of this story: the role of Soviet women on the home front, which is the focus of an Australian Research Council-funded project with Professor Dr Beate Fieseler of Heinrich-Heine University, Germany.

Do you think Soviet women on the home front contributed to the war effort only by reason of political coercion, or did they consent through a sense of patriotic duty?

A combination of both, it seems. Younger, urban women – those brought up in the 1930s under Stalin – tended to be more enthusiastically patriotic and pro-Soviet. Women in the countryside were far less so; as a legacy of forced agricultural collectivisation and the destruction of the Orthodox Church in the early 1930s, they were often hostile to the Soviet political system. However, there is no doubt too that appeals to motherland, motherhood and family loyalty to menfolk on the frontline resonated with and motivated many women on the home front.

What do you think modern generations can learn from your research?

The achievements of women in the Soviet Union, notwithstanding the fact that they occurred in a society that was in the throes of force-marched modernisation and total war, confirm that gender, not biology, determines the social roles of the sexes.

How would you like to see your work advance in the future?

In two years it will be the centenary of the 1917 Russian Revolution. I would like to give that decisive event, which erupted incidentally on International Women's Day, 8 March 1917, an ordinary human face rather than simply a political one. I would also like to revisit the question of why the Soviet system collapsed – did it simply fall, or was it pushed?

THE INVASION OF the Soviet Union by Nazi Germany and its Axis allies on 22 June 1941 unleashed an apocalyptic, genocidal war that took the lives of nearly 27 million Soviet citizens. The ultimate victory of the Red Army in what the Soviets deemed the 'Great Patriotic War, 1941-45', may be ascribed in good part to the efforts of the Soviet home front, which was overwhelmingly female.

Mass conscription of able-bodied men into the Red Army was promptly followed by an influx of women into previously male-dominated sectors of employment. If it was not for the dogged toil of Soviet women, who constituted the majority labour force in wartime industry and agriculture especially, the gears of the motherland would undoubtedly have ground to a halt.

UNEARTHING THE FACTS

Rendering an accurate historical representation of the wartime lives of Soviet women is no small task; not only because of the archival research required, but also because the Patriotic War has become integral to Russian national pride. Such is the sacralisation of the patriotic, heroic narrative of 'The Victory', that critical historical analysis is almost blasphemous. Historians are confronted with the challenge of writing history according to inviolable facts. The extraordinary hardship endured by women on the home front has been largely obscured by the heroic, patriotic narrative. For instance, Soviet wartime propaganda assured Red Army soldiers fighting on the frontline that their wives and children at home were well cared for. The reality was often otherwise, with women frequently begging authorities to meet their most basic needs.

Having scoured the archives, Professor Roger Markwick of the University of Newcastle, Australia, and Professor Dr Beate Fieseler of Heinrich-Heine University, Germany, have unearthed considerable evidence of the plight of women on the home front and of their indispensable role in what was undoubtedly the bloodiest of all conflicts in the history of warfare. Several key questions have played on the minds of these researchers: what sustained the seeming loyalty of women

Drawing on hitherto untapped primary sources, an Australian Research Council-funded collaboration between **The University of Newcastle**, Australia, and **Heinrich-Heine University**, Germany, casts new light on the crucial contribution Soviet women on the home front made to the defeat of Nazi Germany in the Second World War

to the Soviet war effort, notwithstanding draconian repression under Stalin and the severe wartime deprivation? And to what extent, if at all, did women taking on largely masculine wartime roles contribute to their emancipation?

It is unsurprising that this project, and the questions it asks, draws on the enduring research interests and expertise of Markwick and Fieseler. Historical revisionism was the subject of Markwick's PhD thesis and subsequent book, *Rewriting History in Soviet Russia: The Politics of Revisionist Historiography 1956-74*. Fieseler, who has extensively researched the terrible fate of Soviet war invalids, is a leading specialist in Russian and Soviet gender history.

SURVIVAL WITHOUT LIBERATION

Soviet authorities exalted working women, boasting of their emancipation from women's traditional domestic burdens. While Soviet women in the 1930s were often undertaking male jobs long before their feminist western counterparts, at the same time, Soviet women were urged to assume traditional family roles, returning to them without demur at war's end. Indeed, the centrality of family in Soviet patriotism, manifest in the term 'motherland', made motherhood a particularly admirable occupation, particularly to redress the demographic crisis due to catastrophic wartime losses.

Archival sources speak not of liberation but of survival as the principal wartime motive of Soviet working woman. Vira Sirova, a mother of three, featured in a 1943 communist party report, exemplified the predicament of those women who could not supplement their husband's army allowance by working. Sirova was unable to work, her children too sickly to be left alone; she resorted to burning her possessions so as to keep her apartment warm through the unforgiving winter.

Other women took on the most gruelling, dangerous work. Under the slogan 'Every log a blow to the enemy!', women laboured in the timber industry. Logging was a perilous occupation, often carried out by Gulag forced labour. As an essential wartime industry, women in the timber industry worked under military regulations.

In recompense for this gruelling labour, women were afforded only the most basic, subsistence rations. Afflicted by malnourishment, hunger and ill health, women aged 18-45 could be 'mobilised' to work, except those with very young children. Factory employment was one's best chance of survival, since they provided wartime rations. But conditions were so harsh that women employees still absconded in search of better conditions, despite draconian punishment, including Gulag labour.

REWARD AND PUNISHMENT

Punishment was not the only means of ensuring compliance. Role models were made of women who exceeded their quotas at work, a ploy to instil home front ardour and encourage more women to join them. Excellence at work was also, ostensibly, rewarded with the provision of better rations and conditions.

The Communist Party and the Young Communist League (Komsomol), working through workers' councils (Soviets) and enterprise committees, propagandised the war effort. Coercion alone would not have sufficed to sustain the war effort, unless the party state could amass support among crucial sectors of the populace both on the home and military fronts. "As a result of the vast male losses, in the aftermath of war women bore a triple burden: reproduction, industrial reconstruction, and re-establishing domestic life, including coping with millions of returned servicemen, often traumatised or invalided," Markwick concludes.

This novel addition to the historiography of the war against Nazism on the Eastern Front, attests to Soviet women's decisive but little recognised contribution to the victory.

'I WAS A HORSE AND A MAN': WOMEN, STALINISM AND THE SOVIET HOME FRONT, 1941-45

OBJECTIVES

To illuminate the roles and experiences of Soviet women on the home front in the Second World War in order to determine – given the draconian Stalinist state – what motivated women to support the war effort, or otherwise, and to what degree – if at all – women's wartime assumption of masculines roles was emancipatory for Soviet women.

KEY COLLABORATORS

Professor Dr Beate Fieseler, Heinrich-Heine University, Germany

Dr Euridice Charon Cardona, The University of Newcastle, Australia

PARTNER

Heinrich-Heine University, Germany

FUNDING

Australian Research Council (ARC)

CONTACT

Professor Roger Markwick
Head of School

School of Humanities and Social Science
The University of Newcastle
Callaghan
NSW 2308
Australia

T +61 2 4921 5172
E roger.markwick@newcastle.edu.au

www.newcastle.edu.au/profile/roger-markwick

bit.ly/Markwick_RG

http://linkd.in/1U2foHd

http://bit.ly/Markwick_Fb

@RogerMarkwick

ROGER MARKWICK is Professor of Modern European History and Head of the School of Humanities and Social Science at The University of Newcastle, Australia, which he joined in 2001. Awarded his PhD in 1995 by the University of Sydney, he has particular expertise in modern Russian and Soviet history.

INSTITUT PASTEUR

In an enlightening interview with *International Innovation*, **Professor Christian Bréchot**, President of the Institut Pasteur, reveals the tremendous progress made by the world-leading research organisation, which continues to pave the way to enhanced scientific understanding and better public health

Named after renowned chemist and microbiologist, Louis Pasteur, how does the Institut Pasteur support the advancement of science, medicine and public health?

Although there are many high-quality research institutes worldwide, the Institute Pasteur has three unique differentiating qualities. The first is its name; people around the globe know of Louis Pasteur and his legacy. There is therefore an expectation of excellence associated with our work – and, to date, 10 of the Institut's scientists have been awarded the Nobel Prize.

The second is that we have a blend of activities; the Institut supports basic research across medicine and public health in a multidisciplinary way. We conduct research on microbiology, as its part of our heritage and history, but we also dedicate our efforts to immunology, neuroscience, developmental biology, genetics and cancer. Additionally, we support public health related activities and, in particular, the surveillance and monitoring of infectious diseases. The Institut Pasteur is also a major education centre; we have a high number of undergraduates, Master's and PhD students as well as postdocs. The Institut is also an important partner for industry, and we collaborate extensively.

The third is our international perspective; though based in France, the Institut Pasteur is not a French organisation, it is global. This has been the vision of our Founder from the very beginning. The Institut was founded in 1888, and as soon as 1891, Pasteur sent someone to create the first institute in Saigon (now Ho Chi Minh City). The headquarters in Paris is at the heart of a network of 33 institutes in 26 countries over five continents; we are presently creating another institute in Guinea, West Africa, following the Ebola crisis. So far, we have 10 institutes in Africa, nine in Asia, two in South America, and many in different parts of Europe and New Caledonia.

In what manner are scientists at the Institut endeavouring to accelerate understanding of the many physiological and pathological processes involved in disease pathogenesis?

It is important to emphasise that we are in a very exciting period of science, where interdisciplinarity is somehow fashionable; but it is also at the heart of modern science and medicine. In fact, the key to understanding disease lies at the interplay between humans (the host), the animal (the vector and origin of many infectious disease transmitted from animal to human, known as zoonoses), and the environment. Our centres are working in Paris and throughout the entire network to explore this interplay of host genetics and how it affects our sensitivity to, and severity, of disease. They are working on viruses, bacteria, fungi and parasites. This is highly interdisciplinary research, which benefits greatly from the expertise of our institutes in Africa, Asia and South America.

Could you describe the Institut's approach to developing methods of diagnosing and treating disease?

From the very beginning, the Institut Pasteur has been dedicated to creating new concepts and knowledge with very basic research, but always with the intention of transferring this knowledge to medicine, public health and industrial partnerships.

During the Ebola crisis, for example, I set up a taskforce within the 33 institutes to address this major epidemic. In fact, we have been at the forefront from the very beginning in the fight against Ebola, because we were the first to describe (in March 2014) the virus at the origin of the epidemic. We created the taskforce with the idea of merging the forces within Pasteur working on diagnosis and treatment – even if they were not working on Ebola or infectious disease at that time, in order to focus their efforts on this crisis. We have been able to generate a novel approach for diagnostic tests for immediate testing on the ground in Senegal, Guinea and the Ivory Coast. This is the way we work; we start from basic knowledge on some proteins of the virus and nucleic acids, then we transfer that knowledge to diagnosis. We don't want to do this by ourselves, we want to work with industrial partnerships.

Before I took up the position of President of the Institut Pasteur in 2013, I was Vice President of a global holding of several companies. One of these was bioMérieux, which is dedicated to diagnostics. I have been convinced for a long time of the necessity of partnerships for diagnosis and therapeutics. At the Institut Pasteur, we have a portfolio of around 300 family patterns and around 80 per cent of these are focused on diagnosis. I'm now working with my colleagues to investigate new patterns for treatment; we are dedicating a lot of time to chemistry-based research.

From medical student to President of the Institut Pasteur

Why did you decide to dedicate your career to medicine and its associated fields?

I started off as an MD, but I have always been interested in research. I was very fortunate in that my military service enabled me to work as an MD in Tunisia, North Africa. Because of this, I was exposed very early in my career to liver disease. This was around 1975, and I was very much intrigued and stimulated by cirrhosis and chronic hepatitis, which were, at that time, of unknown origin. Now, we know that they are related to hepatitis B and C viral infections.

When I came to Paris and started working as a resident, I wanted to work in research, so I took a number of courses. These were the very early days of molecular biology understanding, and I had been very fortunate to have the opportunity to work at the Institut Pasteur as a PhD student. This led me to apply this young discipline to virology and cancer, where I focused on hepatitis and liver cancer. Then, I went on to work both in the clinic, where I was Head of the Liver Department at the Necker-Enfants Malades and Head of the Cell Biology Department at the Necker School of Medicine (where I set up my own laboratory), which is 500 metres from the Institut Pasteur. Now, of course, my role is that of President of the Institut.

> “When I started as a student at Pasteur, we set up the first diagnostic test to detect the hepatitis B virus in blood”

What role does interdisciplinary collaboration play at the Institut Pasteur?

I have three key points to emphasise about our interdisciplinary work ethic. The first is that we have embarked on significant reinforcement to attract and recruit new scientists with an interdisciplinary mode of thinking who can interact with those from other disciplines.

Secondly, we created flexible structures that span across our 11 departments and the 33 institutes, and aim to merge expertise on these major challenges. More specifically, we have four centres: the Center for Bioinformatics, Biostatistics and Integrative Biology; the Center for Translational Science; the Center for Global Health; and the Center for Innovation and Technological Research.

Thirdly, we have developed transversal research programmes, which provide financial incentive and support for research activities across the 11 departments. This work includes explaining the link between microbes and noncommunicable diseases, which is a very interesting and important prospect for the future. Noncommunicable diseases concern cancer, neurodegenerative disease, obesity and diabetes on the one hand and microbes, infectious diseases and microbiology on the other. We have much evidence that points to the role of microbes in a substantial fraction of so-called noncommunicable diseases. In fact, 25 per cent of cancers worldwide are associated with pathogens. There is also growing evidence for the important role of intestinal bacteria in metabolic disorders (obesity and diabetes) and possibly, cancer and neurodegenerative disease.

What are the Institut’s key short- and long-term scientific priorities for 2014-18?

We have four general transversal scientific priorities. As a first priority, we have set up the very important development of integrative biology, bioinformatics and quantitative biology. This is at the heart of modern science and many institutes worldwide are also setting this up as a priority, which is excellent. We want to integrate this into the international network. The second priority is epigenetics and how there are mechanisms beyond our knowledge of the human genome that drive bacterial and viral infections and development, which is very much an interdisciplinary theme. The third priority is to work at the interplay of microbes, microbiology and noncommunicable disease. Finally, as mentioned previously, the fourth is the interplay between host genetics, the pathogen, the vector and the environment. We have more focused priorities on the renewal of some departments; for example, we need to reinforce our work on antibiotic resistance, tuberculosis and neuroscience, which are, of course, very important issues.

Can you outline the ways in which the Institut enables R&D?

I would like to highlight the cultural aspect of science, and the blend between basic research and R&D to address the challenges of the future. We have adjusted funding from our industrial partnerships, which now represents 20-25 per cent of our overall budget – which is very significant. More importantly, we know that there are a number of projects that you can only achieve in the context of industrial partnerships.

When I started as a student at Pasteur, we set up the first diagnostic test to detect the hepatitis B virus in blood, which at the time was a new technology. We did this in partnership with Abbott Laboratories, as we had the early conviction that we would benefit from this association.

I was recently in a meeting in the US and I was discussing the formation of strategic partnerships with presidents and CEOs of several high-level pharmaceutical and diagnostic companies, in order to understand each other's priorities. This is a major part of private-public partnerships, academies and companies; it's important to share the objectives from the start of a project to avoid the very frequent misunderstandings that unfortunately complicate research institute partnerships.

In recognition of the discovery of the parasite that causes malaria, Alphonse Laveran was the first of the 10 Institut Pasteur scientists to have received the Nobel Prize. How does the Institut itself celebrate research excellence?

We ensure that we celebrate when our scientists are awarded prizes, and emphasise how significant this is for the Institut. There are specific celebrations for these prizes for the entire scientific community to attend. We evaluate our scientists at regular intervals to assess their accomplishments; those with a high level of achievement also receive financial rewards. We are creating what will be called the 'Chairs of Excellence' to award bonuses on top of permanent salaries in recognition of the quality of work and attainment of specific missions within basic research, public health, education, international activities and industrial partnerships. We make a clear distinction between those who have average results and those who have excellent results. Recognition of excellence is one of the most difficult activities for all research institutions; it is especially difficult at the Institut Pasteur, because we have to recognise excellence across the diversity of all our missions. We must understand that excellence at Pasteur is not only excellence in basic research, but also work being undertaken at our institutes in Africa or Asia, for example.

More recently, what have been some of the organisation's biggest breakthroughs?

It's hard to choose because there have been so many! We have had HIV breakthroughs, which led to the Nobel Prize in 2008. There have also been the long-standing successes of vaccination against hepatitis B, which was the first vaccine based on genetic combination – a landmark success. Another achievement was the research into intestinal microbiota and bacteria and the discovery of how it profoundly affects the pattern of immune response. This is an emerging field and it is crucial to understand how normal intestinal bacteria can modulate the impact of external pathogens, viruses and bacteria, and how this interplay modulates the severity of disease and the type of response. In neuroscience, there have been many breakthroughs in the genetics of autism; our scientists have been at the forefront of identifying how some genes might be predisposing factors to the condition. Regarding neuroscience, I would also like to raise the fact that even in the adult brain, there is a degree of plasticity in neuronal cells, which means that we have a capacity for neuronal regeneration and adjustment. The Institut has not been the only one to investigate this, but our scientists have been at the helm of these discoveries. I could give many more examples!

www.pasteur.fr/en

INSTITUT PASTEUR'S 11 RESEARCH DEPARTMENTS:

- Structural Biology and Chemistry
- Developmental Biology and Stem Cells
- Cell Biology and Infection
- Immunology
- Infection and Epidemiology
- Genomes and Genetics
- Microbiology
- Mycology
- Neuroscience
- Parasite and Insect Vectors
- Virology

> "We have been at the forefront from the very beginning in the fight against Ebola, because we were the first to describe the virus at the origin of the epidemic"


GGGAACCC

National Human Genome Research Institute

Genomics holds promise to revolutionise the diagnosis and treatment of disease. **Dr Eric Green**, Director of NHGRI, explains the organisation's past, present and future roles in – as well as the monumental importance of – this continually evolving scientific discipline

GENOMICS REMAINS ONE of the most vibrant and exciting areas of biomedical research. Upon the completion of the Human Genome Project (HGP) approximately 12 years ago, some were misled to think that genomics was old news; this couldn't be further from the truth. Completing the HGP simply set the stage for what would be a significant expansion of the relevance of genomics across many areas of science. At the US National Institutes of Health (NIH)'s National Human Genome Research Institute (NHGRI), we focus on understanding the role of the human genome in health and disease, including studies aiming to establish how to use genomic information to improve the practice of medicine. There are, however, many other areas of genomics that we aren't directly involved with, but are also incredibly relevant, including microbiology, studies of ancestry and evolution, forensic science, agriculture, general biology and so forth. Our basic understanding of genome structure and function continues to grow, and even within biomedical applications, the evolution of the field will continue to inspire, especially as it becomes more clinically relevant.

DIAGNOSIS AND TREATMENT OF DISEASE

With regard to genomics and the practice of medicine, the past decade has revealed the very tip of the iceberg. I would not claim that genomics has been transformative in terms of clinical applications yet; in fact, it has just started to bear some early fruit that is exciting and illustrative of its future potential – but far more is to come in the next 10-20 years. That said, there are already vivid examples of genomics being used for cancer diagnostics as an important part of the decision-making process with regard to selecting the best treatment for each individual patient.

In other clinical settings, individuals with very rare disorders have benefited from genomics. Some of these stories have been told by the popular press because these individuals have faced a difficult diagnostic odyssey, in which they have gone from healthcare professional to healthcare professional in search of a diagnosis for their rare condition. Now, we simply sequence their genome. In some cases, this will reveal the cause of their illness. In a subset of those cases, it will point to new therapy options.

A third area of progress in clinical genomics has been in pharmacogenomics, which is the selection of the right medication and dose for a particular person. Basically, we all respond differently to medication because we metabolise drugs differently, and some of that is influenced by what's in our DNA. We are figuring out how to better match specific spelling differences in our genomes with drugs, so that we know exactly what to look for and can identify if a person will be a good or bad responder to a particular medication.

Another area that has picked up in the past decade is prenatal genomic testing. Previously, genomic testing of unborn babies was typically undertaken by accessing foetal DNA through invasive procedures, such as amniocentesis or chorionic villus sampling; these invasive procedures are now starting to disappear from practice. Today, we can do a simple blood test of a pregnant woman and use new methods for sequencing DNA to detect foetal DNA floating around in the mother's bloodstream – and we can obtain the same amount of diagnostic information as we could with the more invasive procedures.

PERSONALISED MEDICINE AND PREVENTIVE ACTION

If an individual has a particular predisposition to a disorder based on their DNA sequence, genomic testing can help them make informed decisions about prevention; Angelina Jolie's story is emblematic of the power of personalised medicine and how knowledge of her predisposition to breast and ovarian cancer enabled her to choose preventive surgery.

At the population level, we have the ability to monitor disease. With increased screening to detect conditions earlier comes the potential to reduce morbidity. Additionally, gaining a better understanding of differences across international populations or subpopulations may prove helpful for tailoring medical care for specific communities.

CLEAR COMMUNICATION OF GENOMICS

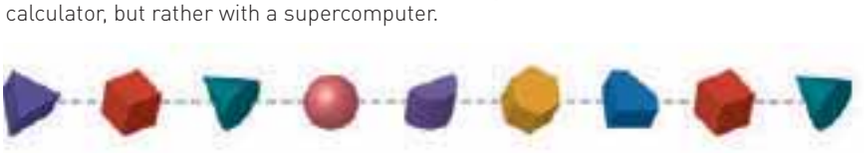
We are beginning to see that genomics will be part of the standard language that healthcare professionals use when communicating with their patients. Globally, so many people are affected by cancer, and, increasingly, genomics will be central to the analysis of tumours that determines the best way to treat cancer, requiring that the practitioner communicates genomic information to the patient and explains how genomics is aiding clinical decisions. DNA testing will also help doctors figure out the most appropriate medication on an individual basis. At NHGRI, we think a lot about the issues surrounding genomic literacy; we need to make sure that people understand the fundamentals of genomics, so that when a physician or nurse sits them down to talk about their genome or genomic testing, they appreciate what that means. Therefore, at a societal level, we need to raise everybody's awareness and understanding of simple genomic concepts.

BIG DATA POST HGP

For researchers, genomics has undergone a radical change in the past 10-15 years, where it has become an overwhelmingly data-intensive field. Looking back on when the HGP ended, the amount of data that we had was fairly trivial because the technologies required to generate DNA sequence data were expensive. The past 10 years have seen a revolution in technology, such that the number one complaint of almost every genomics researcher is that they are overwhelmed with data and are trying to figure out how to analyse it all. This problem is only going to get bigger over time because other scientific disciplines are also getting better technologies, allowing them to generate large amounts of data as well. Genomics is therefore illustrative of what's going on across all of biomedical research in that we are becoming a data-intensive profession. Thinking about how to train the next generation of scientists, so much more of what will happen in biological research in the next 50 years is going to take place at a computer than a bench – and that's a big challenge.

> With regard to genomics and the practice of medicine, the past decade has revealed the very tip of the iceberg

I think that the concept of 'big data' and its analysis is going to be the biggest mountain to climb in establishing the best way to use genomics to improve human health. As we try to analyse people's medical records, we are going to merge and integrate this information with their genomic data as well as all sorts of data about their lifestyle, physiology and diet. Elements of daily life will be increasingly measured with new technologies and little sensors that we will wear. That's the future – and imagine doing that on a very large scale and having it be incredibly revealing! This will generate prodigious amounts of data, but if we can effectively mine these data, they will be exceptionally rich. These studies will be data-intensive, as it is not somebody sitting with a calculator, but rather with a supercomputer.



A word with the author

Dr Eric Green provides an inside look into the pioneering work being undertaken at NHGRI and offers his personal perspective on how genomics is shaping life and science

What are some of the most exciting projects being run by the NHGRI at present?

Wow, that's like asking who your favourite child is! There are so many exciting projects being undertaken across the full continuum of activities, from basic to clinical research. I continue to get excited about our flagship projects like ENCODE, the Encyclopaedia of DNA Elements, because it has a laser focus on simply understanding how the 3 billion letters of information that make up the human genome actually function to choreograph human biology. It sounds simple but of course it's not, and we are going to be working on this for decades. There is no question that humans are incredibly complicated, and we do not fully understand how those 3 billion letters in our genome influence whether we are a healthy or not-so-healthy human. At a fundamental level, this is incredibly exciting! ENCODE is not the only project trying to figure this out, but it is emblematic of the efforts established to rigorously decipher the human genome blueprint.

If you move a little away from basic science and look at translational research, we are now shifting towards a position where we can tackle some of the biggest healthcare burdens in the world, and these are common diseases (like hypertension, diabetes, autism, Alzheimer's and asthma). We will try to figure out the genomic influences of those diseases by taking very large collections of people with and without the disease and comprehensively studying them at the genomic level. Five years ago, we could not afford such studies, and now we can, so I think there will be large efforts over the next five years to tackle these big healthcare burdens worldwide and figure out if something at the DNA level is influencing the risks and pathways that are leading to disease. That is going to give us great insight about diseases that we think about in too simple a way at the moment. For example, diabetes is probably a collection of diseases; we need to learn the complete taxonomy of diabetes by undertaking very rigorous genomic studies.

From a more clinical perspective, we have a number of studies at NHGRI to use genome sequencing as part of clinical care. That is the new frontier, and it is also new for the Institute to be clinically orientated, as our origins date back to being created for the HGP as a basic science enterprise to map and sequence the human genome; but we are now growing and evolving to take on clinical research studies. One of the reasons we got involved with genomics research to begin with was to see if we could use genomic information to improve patient care, specifically by better diagnosing and treating diseases. Although they are still pilot studies – whether looking at newborn babies, people with cancer or pharmacogenomics – our early efforts are very exciting.

1 October 2015 marks the 25th anniversary of the launch of the HGP. To be running an organisation that has evolved considerably and is using genomic tools to try to improve clinical care is pretty fascinating. If you had asked me 25 years ago whether I would be doing this in my career, I doubt that I would have said yes; I really thought it would take much longer for genomics to become clinically relevant. This is all exciting because it is happening far faster than any of us ever imagined.

How has your vision of the world been shaped by science and, in particular, genomics research?

At a very simple level, part of my attraction to genomics is trying to understand our own blueprint.

If you are a life science person (such as a physician or researcher) like I am, then you are driven to explore the fundamental mechanisms of biology and disease – and you cannot get more fundamental than the blueprint. There are many different ways to study disease, but we are looking at the most basic level and operating at this level in terms of evolution, development, physiology and disease. I view genomics as being at the core of life sciences and how organisms evolve and operate. However, I would also say that a key factor that drives genomics forward is technological innovation. At the same time as studying the core biological principles, progression really reflects the advances in technology.

genome.gov

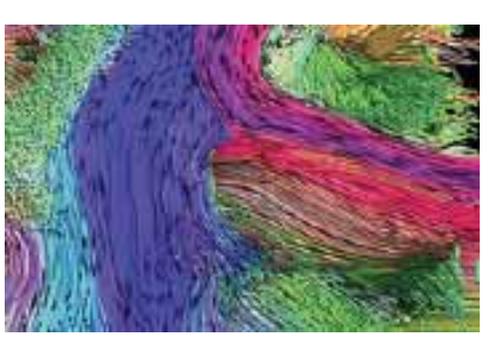
NIH National Human Genome Research Institute

Unravelling the enigma surrounding brain structure and function

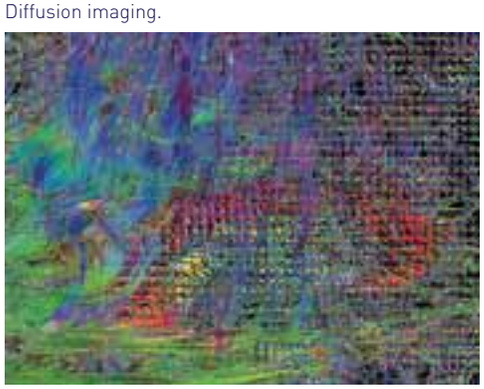
Professor Paul Thompson is the Director of ENIGMA – a project that seeks to understand the brain through extensive collaboration. Below, he discusses the project's progress, specific areas of focus and some of its most surprising findings to date

Welcome back to *International Innovation*! It is a pleasure to speak with you again about the ENIGMA project. How has ENIGMA – the largest brain imaging study in the world – evolved since we last spoke?

Thank you! Since last year, we have combed through over 50,000 people's brain scans and DNA to work out how brain diseases affect us, how they emerge and spread, and what resists them. We are doing this work in 35 countries, to compile the most detailed picture ever of the brain across the world. Take ENIGMA's studies of depression, bipolar illness and schizophrenia, for example. By looking at brain scans from over 20,000 people, we see how depression strikes the hippocampus (the brain's learning and memory system); people who are depressed have a physical loss of tissue in the brain's learning centres, as well as in parts of the brain involved in motivation and reward. The changes are greatest in people who have been ill the longest, so early treatment is crucial.



Diffusion imaging.



Mapping fibres in the brain.

ENIGMA's group studying post-traumatic stress disorder (PTSD) also sees differences in the brains of combat veterans and in survivors of childhood trauma and traumatic brain injury. We are discovering what promotes recovery from trauma, and if the same things work in different countries. ENIGMA's groups studying epilepsy, Parkinson's disease and stroke recovery can quickly compare notes – and share new leads – with our groups studying anorexia, addiction, obsessive compulsive disorder, HIV, autism and ADHD. For some of these diseases, ENIGMA has published the largest ever studies this year. They show remarkable consistencies in how these illnesses affect the brain worldwide, and offer some clues on how to resist them.

Clearly, ENIGMA covers a lot of ground. However, there is one area that I would like to turn your attention to – healthy ageing. Why is ENIGMA keen to investigate this area in regards to brain research?

Whether or not we suffer from depression or have a loved one affected by a brain disease, one thing is certain: we are all ageing. The brain ages like the rest of the body – it grows rapidly in childhood and then declines. We all differ in how our brain ages – partly due to genetics, our diet, our family environment and friends, what we do with our brain, and how we spend our time. So we are all keen to know what protects our brain from ageing and what we can do about it.

Most studies to date have only involved a few hundred people, making it hard to tease apart what matters most, or even if some factors matter at all. So you may see in the news that dietary supplements – such as omega-3, or folate – might protect the brain, or that even mild levels of alcohol harm the brain. But is this true? And is it true for everyone, or just some people or in some situations? ENIGMA's data from 35 countries examine tens of thousands of people, making it easier to disentangle how different factors affect the brain, versus all the other things that happen to us in our life.

What have you found to be the most surprising elements of ENIGMA's results to date?

It was absolutely stunning to me that we could see the effects on the brain of single letter spelling differences in our DNA. We all vary in our genetic code, so in ENIGMA we decided to launch an effort across 250 institutions worldwide who had been collecting brain scans and DNA from large numbers of people. We hit upon 30 hotspots in our DNA that predict brain structure, and some affect our risk for disease – we're finding more all the time. As so many things affect our brain – our environment, education and our diet. It was truly stunning to me that in every population of the world we could see these DNA differences that predicted brain measures. It is the most extraordinary finding I have seen in 25 years as a scientist.

What benefits does having such a wide network and large pool of project participants offer both to the project and to the results it delivers?

The greatest benefit of a worldwide alliance is speed and efficiency. Obviously, if you and I were to ask the government, or a wealthy donor, to collect 50,000 brain scans at US $500 per scan, it would cost over $25 million and take about 10 years. It would probably be shouted down or people would give up. But people had been collecting brain scans and DNA all over the world, they just weren't studying them together in a global study. That is what ENIGMA achieved. So, we didn't have to buy all the computers and infrastructure to analyse them – just as you can use the internet without having to pay for all the computers that store the data, or the people who generated all the data.

The second benefit is the sheer collective brilliance of people around the world in cracking a scientific problem. When ENIGMA published its first study, we got an email from a famous Russian geneticist in Dagestan who said, "I think I know what the gene does that you discovered". Dr Kazima Bulayeva, a geneticist and medical doctor, had been studying ethnic isolates in Chechnya and Dagestan for decades; she found the same

gene as we did, implicating the gene in mental illness for the first time, a gene that ENIGMA found has the greatest effect on the size of the brain's memory system. Bulayeva and I became good friends and we now collaborate with people across Russia, including in Siberia, and, on related questions with people across Asia and in Thailand and Cambodia, as well as Korea, China and Japan.

It gives you pride and faith in humanity to see people from cultures so diverse jointly cracking the enigmas of the human mind. It is like chess or mathematics. There is no monopoly on good ideas, but a collective interest, and we can all take part.

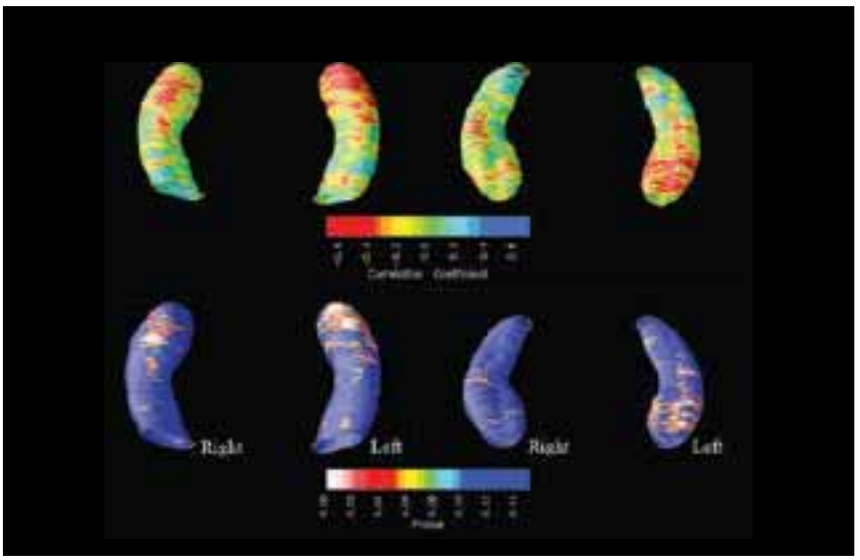
Finally, how would you like to see the project evolve in the future?

It is quite hard to fund ENIGMA as the scientists are in 35 countries. So we are looking for ways to pay for the work. ENIGMA saves money and offers a high yield on the invested time by making use of data already collected. By getting more people to work together, it gives us a source of power that we have never had. *The New York Times* described ENIGMA as giving brain research a new source of power, while the medical journal, *The Lancet*, highlighted ENIGMA as a project where "crowdsourcing meets neuroscience".

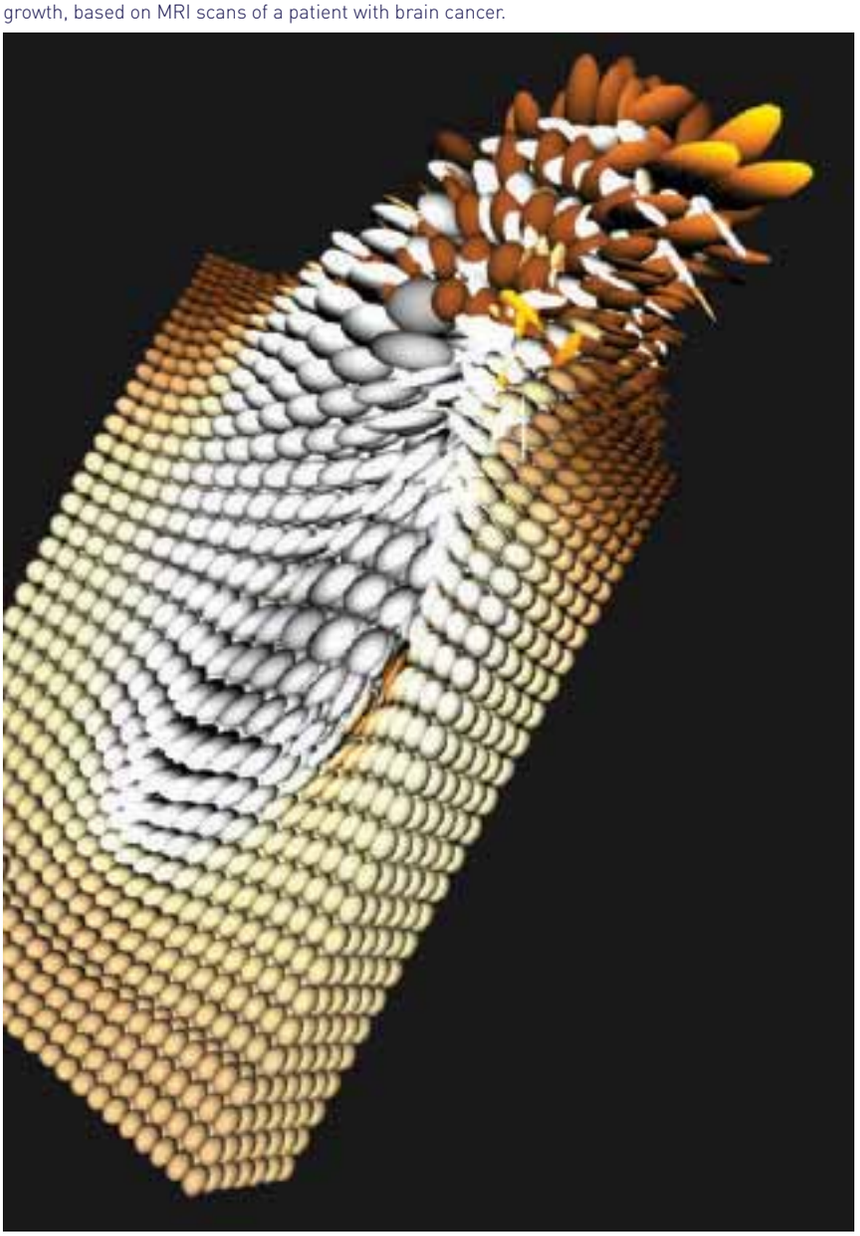
In the coming years I'd like to see ENIGMA's projects on different diseases spin off to become financially sustainable in the long term. We should be able to boost public health by discovering factors that resist brain disease and brain ageing. ENIGMA is just one piece in a global effort tackling brain disease, but the sheer breadth of collaboration in ENIGMA is very unusual in science.

It gives you pride and faith in humanity to see people from cultures so diverse jointly cracking the enigmas of the human mind

Correlation of depression severity with tissue loss in the brain's learning and memory centre – the hippocampus.



Tensor tumour: this model of tumour growth in the brain reveals the direction and speed of growth, based on MRI scans of a patient with brain cancer.



Saving the brain by stalling its decline

The ENIGMA project is the largest brain imaging study in the world. It brings brain scientists from around the globe together to look at a myriad of brain diseases and to understand the factors that help or harm the brain, including those that keep us healthy as we age

THE ENHANCING NEURO Imaging Genetics through Meta-Analysis (ENIGMA) project is one of the largest scientific initiatives in history. Since it began six years ago, it has brought together over 500 scientists from 35 countries to discover the factors that help or harm the brain. By pooling worldwide experts in fields such as medicine, mathematics and the genome, the project analyses 18 major brain diseases, studying what causes them, what treatments are best, what factors put individuals at risk and what protects us.

International Innovation first published an article about ENIGMA in May 2015 and, since then, the project has evolved to the point where the brain scans of over 50,000 people have been analysed. Within the project, there are over 30 active working groups, including the recently established Save the Brain project. The main goals and overarching aims of Save the Brain are to discover the factors that keep the brain healthy as we age. While there is a wealth of evidence regarding what harms the brain – such as brain trauma, concussion, untreated depression and drug and alcohol abuse – very little is known about what helps us.

By analysing brain scans from thousands of people, the researchers hope to build a portfolio of evidence of factors that can help protect the brain as we age. Professor Paul Thompson is the Director of ENIGMA. He is clearly a passionate advocate for what this groundbreaking project seeks to achieve. "Alzheimer's disease, for example, doubles in prevalence every five years after the age of 60. So if you could delay Alzheimer's by five years, only half as many people in each age group would have it," explains Thompson. "So we need to work out what factors delay disease and what factors boost the brain's 'reserves' and offer a greater resilience to brain decline."

With that in mind, the team working on the Save the Brain project is studying several factors, such as cardiovascular health and diet, stress reduction, hormonal changes, alcohol and drug abuse, and medications and supplements. Each topic facilitates the building up of new information to inform strategies that slow down the brain's decline.

The investigations have so far uncovered some fascinating discoveries, such as the significant impact cardiovascular health and physical fitness have in delaying dementia. For instance, people who walk for half an hour every day have younger looking brains than those who do not, while the rate of brain loss is even slower for people who exercise more.

According to Thompson, each different activity has different health effects. "High intensity exercise gets oxygen-rich blood into the brain, but milder forms of exercise – even meditation – can reduce stress, which is also a big killer of brain cells," he explains. "People with high levels of the stress hormone, cortisol, suffer fastest erosion of brain tissue, making it crucial to get those stress levels down." Thus, exercise and stress reduction are the two biggest ways to save millions of brain cells from dying every year.

CRACKING THE CODE

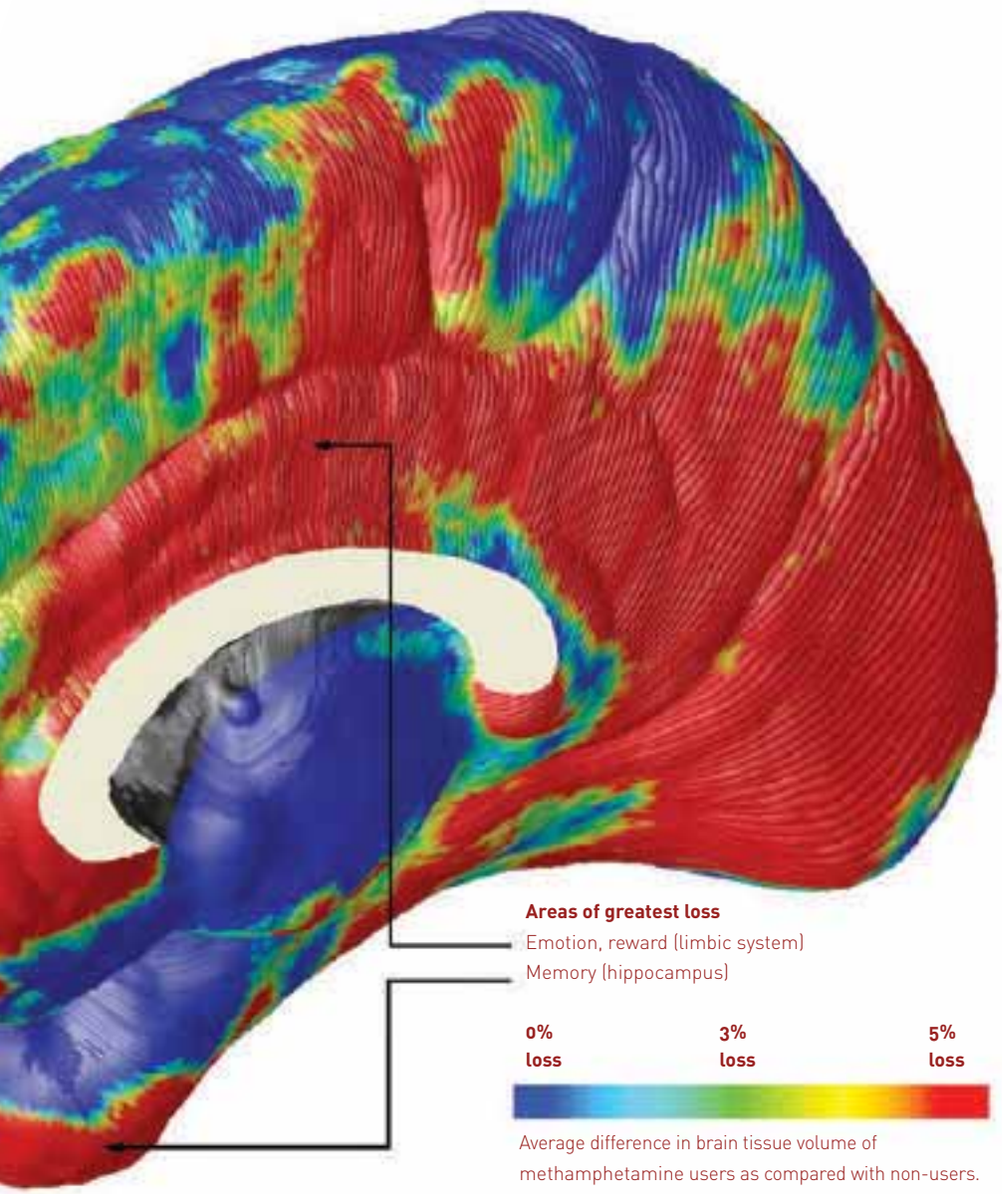
Studies of Alzheimer's disease over the last 20 years show that a person's body mass index (BMI) is an excellent predictor of how fast the brain is ageing. Interestingly, BMI has been shown to correlate with a person's educational level and, though there are obviously other factors at play, people who are more educated tend to have a lower BMI.

This was a major motivation that pushed the team to look into the blood for markers of healthy ageing and investigate the DNA of individuals. Ultimately, this led to 300 scientists from ENIGMA publishing papers using DNA and brain scans in an effort to crack the genetic code of the brain.

They found eight markers in the genome where different people's genes have a different 'spelling' and, on average, people with some of these spelling differences had brains that looked 3-4 years older. By pooling DNA from around the world, ENIGMA has managed to find

Researchers have mapped brain decay caused by methamphetamine use. The damage affected memory, emotion and the reward system.

The project analyses 18 major brain diseases, studying what causes them, what treatments are best, what factors put individuals at risk and what protects us



Average difference in brain tissue volume of methamphetamine users as compared with non-users.

over 30 markers in the genome that affect the brain in ways that are harmful or protective. Armed with these findings, researchers are now investigating what treatments can interact with those genes to promote healthy ageing and thwart brain disease.

BRAIN HEALTH BLOOD TESTS AND BEYOND

One of the most exciting initiatives the Save the Brain project is working on is a blood test for brain health. Their aim is to create a cheap and widely available blood test that enables researchers to look for any abnormalities that could act as markers for brain ageing.

"We want to look for things such as thyroid hormone, testosterone, oestrogen, B vitamins such as folate, amino acids such as homocysteine, and a massive range of other markers, such as gene expression, and measures of mobility, that are getting easier to assess," explains Thompson. "Our centre is pursuing 'big data' analysis methods to try to work out what the best predictors are, based on brain data and clinical data from all 35 countries under our umbrella."

By comparing data collected from around the world, the team will get a real sense of what health predictors are the most reliable, and for which people. The potential benefits associated with Save the Brain and ENIGMA in general are extremely far-reaching. The unprecedented scale of the projects could lead to some equally unprecedented findings that could help protect our brains and slow down the ageing process.

ENIGMA

OBJECTIVES

- To create a network of like-minded individuals interested in pushing forward the fields of brain research, imaging and genetics and to share ideas, algorithms, data and information on promising findings or methods
- To discover what keeps the brain healthy as we age and to look for protective factors by analysing brain scans collected all over the world every day
- To replicate promising findings via member collaborations, ensuring consistent and reproducible discoveries

FUNDING

US: National Institutes of Health

Australia: National Health and Medical Research Council

Europe: European Research Council • Seventh Framework Programme (FP7) • Wellcome Trust • Medical Research Council • NHS • Research Councils of Norway and Sweden • German Federal Ministry of Education and Research • French National Agency for Research • Science Foundation Ireland • Netherlands Organisation for Scientific Research • Scottish Mental Health Research Network

Japan: Ministry of Health, Labor and Welfare

Other: Funding bodies across Canada, South Africa, Asia, Saudi Arabia and the Russian Federation

CONTACT

Professor Paul Thompson
Leader of the ENIGMA Consortium

ENIGMA Center for Worldwide Medicine, Imaging and Genomics
Keck School of Medicine of University of Southern California (USC)
4676 Admiralty Way
Marina del Rey, California 90292, USA

T +1 323 442 7246
E pthomp@usc.edu

http://enigma.ini.usc.edu

http://enigma.ini.usc.edu/news

http://bit.ly/PaulThompson_GP

http://bit.ly/PaulThompson_RG

http://bit.ly/PaulThompson_LI

@enigmausc

PROFESSOR PAUL THOMPSON gained a Master's degree at the University of Oxford, UK, and a PhD from the University of California, Los Angeles, USA, where he later held a professorship. He moved to his current position at USC in 2013 where, in addition to conducting his research, Thompson is Associate Dean for Research at the Keck USC School of Medicine and Director of the University's Imaging Genetics Center.

Linking Alzheimer's and nutrition

As head of her lab, **Assistant Professor Ai-Ling Lin** speaks about her team's work to develop dietary and pharmacological interventions to slow down brain ageing and the progression of Alzheimer's disease

How have your experiences travelling the world as a child with missionary parents to visit people in churches and hospitals, as well as inspiration by the likes of Isaac Newton and Albert Einstein, influenced your work?

I wanted to be a physicist, but also hoped to be able to help and care for people in some way. Having a PhD in medical physics and working in the medical research field made both of these dreams come true. On the one hand, I acquired in-depth knowledge of physics and engineering of medical imaging, while on the other, I applied the technology to address important medical issues through basic research and clinical investigations. Now, using magnetic resonance imaging (MRI), my research goal is to develop surrogate markers that might detect brain function changes in ageing and Alzheimer's disease at an early stage. Ultimately, this could lead to the identification of effective therapeutics to slow down brain ageing and prevent Alzheimer's disease.

Your mouse model study shows that caloric restriction is associated with preserved vascular function. Can you provide further insight into the nutritional intervention arm of your research?

Brain vascular integrity plays a major role in determining cognitive functions, such as learning and memory. In our studies, we found that old mice treated with caloric restriction had preserved cognitive functions when compared with young mice. Our findings are also consistent with others, showing that caloric restriction impedes cognitive impairments in mouse models of human Alzheimer's disease. In addition, caloric restriction improves insulin sensitivity and preserves glucose homeostasis, which contrasts diabetes. Through our research findings, we suggest that nutritional interventions are crucial and effective to preserving cognition in ageing and reducing risks for Alzheimer's disease.

The other arm involves the use of rapamycin. Your research found that mice treated with the therapeutic agent had restored cerebral blood flow, blood-brain barrier integrity and glucose metabolism compared to age- and gender-matched wild-type controls. How effective could this be for humans?

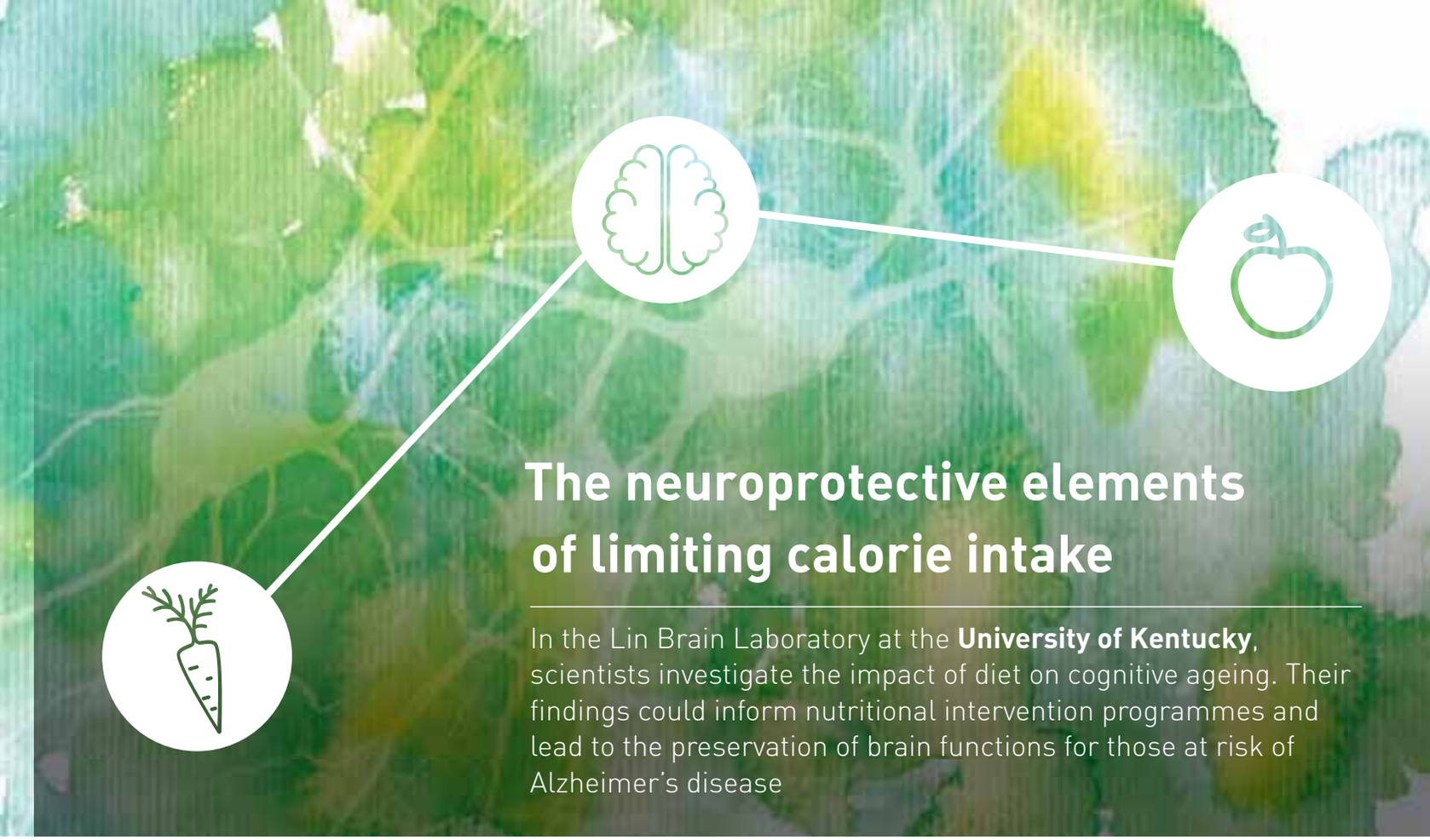
Rapamycin is a drug approved by the US Food and Drug Administration. It has been widely used in the clinic and was originally used as an immunosuppressive agent to prevent the rejection of organs in transplant patients. It is now also being used as an anti-tumour agent. We learned from recent studies that rapamycin can improve immune functions in the elderly with minimal side effects when the dosage is carefully implemented. All of this indicates that rapamycin can be safely used in humans and have multiple beneficial effects. However, it has not been applied to age-related neurodegenerative disorders, nor has neuroimaging been applied to study the treatment efficacy of rapamycin on neurovascular and neurometabolic functions in humans. It is our future goal to bring rapamycin to clinical trial for this purpose.

What role should governments play in the service and education of their citizens regarding healthy diets?

I think governments can have at least three major functions. First, they can develop programmes to ensure access to healthy, high-quality food. For example, the New York City Department of Health developed an innovative programme incorporating street vendors, and the Mayor of Philadelphia helped build a supermarket to help people in the neighbourhood get access to fresh fruit and vegetables. Second, governments can also develop programmes to educate their citizens on how to choose healthy diets. For instance, I have seen 'traffic light' programmes to indicate the foods you can consume always (green), sometimes (amber) and less often (red). Finally, governments (state and federal) can ensure funding and financial support for research and education to address health disparities.

Can you describe your future research goals?

Unlike the 'one-size-fits-all' approach, precision interventions take into account individual differences in people's genes, gut microbiome, environments and lifestyles. In the 2015 State of Union address, President Obama indicated that precision medicine will be a "bold new research effort to revolutionise how we improve health and treat disease". For nutrition, researchers have developed algorithms to prescribe personalised diets by lowering post-meal blood sugar responses. This can also apply to the prevention of dementia. In the future, we would like to be able to provide personalised medicine advice for patients with brain disorders and monitor their progress using neuroimaging and cognitive testing.



The neuroprotective elements of limiting calorie intake

In the Lin Brain Laboratory at the **University of Kentucky**, scientists investigate the impact of diet on cognitive ageing. Their findings could inform nutritional intervention programmes and lead to the preservation of brain functions for those at risk of Alzheimer's disease

The weight of evidence supporting this resistance to insulin is shown in the increased recognition of Alzheimer's disease as 'type 3 diabetes'

THE HUMAN BRAIN is the main organ of the central nervous system; it receives input from all sensory organs and communicates with all muscles to enable their movement. Of all the vertebrates, the human brain is the largest relative to body size. Although the brain represents only about 2 per cent of a person's total body weight, it utilises 20 per cent of oxygen and 25 per cent of glucose in the human body. While this energy supply is normally obtained from blood glucose, the brain is able to source alternative energy from ketone bodies during periods of low glucose, such as when fasting or exercising, or due to limited carbohydrate intake.

It is generally considered that healthy functioning of the brain relies upon the maintenance of cerebral metabolic rates of glucose and blood flow. A decrease in these rates, as happens with ageing, leads to functional losses resulting in a wide range of neurodegenerative conditions – one of which is Alzheimer's disease, the sixth leading cause of death in the US.

It is known that age is one of the biggest risk factors associated with the onset of Alzheimer's. Thus, as members of the ever-burgeoning global population continue to live longer, the need to understand the precise disease mechanisms becomes increasingly pressing. This would enable the development of more effective intervention strategies and therapeutics, relieving the burden of Alzheimer's for individuals and wider society.

TYPE 2 DIABETES AND ALZHEIMER'S

With that in mind, a researcher based at the University of Kentucky has been conducting a wide variety of investigations to better understand brain ageing and the progression of Alzheimer's disease. Assistant Professor Ai-Ling Lin heads the Lin Brain Laboratory, where research into preserving brain functions for individuals at high risk of Alzheimer's disease is performed.

In addition to age, it is known that type 2 diabetes also dramatically increases the risk of developing Alzheimer's. "Impaired glucose utilisation, abnormal blood glucose levels and dysfunctional insulin signalling – known as insulin resistance – are the major symptoms of individuals with type 2 diabetes," explains Lin. "More and more evidence shows that patients with Alzheimer's disease have insulin resistance in the brain, which impairs the energy supply to neurons and leads to cognitive defects."

The weight of evidence supporting this resistance to insulin is shown in the increased recognition of Alzheimer's disease as 'type 3 diabetes'. Therefore, it is essential to find ways of preventing the onset of diabetes in order to preserve brain function and reduce incidence of neurological degeneration.

RESTRICTING CALORIC CONSUMPTION

One investigation Lin has led is to better understand how restricting caloric intake can increase ketone body metabolism and preserve

ALZHEIMER'S DISEASE AND NUTRITIONAL INTERVENTIONS

OBJECTIVE

To investigate the correlation between nutrition and cognitive ageing in order to develop interventions that preserve brain function for conditions such as Alzheimer's disease.

KEY COLLABORATORS

Dr Arlan Richardson, University of Oklahoma Health Science Center, USA

Dr Fahmeed Hyder, Yale University, USA

Dr Anika Hartz; **Dr Zhenheng Guo**; **Dr Ming Gong**, University of Kentucky, USA

FUNDING

National Institute of Health: K01AG040164 and UL1TR000117

American Federation for Aging Research

Donors Cure Foundation

CONTACT

Assistant Professor Ai-Ling Lin

Lin Brain Lab
307 Sanders-Brown Building
University of Kentucky
800 S. Limestone
Lexington, Kentucky
40536-0230, USA

T +1 859 323 6671
E ailing.lin@uky.edu

http://reveal.uky.edu/lin_ai-ling

www.youtube.com/watch?v=tHUc44nkp5c

https://med.uky.edu/users/ali245

DR AI-LING LIN is Assistant Professor of the Sanders-Brown Center on Aging and the Department of Pharmacology and Nutritional Sciences at the University of Kentucky. She holds a PhD in Radiological Sciences from the University of Texas Health Science Center at San Antonio. Her research goals are to identify effective nutritional and pharmacological interventions to preserve ageing brain functions and prevent Alzheimer's disease using multimodal neuroimaging techniques. Outside of work, she loves to read, travel and play piano.

the blood flow in ageing brains. While caloric restriction has been shown to increase the life span and health of many species, the effects of it on *in vivo* brain functions is still largely unexplored. Thus, Lin and her team set about studying the effects of caloric restriction on the brain's metabolism and vascular functions.

They used neurological imaging techniques to analyse the brains of ageing rats on a calorie-restricted diet and found that there was reduced glucose uptake, but an increase in the level of ketone bodies. Importantly, this shift in metabolism was found to be associated with the preservation of vascular function and blood flow to the brain – both of crucial importance to maintaining brain function. That caloric restriction appears to be neuroprotective places greater emphasis on the need for individuals – especially those at increased risk of Alzheimer's – to eat a nutritionally balanced diet.

GOVERNMENT ACTION

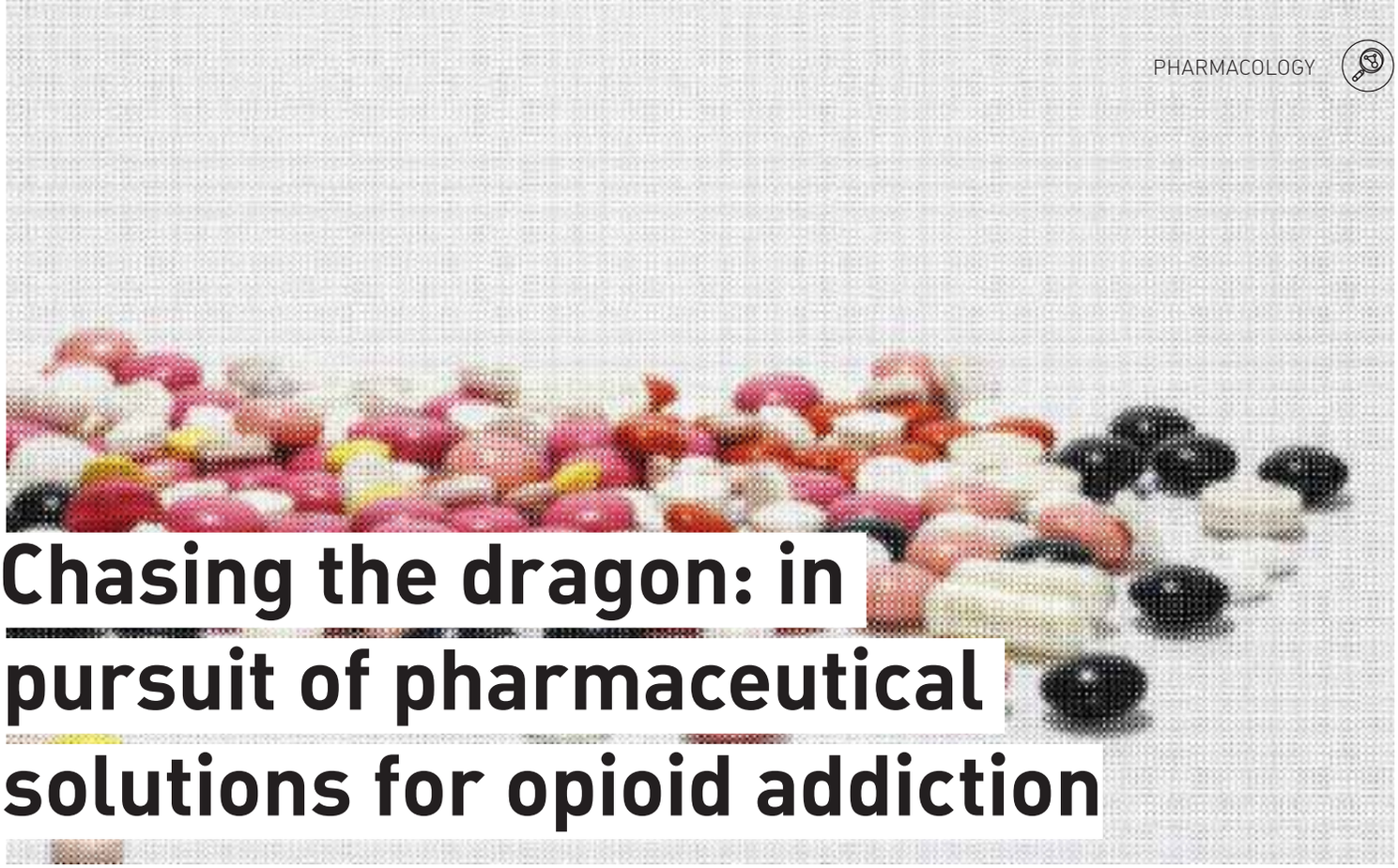
With that in mind, one of Lin's future goals is for her team's activities to inform key decision makers in government agencies about the importance of facilitating nutritionally balanced diets. This is particularly important for Kentucky because the state now has the twelfth highest adult obesity rate in the nation, according to *The State of Obesity: Better Policies for a Healthier America*. The University of Kentucky has brought researchers together to solve a number of health disparities, including obesity, as well as premature death from conditions such as cancer, stroke and cardiovascular diseases – a goal that could not be achieved without support from the state.

While it is easy to make dietary recommendations to members of the public, it is not always as straightforward as purchasing the correct foodstuffs and incorporating them into a diet. And, although the relationship is extremely complicated and not fully understood, there is a wealth of evidence suggesting a link between poverty and obesity.

One reason for this association is that individuals in impoverished regions have poor access to fresh food, but there is also evidence supporting the idea that people living in poor countries are less active. There are several reasons for this, including the fact that violence tends to correlate with poverty, so individuals become more reluctant to venture outside through fear. In addition, poor people are less likely to be able to afford things such as exercise equipment and gym memberships.

Lin is therefore intent on encouraging governments to provide services and education for their citizens regarding the importance of healthy diets. "Governments can play a crucial role in facilitating the supply of quality food to these areas," explains Lin. "I believe that with the support of governments, people could obtain higher quality nutrition and make better decisions regarding their diet." Crucially, Lin emphasises the need to educate children. If the importance of a balanced diet can be instilled in an individual at a young age, it is far more likely to stay with them throughout their lives. And, significantly, this information would be cascaded down to their children, thereby becoming common practice for all society. Another goal for Lin is to encourage governments to provide funding and financial support for research and education to solve health disparities.

Much has been made of the increasing prevalence of type 2 diabetes on a global scale and the need to eat healthily. However, with Lin's research activities, the onset of neurological diseases such as Alzheimer's – or type 3 diabetes – can be prevented. Ultimately, these findings help inform government programmes that can facilitate a healthy mind and body.



Chasing the dragon: in pursuit of pharmaceutical solutions for opioid addiction

Interdisciplinary researcher **Professor Robert Levenson** discusses his multifarious career as a molecular biologist, neurologist and pharmacologist, as well as the overarching objectives of his work on opiate addiction

Could you explain what motivated you to enter the pharmacology field and why you decided to focus specifically on opioid addiction?

It's a roundabout story. I'm not really trained as a pharmacologist – I'm a cell molecular biologist, and when I started my career my real interest was in developmental biology and the things that regulate development. I began my professional career at Yale. This was back in the mid-1980s when I was working on a protein that turned out to be very important for brain function. I hadn't actually thought about the brain until I worked on this protein. For years, I tried to set up a collaboration with a neuroscientist at Yale who's pretty famous – but she kept on rejecting the idea of me getting involved in a collaboration with her because she didn't see where we overlapped. Then one day she approached me because she was looking for someone who could make antibodies – something we could do very well – and asked if I would be willing to collaborate with her on making antibodies against dopamine receptors. So that was my entrance into the brain and receptors.

Why did you focus on dopamine receptors in particular, and why are they important in human health?

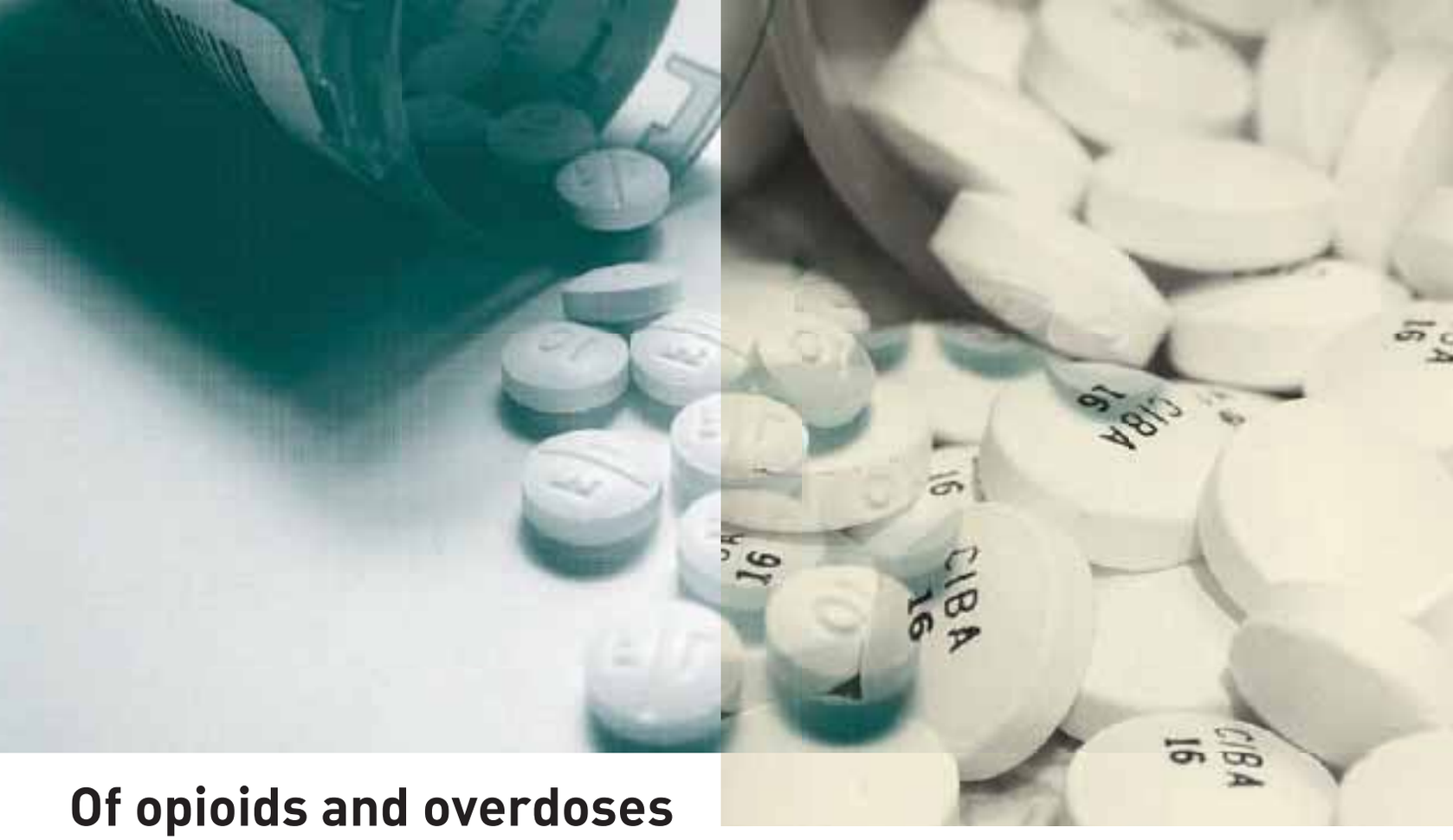
Dopamine receptors are the targets that are used to treat schizophrenia, so for about five years I made antibodies with this professor. Eventually, I got tired of making antibodies but I became very interested in the concept of dopamine receptor biology and its role in schizophrenia. What struck me as being the central paradox was that all the drugs that were available at the time worked through dopamine D2 receptors – and so one would have naively thought: 'Well, there must be something wrong with dopamine reception in the brains of schizophrenics'. The paradox was that when you compared the primary structure/expression of these receptors between schizophrenic and normal brains, you saw that there was absolutely nothing wrong with them! So the question was: how did the drugs provide therapeutic efficacy at a target which, for all intents and purposes, seems to be normal?

What accounts for the sudden rise in opioid-related deaths in recent years?

In the US now, the number of deaths caused by opioid abuse outnumbers the deaths caused by auto accidents. That's pretty astounding – and there are many reasons why the death rate has been increasing. One is that the number of people using these drugs has increased – and there is a direct correlation between the number of people using the drugs and the number of people who are overdosing on them. The other reason is that heroin has become so cheap that it is replacing prescription opioid drugs as the drug of choice. Opioid medications are expensive and it's getting harder for drug addicts to get hold of those drugs. More people are now turning to heroin – and part of the problem with heroin is that you don't know what you're getting. A lot of heroin is mixed with pretty toxic substances and many heroin addicts use heroin synergistically with other drugs of abuse – so the drugs actually become more powerful. And now there's another problem: fentanyl, a synthetic opioid that is cheaper than heroin and about 100 times more powerful. So all of these factors contribute to the increase in drug-related deaths.

Do you anticipate that your research will feed into the development of therapeutics?

That would be the long-term goal for sure. It's difficult to predict when this would happen, because we still don't know if the targets we have uncovered have any real impact on drug addiction or relapse. That is the stage we are at, at present. If we can really convince ourselves and the scientific community that the molecular targets we have identified do impact drug taking or drug seeking, then it's pretty clear that they would be targets for the development of novel drugs.



Of opioids and overdoses

The human relationship with opioid drugs is long and sordid – but today, researchers at **Pennsylvania State University** in the US are hot on the trail of molecular answers to age-old problems like addiction; their results could change the face of pain relief

OPIOID DRUGS ARE drugs that act on the opioid receptors to produce analgesic effects – that is, they kill pain. Opiates derived from natural sources, such as poppies, have been used recreationally and as painkillers for many centuries – but their use has always been associated with side effects like addiction, as well as premature death.

Although opiates are recognised as being among the most problematic drugs of abuse today, opioid drugs that activate the same receptors can still be obtained; even these improved forms of drug can cause harm, however. In 2014 alone, the Centers for Disease Control and Prevention (CDC) attributed more than 47,000 deaths to prescription drug abuse. The CDC estimates that 44 people die each day from prescription pain medication overdoses, with nearly 7,000 people treated in emergency rooms for misusing these medications.

The nonmedical use and abuse of prescription opioid drugs has become a substantial public health problem in many countries, including the USA. In January this year, the American Association of Medical Colleges and the Congressional Academic Medicine Caucus held a Capitol Hill briefing to highlight efforts at medical schools and teaching hospitals that are responding to the opioid epidemic that has been gripping communities from small towns to large urban centres. The figures quoted at this event were shocking, to say the least: the National Institute on Drug Abuse asserts that from 1992 to 2003, misuse of opioid prescription painkillers increased by 140 per cent – and, according to the 2013 National Survey on Drug Use and Health, almost 2 million Americans are opioid-dependent.

REDUCING RELAPSE

Opioid addiction is characterised by craving, evidence of self-harm, the illicit purchasing of opioids, taking of non-prescribed opioids and other aberrant behaviours. The consequences of this epidemic in the US include overdose deaths, which now outnumber deaths caused by auto accidents.

Drug overdoses still frequently occur despite the availability of the opioid blocker, naloxone, for the rapid treatment of respiratory depression. This is, in part, because addiction is nothing if not complex. Efforts to treat the problem with standard agonists and antagonists have failed. While the causes of this epidemic are complex, they likely include over-prescription of pain medications – and recidivism rates are also a notable problem.

The nonmedical use and abuse of prescription opioid drugs has become a substantial public health problem in many countries

This is a national problem, and new approaches to it are sorely needed.

One group of researchers at Penn State University in the US is working on advancing such novel approaches through a better understanding of the underlying mechanisms of vulnerability to addiction and relapse. Dr Robert Levenson is Distinguished Professor of Pharmacology and Neural and Behavioral Sciences and Co-Director of the MD/PhD Program at the University's Department of Pharmacology, in addition to his role as leader of this research team. "If we are to develop novel therapeutics that can effectively prevent opioid addiction and relapse in humans, we need innovative ways of approaching this problem," Levenson remarks.

THE BARE BONES OF ADDICTION

Addiction, by nature, is a chronic disease of relapse – and humans are known to relapse to drug-seeking and taking behaviour following months or even years of abstinence. The goal of this research is to develop an understanding of the molecular mechanisms underlying vulnerability to addiction and relapse – that is, the causative factors of addiction at the molecular level. Knowledge of these molecular mechanisms could serve as a platform for the development of novel therapeutics to prevent relapse to drug use without the stigma or risk associated with opioid replacement therapies such as methadone or buprenorphine treatment.

To achieve this goal, Levenson and his colleagues have focused on a cellular protein termed the μ-opioid receptor – a protein expressed on the membranous surface of cells which interacts with opioid drugs and mediates their effects on the cell. When the gene for this protein is deleted in animal models, they become resistant to addiction – but they also no longer experience relief from pain when treated with the drugs.

GOING WNTLESS

The Levenson lab began its present course of study in 2010 when Jay Jin, then an MD/PhD student in Levenson's laboratory, made the surprising observation that, in neurons of the mammalian brain, the μ-opioid receptor also interacts with another protein called Wntless. The Wnts, the family of proteins to which Wntless belongs, regulate a variety of events during embryogenesis including proper development of the brain. In the adult brain, the Wnt signalling pathway also regulates neuronal activity, including the numerous contacts the dendritic spines of neurons make with other neurons that are important for intercellular communication, and the production of neuronal stem cells.

Opioid drugs, as Jin discovered, interact with this signalling pathway. The important neuronal functions of the Wnts are blocked via the effects of opioid drugs, and the interaction between Wntless and the opioid receptors is enhanced via treatment with opioid drugs. Jin's experiments therefore suggested, for the first time, that the Wnt signalling pathway may play an important role in the manifestation of addiction-like behaviours and relapse to drug taking after abstinence. Since the publication of the paper describing these important results was published, a number of other labs have reported that Wnt signalling also plays an important role in mediating cocaine-induced behaviours as well as relapse to addictive drugs such as ketamine.

FIGHTING FIRE WITH PHARMACOLOGY

To better understand the role of Wnt signalling in opioid addiction, Levenson developed on these revelations by analysing the expression of the Wntless protein in a rodent behavioural model in which rats were trained to self-administer heroin. These behavioural studies were carried out by Diana Tacelosky, an MD/PhD student in his lab, in collaboration with Dr Sue Grigson, an internationally recognised expert in the field of addiction research at Penn State. Using this model, in which drug self-administration was similar for all subjects during the acquisition phase of training, the team showed that reduced expression of Wntless in the prefrontal cortex of rats was associated with greater addiction-like behaviour for heroin in general, and with a greater willingness to work for the drug in particular.

These data thus linked reduced Wnt signalling to the explicit motivation for the drug rather than to differences in total drug intake, and gave the Pennsylvania researchers an idea: by stimulating Wnt signalling, they hypothesise, they could prevent acquisition and/or relapse to addiction-like behaviours in the context of heroin.

"The focus of our current research programme is therefore designed to test this hypothesis," Levenson explains – and, in order to do this, the team is taking a pharmacological approach to determine whether it is possible to prevent relapse to drug-seeking behaviour in heroin-addicted rats after a period of abstinence. The idea here is to overcome the inhibiting effect of opioids on Wnt signalling by treating rats with a synthetically produced small organic molecule that has previously shown by others to stimulate Wnt signalling in the brain.

A positive outcome from this type of approach would establish the Wnt signalling pathway as a key cellular component contributing to vulnerability for opioid addiction and relapse – and could lead to new avenues for the pharmacotherapy of drug addiction in human opioid addicts.

OPIOID ADDICTION AND RELAPSE

OBJECTIVE

To discover the molecular mechanisms that are responsible for causing vulnerability to addiction and relapse.

CONTACT

Professor Robert Levenson
Distinguished Professor of Pharmacology and Neural and Behavioral Sciences

The Pennsylvania State University
500 University Drive
Hershey
Pennsylvania, 17033
USA

T +1 717 531 4545
E rlevenson@hmc.psu.edu

http://bit.ly/1pgXg1F

ROBERT LEVENSON received an AB from Bard College in 1967, an MS from New York University in 1971 and a PhD from SUNY Stony Brook in 1976. He also attended Medical School at the University of Florence, Italy, from 1968-1971. In 1984, he was appointed Assistant Professor of Cell Biology at Yale University School of Medicine and was promoted to Associate Professor in 1990. Levenson joined Penn State College of Medicine in 1994 as Professor of Pharmacology. He has served on numerous National Institutes of Health (NIH) study sections and has been Co-Director of the MD/PhD Program since 2004.

Health policies and interventions: promoting positive development

Professor Diana Fishbein is Director of the Bennett Pierce Prevention Research Center at Pennsylvania State University in the US. Her research focuses on understanding the effects of environmental influences on brain development and, in turn, behavioural health. She discusses her background, the life experiences that motivate her and some exciting projects she is leading

NPSC Board of Directors retreat

How did you develop an interest in mental health, emotional and behavioural problems and what motivates you in your research?

My professional interests and motivations began with my childhood experiences. I was raised in a disadvantaged neighbourhood just outside of Washington, DC with a high rate of crime, alcoholism, domestic violence and child abuse. I was one of the fortunate individuals with a healthy home life, but I had friends whose mothers were prostitutes, who were left outside on a cold night for minor misbehaviours, who were beaten and exposed to alcoholism, violence and other atrocities.

I realised early on that despite our similar neighbourhood-level experiences, a tremendous amount of individual variation contributes to ultimate outcomes. In fact, most of my peers did not become dysregulated or maladaptive, despite their experiential history. By fifth grade, I knew what I wanted to do when I grew up – devote my life to shedding light on the circumstances and conditions that lead to individual differences beyond what the environment confers. I needed to know what set apart individuals who were resilient from those who were unable to resist maladaptive trajectories. Ultimately, the goal of my research is to apply this knowledge to design interventions and policies that more effectively prevent the development of behavioural problems.

Congressional briefing of US Capitol Hill

You are the Director of the Bennett Pierce Prevention Research Center for the Promotion of Human Development (PRC). Can you provide some details about the Center?

The PRC has an international reputation as a leading-edge centre for prevention research. It was established in 1998 by Dr Mark Greenberg – and endowed by Edna Bennett Pierce – to

engage community, university and government colleagues in the development of research and outreach initiatives focusing on the risk and protective factors that affect child and family functioning. The Center's mission is to conduct cross-cutting research, train new investigators, disseminate knowledge and provide technical assistance to policy makers and communities on the prevention of human problems – spanning behavioural, academic, mental health and physical health – and to promote positive development in children, adolescents, families and communities.

What are some of the main achievements of the Center to date and its aims for the future?

Important to its many initiatives and activities is the PRC's strategy of recruiting national experts with a diverse skill set directed toward various questions that are still outstanding in prevention science. The PRC, in turn, provides the resources and the 'learning community' that is needed to advance the science and contribute to the overall body of work, as well as exert a positive impact on the phenomenon under study. Areas of particular interest currently include childhood and adolescent development, emerging adulthood, family science, compassion and mindfulness, and education, among others. Studies are inherently translational, starting with discovery science – such as neurobiology, genetics and behavioural science – and translating those findings to guide intervention development, implementation, evaluation and dissemination. Then, scaling and institutionalising evidence-based practices (EBP) for sustainable and large-scale impact. Researchers at the PRC are providing leadership on outstanding prevention science questions, thereby positively influencing both the scientific field and, in turn, the quality of people's lives throughout the US and around the world.

Are there any particularly innovative or exciting projects and initiatives being conducted at the PRC that you would like to highlight?

The work conducted by PRC investigators is both innovative and impactful. PROmoting School-community-university Partnerships to Enhance Resilience (PROSPER) advances the development of sustainable partnerships among schools, communities and universities to facilitate the delivery of evidence-based interventions designed to reduce adolescent substance use and problem behaviours and to promote youth competence. This project exemplifies the PRC's translational breadth in its focus on genetics and neuroscience, prevention trials work, dissemination and cost analysis. In the 28 communities that participate, findings reveal significant improvements in youth outcomes.

And as the new Director of the PRC, my strategic plan includes the incorporation of neuroscience into prevention research and practice. We will explore mechanisms of behavioural change in response to intervention to address the question: what works best, for whom, why and under what circumstances? This programme of research will ultimately inform the development of novel interventions that benefit more recipients.

In what ways has the PRC set the stage for translation and innovation in the scientific arena and community in general?

The PRC has long been a world leader in the advancement of prevention science relating to the translation and dissemination of effective preventive interventions. In 1999, the PRC hosted a scientific meeting of the country's leading prevention researchers. The aim was to begin to develop some of the first conceptual models for studying intervention implementation to facilitate the movement of evidence-based programmes to widespread practice. At the same time, PRC researchers conducted one of the first comprehensive research reviews to identify model programmes for the prevention of children's mental health and behavioural health problems.

The PRC's portfolio of research related to translation, dissemination, implementation and sustainability has grown tremendously. Work in this area includes large, multi-state and multi-site randomised trials of new models for disseminating evidence-based programmes, large-scale studies of the replication of EBPs under natural conditions to examine barriers and predictors of implementation quality and sustainability, the study of coalition models to promote and support going to scale, and developmental and comparative trials of EBP adaptations.

Making prevention a priority

Behavioural, mental and physical health problems are a significant burden on individuals and societies around the world. Treatment is one solution – but an enterprising team of researchers from **Pennsylvania State University** believes that prevention is the key to driving positive change in families and communities and for informing effective governmental policies

IN 1895, THE temperance activist Joseph Malins wrote a poem entitled 'The Ambulance Down in the Valley', in which he describes a town engaged in a bitter dispute about the best way to deal with the problem of people falling off a cliff. For many of the townsfolk, the tried and tested method of parking an ambulance at the bottom of the valley was seen as a sufficient means of dealing with this problem.

However, midway through the poem, one man suddenly stands up and suggests to his peers that they erect a fence at the top of the cliff, preventing people from falling in the first place and thereby doing away with the need for an ambulance. Thus, the poem emphasises the value of prevention over cure – and over 120 years later, it is still quoted and referenced in modern-day health resources.

The importance of prevention in the field of healthcare is the cornerstone of the activities of researchers at the Bennett Pierce Prevention Research Center (PRC) at the Pennsylvania State University in the USA. The aim of the Center is to conduct research that examines how community residents and organisations can work together to promote healthy lifestyles for all members of society and to develop and implement innovative interventions that prevent children and adolescents from developing behavioural

health problems and foster positive outcomes for families.

FOUR FACTORS FOR PREVENTION

The Director of the Center, Professor Diana Fishbein, is a passionate advocate for the benefits associated with preventive measures that address individual and societal problems before they develop. "Using analytics developed by statisticians and economists, the scientific method of evaluating outcomes gives us unbiased evidence of what works for whom, why and under what circumstances," explains Fishbein. "Policy makers and practitioners can use the evidence generated by scientific research and evaluation to effectuate positive change for individuals, families and communities."

Basing decisions on rigorous scientific evidence ensures that solutions to many of our social problems can be systematically and effectively applied, irrespective of ideological or political leanings. Indeed, an objective, science-based approach is vital for solving some of the most taxing and persistent problems facing society today.

Importantly, successful and well thought out preventive policies adhere to four conditions. First, they aim to recognise early warning signs that predict or lead to poor outcomes. Second, they are developmentally and culturally appropriate and accessible to the communities they serve. Third, they focus on reducing exposure to detrimental conditions, or address the effects of such conditions. And fourth, they demonstrate the cost savings of prevention. In considering these factors, the concepts and strategies of prevention science are upheld and improve young people's chances of growing up as healthy and well-rounded individuals.

IDENTIFYING MALLEABLE MECHANISMS OF BEHAVIOURAL CHANGE

Alongside her role as Center Director, Fishbein also founded and directs the Program of Translational Research on Neurodevelopment and Adversity (P-TRAN) within the PRC. P-TRAN is an innovative, transdisciplinary programme of research that focuses on ways in which environmental conditions influence the developing brain and, in turn, behaviour. "Our working model proposes that risk for behavioural problems varies between individuals and can only truly be understood by recognising that our orientation to and processing of environmental inputs rely integrally upon genetic and neurobiological mechanisms," explains Fishbein.

Crucially, the programme recognises that such underlying mechanisms interact with various psychosocial and environmental factors that affect the way individuals develop – in either a positive or negative trajectory. Research suggests that neurodevelopment is not fixed, suggesting that there is always the potential for evidence-based interventions to successfully improve development and overall behavioural health outcomes if programmes are appropriately targeted. Accordingly, nothing is considered beyond the scope of hope – where prevention science aims to stop the problems from developing in the first place, intervention strategies are able to ameliorate problems that are emerging.

As such, the team at P-TRAN works on integrating theoretical perspectives and empirical methods from multiple disciplines. Importantly, their ambitions for the future revolve around tailoring interventions to mechanisms that underlie behavioural problems and individual-level characteristics. "The premise behind our research is that tailored, targeted interventions will be most effective when psychosocial and pharmacologic manipulations are mapped to an individual's unique constellation of social, psychological and biological attributes," explains Fishbein. "This reinforces more adaptive and normative phenotypes."

To exert a sustainable impact on the phenomenon under study, the ultimate aim of P-TRAN is to transfer scientific findings for use in communities and for use by policy makers.

TRANSLATING AND TRANSFERRING FINDINGS TO ACTION

Fishbein also spearheads the National Prevention Science Coalition to Improve Lives (NPSC). This organisation is comprised of scientists, educators, community stakeholders, practitioners and clinicians, policy makers, and foundation representatives. The aim of the NPSC is to improve the chances for children and adolescents to lead healthy, successful lives, and for families and communities to thrive by facilitating the transfer of knowledge to practice and policy.

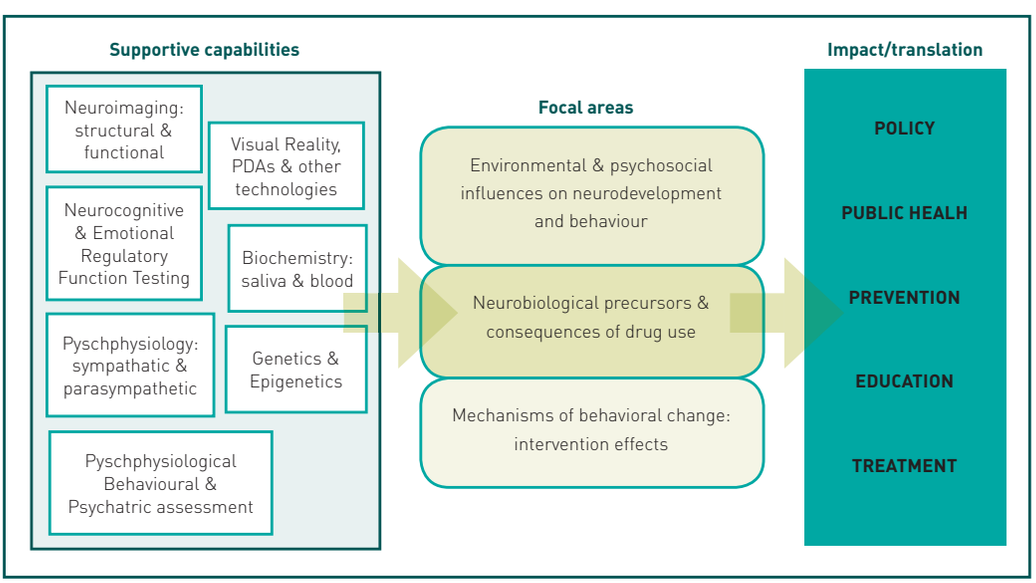
"NPSC has convened national experts to present findings from prevention science to federal decision makers," explains Fishbein. "More broadly, we routinely engage in a bipartisan manner with US Congressional offices and Congressional Caucuses, where some are incorporating the evidence-based knowledge we convey in proposed legislation." Encouraging uptake is an extremely important aspect of Fishbein's research activities. Not considering the potential for impact is akin to suggesting that fences should be erected on the cliffedge to prevent people falling off – but never actually getting around to building them. The research underway is of vital importance – but unless it leads to action, it merely exists as an idea, albeit one that is backed up by solid scientific evidence.

Thus, NPSC also collaborates with US federal agency administrators interested in incorporating prevention science in their strategic plans. In addition, members continuously write and publish opinion editorials, white papers, policy statements and fact sheets to help inform decision makers and constituents.

PREVENTION IS BETTER THAN CURE

Despite the fact NPSC is still a relatively new organisation, it has 450 members to date and continues to grow. It has also formed numerous affiliations with national organisations, institutions and universities. Ultimately, its aim is to infuse a prevention mentality into the public and private sectors, where the emphasis is on proactively preventing problems, rather than reactively responding to them.

In short, Fishbein and her colleagues are doing away with the ambulance at the bottom of the valley and are instead erecting a fence at the top of the cliff. To rescue those affected by adversity is a worthy feat, but preventing the causes of adversity in the first place is an even more important endeavour.



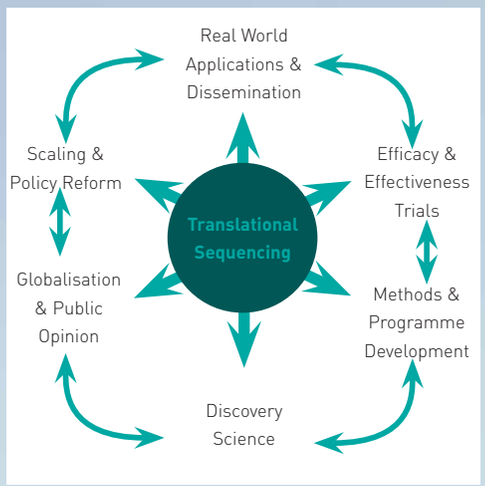
TRANSLATING RESEARCH TO MAKE IT MATTER

Pennsylvania State University's Prevention Research Center (PRC) is a pioneer in implementing and disseminating its findings into interventions with measurable benefits to individuals, families and communities. The Director of the Center, Professor Diana Fishbein, works tirelessly on a range of activities with various researchers at different locations to oversee and facilitate the continuing development of prevention and intervention strategies.

"It has repeatedly been shown that evidence-based programmes can only impact population-level public health if they are effectively taken to scale, implemented with high quality, and sustained over time," explains Fishbein. "PRC faculty engage in rigorous research to improve understanding of the mechanisms that impact the diffusion of innovations for the improvement of health."

In total, the PRC has five distinct translation and dissemination goals:

- Advance the science, policy making, and practice of utilising evidence-based prevention to improve public health
- Conduct rigorous research aimed at identifying the resources and processes necessary to effectively take evidence-based programmes to scale
- Identify and promote practices that lead to high-quality implementation and sustainability of evidence-based programmes
- Develop a model infrastructure for the dissemination, implementation, and sustainability of effective prevention programmes and practices
- Foster networks of researchers, policy makers, and practitioners engaged in efforts to improve public health through evidence-based prevention



PREVENTION RESEARCH FOR INFORMING THE DEVELOPMENT OF EFFECTIVE INTERVENTIONS AND POLICIES

OBJECTIVES

To promote child and famiily wellbeing by facilitating the design, dissemination and scaling of effective prevention policies and interventions.

KEY COLLABORATORS

Dr John VanMeter, Georgetown University, USA • **Dr Ralph Tarter**, University of Pittsburgh, USA • **Dr Emma Rose**; **Dr Mark Greenberg**; **Dr Lisa Gatzke-Kopp**, Pennsylvania State University, USA • **Dr William Aldridge**; **Dr Aysenil Belger**, University of North Carolina, USA • **Dr Neil Wollman**, Bentley University, USA • **Dr Scott Novak**; **Dr Ty Ridenour**; **Dr Jason Williams**, RTI International, USA • **Dr Howard Dubowitz**; **Dr Elliot Hong**, University of Maryland School of Medicine, USA • **Dr Elliot** Stein, NIDA Intramural Research Program, USA • **Dr Tony Biglan**, Oregon Research Institute, USA • **Dr Ronald Prinz**, University of South Carolina, USA • **Dr Steven Porges**, Kinsey Institute, Indiana University, USA

PARTNERS

University of Maryland School of Medicine • Johns Hopkins University • Brown University • RTI International • Georgetown University • The National Institute on Drug Abuse, Intramural Research Program • University of Pittsburgh • Oregon Research Institute • University of North Carolina

FUNDING

The National Institutes of Health • Doris Duke Charitable Foundation • Annie E. Casey Foundation • W.T. Grant Foundation • Robert Wood Johnson Foundation • The State of Pennsylvania • US Department of Education

CONTACT

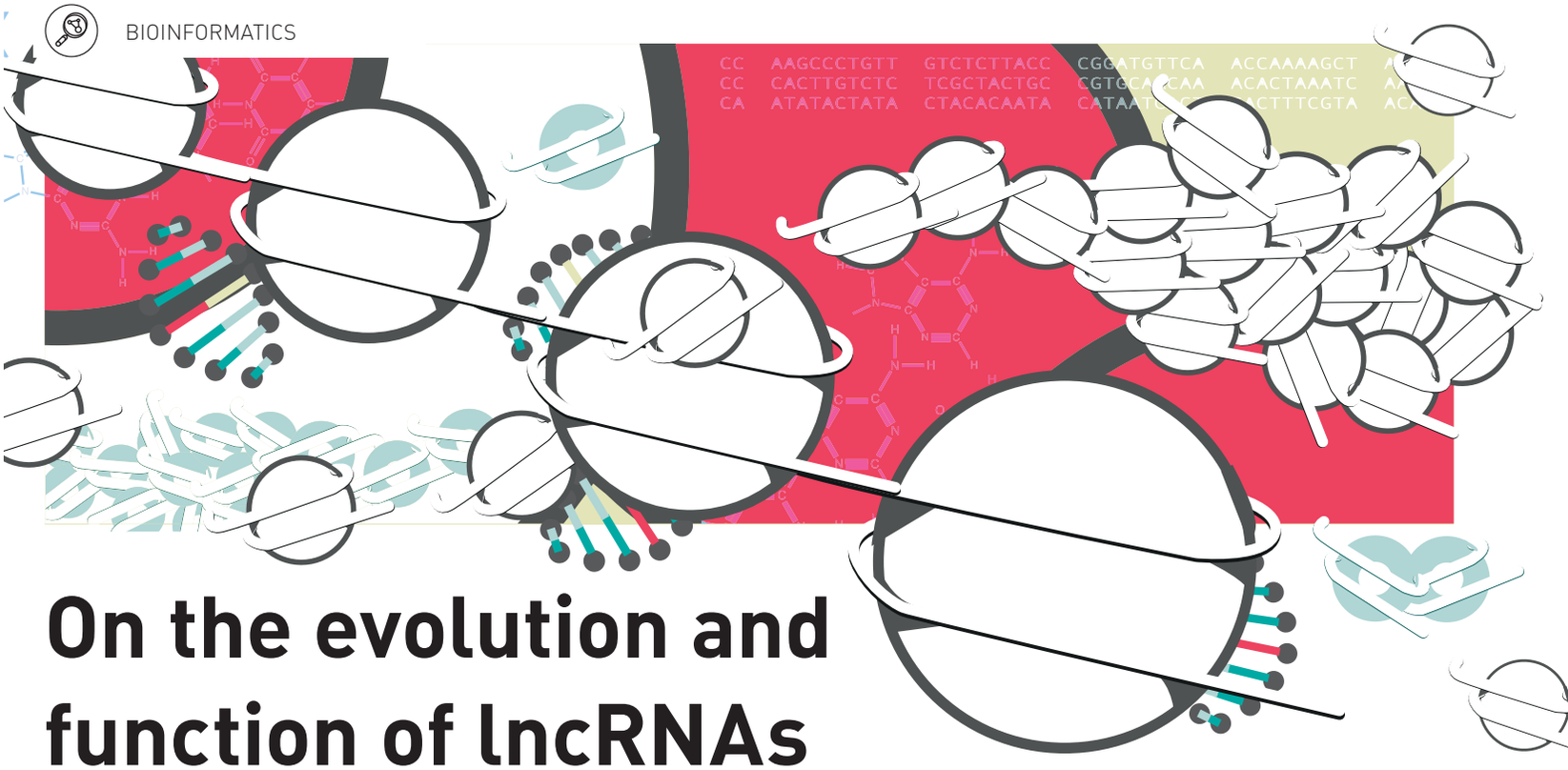
Professor Diana Fishbein
Director, Bennett Pierce Prevention Research Center

302 Biobehavioral Health Building
Pennsylvania State University
University Park, Pennsylvania 16802
USA

T +1 814 865 7377
E dfishbein@psu.edu

http://prevention.psu.edu/people

DIANA H FISHBEIN is Director of the Bennett Pierce Prevention Research Center at the Pennsylvania State University, a professor in the Department of Human Development and Family Studies and the Director of the Program of Translational Research on Adversity and Neurodevelopment. She is also an adjunct professor at the University of Maryland School of Medicine and Johns Hopkins University, a faculty subcontractor at Georgetown University and a guest researcher at the National Institute on Drug Abuse Intramural Research Program. Studies conducted by Dr Fishbein utilise transdisciplinary methods and a developmental approach to understanding interactions between neurobiological processes and environmental factors and their effects on behavioural health.



On the evolution and function of lncRNAs

Professor Hao Zhu describes his work on the evolution and function of long non-coding RNAs, explaining how his new computational approach could provide novel information towards an improved understanding of when and how they regulate epigenomic modification

Firstly, can you explain why you chose to focus your research on long non-coding RNAs (lncRNAs) and provide some context regarding the importance of your computational studies to the medical sciences?

Less than 2 per cent of human DNA encodes protein-coding genes, and there are only slight differences in these highly conserved genes between species such as humans, mice and even fish. This makes it difficult to explain the distinct phenotypes of animals. Recently, considerable DNA regions previously classified as 'dark matter' were found to encode long RNAs that lack protein-coding capacity, and the clade- or species-specificity of these lncRNAs could explain the distinctive phenotypic differences. When I became an independent researcher in 2009, the many new genes discovered meant new opportunities and challenges.

Many non-coding RNAs bind to DNA in unconventional ways, and lncRNAs are not an exception. Since they bind to both DNA sequences and DNA/histone-modification proteins such as DNA methyltransferase and polycomb repressive complexes, the function of many lncRNAs is to regulate epigenomic modification and alter the genome state without changing its DNA sequence. Many diseases, including cancers, are caused by dysregulated gene expression, often as a result of dysregulated epigenomic modification. I am using computational methods to systematically reveal both the DNA-binding motifs within the lncRNAs and their corresponding binding sites in genomes. Taken together, this information will significantly help to explain the mechanisms of many diseases.

How does your research build on the limited information available on lncRNA functional domains, including their origins and evolution?

Experimentally identifying lncRNAs using sequencing techniques was expensive, so I began by analysing the origin and evolution of individual lncRNAs such as HOTAIR and ANRIL. Now, lncRNAs in humans and mice have been systematically identified by the GENCODE project using RNA sequencing (RNA-seq), yet their functional domains still remain unclear.

To analyse lncRNA functional domains, homologous genes are often needed. Sequence alignments can reveal which parts are conserved and which are not. Using the Infernal program developed by Professor Sean Eddy (Janelia Farm Research Campus, USA) running on the Tianhe 2 supercomputer, I spent more than a year searching the orthologous genes of the GENCODE identified 13,562 human lncRNAs in 16 mammalian genomes. These obtained sequences facilitate the analysis of the origin, evolution and functional domains of human lncRNAs.

By what means does your computational method and program, LongTarget, overcome the difficulties involved in deciphering lncRNA functions and erroneous genome methylation?

Identifying the DNA-binding motif (normally 40-80 base pairs) in an lncRNA (may be up to 90 kilobases) is difficult. LongTarget adopts a simple method: reconstruct the DNA sequence of interest using base-pairing rules, align the reconstructed DNA to the lncRNA, and analyse and recognise binding motifs and binding sites simultaneously in the aligned regions. We have analysed considerable lncRNAs that function *in cis* or control an imprinting cluster, and confirmed that this method works well. A challenge we still face is to analyse lncRNAs that function *in trans*, that is, they bind to remote sites on the same chromosome or even to sites on other chromosomes.

Do you have any plans to develop this research further in the next few years?

Yes. My first task is to improve the running speed of LongTarget by implementing an OpenMP version. I then plan to systematically analyse the DNA-binding motifs and binding sites of simian-specific, human-specific and mouse-specific lncRNAs, as this is likely important for deciphering why we are human and to what extent simians are different from rodents. Meanwhile, I plan to analyse the sequencing data of cancers, to pursue a mechanical understanding of dysregulated and cell-specific gene expression in cancer cells and to determine whether cancers show commonalities in epigenomic modification.

A spotlight on genomic 'dark matter'

Researchers from **Southern Medical University**, China, have developed an effective computational approach that helps elucidate long non-coding RNAs' DNA binding motifs and binding sites

LONG NON-CODING RNAs (lncRNAs) comprise a significant portion of the human genome, but do not encode proteins, and were once thought of as the 'dark matter' of the genome. While difficult to detect and characterise, they are known to play important roles in the control of gene expression and other cellular processes by regulating epigenomic modification.

Gene expression can be silenced by either methylating the DNA that encodes them and/or modifying the structural chromatin of the chromosome itself. This epigenomic modification, performed by DNA methyltransferases (DNMTs) and polycomb repressive complexes (PRCs), is often found to be misregulated in cancerous cells where the cell cycle is incorrectly driven by consistently expressed genes. There are relatively few types of DNMTs and PRCs, so cells utilise lncRNAs with specific DNA-binding motifs to target these proteins to the required sites of the genome. The lncRNA forms a triplex with its complementary sequence on the double-stranded DNA using Hoogsteen base pairing. The identification of DNA-binding motifs in lncRNAs and their corresponding binding sites in the genome is therefore crucial for detecting target genes of lncRNAs and examining correct and erroneous epigenomic modification.

FINDING A BINDING MOTIF IN A HAYSTACK

The discovery of lncRNA DNA-binding motifs is experimentally very difficult, because little information is available on their structures, and lncRNAs can be up to 90 kilobases in length while their typical DNA binding motifs are just 40-80 bases long. Professor Hao Zhu and his team at Southern Medical University, Guangzhou, China, have developed an effective computational tool, LongTarget, that can predict lncRNAs' DNA-binding motifs and the genes they target. "The human genome contains more than 13,562 lncRNAs, so computationally predicting their DNA-binding motifs and genomic binding sites is highly valuable," Zhu elaborates. "Predicting an lncRNA's DNA-binding motif could reveal how mutations would influence its ability to bind to DNA, while predicting an lncRNA's binding site(s) reveals which genes it epigenomically regulates."

Zhu tested LongTarget by analysing lncRNAs that silence genes at known genomic regions (imprinting clusters). The program's predictions were found to be sensitive and specific, showing that it is feasible to predict many lncRNAs' DNA binding motifs and binding sites. Zhu also showed that, in addition to the promotor regions and common DNA methylation targets known as CpG sites, lncRNAs also bind to many transposable elements, possibly including those within the lncRNA genes themselves. He proposes that lncRNAs targeting these transposable elements may help to regulate the highly tissue-specific expression of lncRNAs themselves. As the data available on these enigmatic molecules increase, innovative computational studies and tools such as that developed by Zhu will pave the way for novel discoveries in cell biology.

FUTURE APPLICATIONS

Determining the function of lncRNAs is fundamental to our knowledge of the epigenomic regulation of genes and the control of cellular processes. Cancers are caused by misregulated gene expression and it is becoming increasingly clear that lncRNAs may play a significant role. "For a long time, researchers believed that mutations in protein-coding genes or their associated transcriptional factors were the key drivers of many diseases, including cancer," Zhu explains. "Now, increasing evidence shows that aberrant lncRNA-regulated epigenomic modification results in the misregulation of protein-coding genes. The elucidation of how lncRNAs alter gene expression is therefore valuable for the diagnosis and treatment of cancers and other diseases."

LongTarget will also allow Zhu to answer some questions from his previous research on the origin and evolution of lncRNAs; comparing sequences of lncRNAs in related species could provide a useful insight into their often short evolutionary history. He is also striving to improve the efficiency of the program itself, and welcomes any suggestions or collaboration enquiries.

LONGTARGET

OBJECTIVES

- To use computational studies to elucidate the origin, evolution, clade specificity and functional domains of long non-coding RNAs (lncRNAs)
- To identify how lncRNAs alter epigenomic modification and gene expression to gain a better understanding of cancers and other diseases

FUNDING

National Science Foundation of China (NSFC)

National Supercomputer Center in Guangzhou

CONTACT

Professor Hao Zhu

Southern Medical University, China

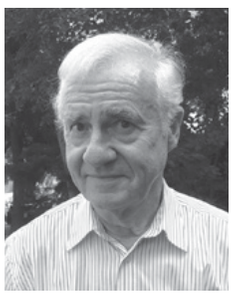
T +86 20 616 486 632
E zhuhao@smu.edu.cn

HAO ZHU worked in a hospital for years. After obtaining an MS in Computer Science, he joined a medical university, where he obtained a PhD in Pathophysiology in 2000. Subsequently, Zhu was a postdoc at the Bioinformatics Institute of Singapore and the University of Nottingham, working on modelling developmental signalling (systems biology). In 2009, he joined Southern Medical University in China, focusing more on genome analysis (especially lncRNA analysis).

Historic scientific accomplishments in the past 200 years, such as the theory of special relativity published by Albert Einstein in 1905 and Alexander Fleming's discovery of penicillin in 1928, represent the foundations from which life-changing developments have emerged. Factors such as improved resources, powerful technologies, open data and multidisciplinary collaboration have propelled R&D across the spectrum of scientific study worldwide

RESEARCH ROUNDTABLE

Q: Since you began your professional career, how have your approaches changed in response to progress?



DR MARTIN CULLUM
(Techbreak, European Science Foundation)

In my professional career of over 35 years in ground-based optical astronomy with the European Southern Observatory (ESO), much has changed. The rapid advances of computers, micro-electronics and photonics have revolutionised the way telescopes and instrumentation are designed and developed. Since the ESO New Technology Telescope that started operation in 1989, all subsequent large telescopes rely on relatively light active structures and thin or honeycomb mirrors instead of the massive constructions of steel and glass of the previous generation.

New technologies have not only allowed telescopes to be built cheaper and much larger than before, but also with a performance that was not imaginable 40 years ago. Similarly, the huge developments in photonics now allow observations that would have been inconceivable previously. The astronomy community worldwide does not have a huge amount of money for technology development. But it has spent development money rather effectively, by collaboration with other organisations, jumping early on the bandwagon of developments undertaken by military, aerospace or communications industries (CCDs and infrared array detectors for example) or investing modest funds to steer current technology developments in a direction useful to astronomy (the communications industry has little interest in sodium lasers, for example, which are fundamental for atmospheric turbulence correction).

A second big change has been the way in which major projects are managed. Forty years ago, it was widely believed that project management was largely a matter of intuition and common sense. With the right person at the top, things usually went OK, sooner or later. Since that time, much has changed. Projects have become vastly more complex and more expensive. National projects have become European projects or, in some cases like the Large Hadron Collider and Atacama Large Millimetre Array (ALMA) telescope, world projects. This internationalisation of projects has also led to projects being developed and manufactured by consortia spread over many different countries, instead of being designed in a single design office as before.

Good project management is now universally recognised as essential for the success of a project. A variety of effective and often simple management tools are now available that did not exist 35 years ago, which today, are considered essential for any large project. These include having a clear project specification at the outset, as well as having change management, configuration control, product assurance, systems engineering, design review, risk management, requirement management and verification management procedures in place and on a scale that is sufficient for the project being undertaken.

Today, the stakes are so high that no organisation can afford a single failure. On the other hand, there are many examples of major science projects like the ESO Very Large Telescope, that were completed essentially within budget, on time and according to specification. Unfortunately, this cannot be said of some government managed development projects, where lack of a clear project definition, technical ignorance and political micromanagement are too often prevalent.

PROFESSOR FREDERIK MAES
(KU Leuven)

Conventional approaches for object delineation in medical image analysis could be crudely categorised as either bottom up or top down. Bottom-up approaches compute pre-specified low-level features from the data and combine these into higher-level hypotheses using a rule-based approach. Top-down approaches rely on a pre-existing parametric model for the object of interest, and fit that to the data using an optimisation approach. Because of advances in computing power, hybrid strategies have emerged in which generic machine learning approaches are applied to a collection of image data to learn suitable models from the data itself by evaluating a large set of random features of which only the most relevant are retained. While these methods are conceptually simple, getting insight into the behaviour of the resulting models can be difficult, and convincing the clinical users of their validity may be challenging.

PROFESSOR SEAN HILL
(Blue Brain Project, École polytechnique fédérale de Lausanne)

Clearly, the development of information technology, large-scale data management and supercomputing has made it possible to understand the brain at a completely different scale than I had ever dreamed of when I started my career. The trajectory of technological development is now even greater, so my focus is on ensuring that we can effectively use information technology to understand the brain, but also to learn from the brain to produce better information technology.

DR ERIC GREEN
(National Human Genome Research Institute)

In the case of my professional career, I have experienced the transition of biomedicine into a data-intensive discipline. Biomedical research was not data-intensive when I was a medical student or graduate student in the 1980s, but now I am at the helm of an institute that is emblematic of biomedical big data. I think that our approaches to everything have to change because so much of what we do is not just about generating the data, but trying to figure out how to analyse it effectively. Therefore, the emergence of data science as a central component of biomedicine has been the major transformative change that I have witnessed in science.

DAVID GUSTON
(School for the Future of Innovation in Society)

My first response to this question is to try to tease out the difference between scientific progress and social progress, which the question may be conflating. Great scientific discoveries are important cultural artefacts in and of themselves. But even if they contribute to important innovations they are not identical to 'progress', which is a more explicitly social and normative category. Humans can certainly effect scientific and technical progress in the absence of social or moral progress, and while it may be easier to effect social or moral progress in the context of technical progress, the latter certainly is not a necessary condition for the former.

If I consider my professional career beginning upon the completion of my PhD in 1993, the most influential aspect of technical progress has been the internet, which was rendered much more usable with the introduction of the first graphical user interface, Mosaic, that very same year. As if to illustrate my point about social and technical progress, at that time, my Consortium for Science, Policy & Outcomes colleague Dan Sarewitz was on the island of Palau, writing a book. We had not yet met, and we began a long-hand correspondence because Palau was not yet connected to the internet, but both Dan and I had shed our typewriters. Accommodating myself to the changing nature of the internet, email, file sharing, video, the cloud, etc., has been a major aspect of my professional career, particularly as I have moved from being a researcher working alone or in a small group to running large-scale collaborations and serving administrative roles in academic organisations.

Now, with the advent of big data – something not surprising at all to me since I studied the fundamental technical and social bases of it as an undergraduate 30 years ago in a class on the sociology of computing – I'm confronted with the possibility that a much more predictive human science may be at hand. While I don't think that this will all turn out even as well as Isaac Asimov's fictional 'psychohistory' turned out in his *Foundation* trilogy, I'm open to the possibility that my insistence that humans are unpredictable may be as illusory as Einstein's insistence that "God does not play dice with the universe". Unfortunately, that potential outcome scares me because, again, technical progress in predicting human behaviour may not come with moral progress in respecting human behaviour.

K LINDSAY HUNTER
(Rising Star Expedition)

Max Planck is quoted as saying that "a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it". Or put more bluntly, he stated that "science advances one funeral at a time". In palaeoanthropology, our science sometimes appears to progress at the pace of geological time. We are notoriously slow to adopt modern methods, though this is changing, and, as was noted recently by Ian Tattersall, in many ways, resemble a 19th Century science in our parochialism.

In a sparse-data field dominated by isolated findings that form the core of our study, we are often subject to tribalism, jealously guarding access to these valuable resources beyond the means necessary simply for their preservation. In such an environment, my optimism that Lee Berger and John Hawks' ethic of open science (both in transparency and academic access) will one day become the prevailing zeitgeist has been met with no little amount of scepticism by my colleagues. However, it is my feeling that the winds of change are blowing across palaeoanthropology, and just as similar weathering processes uncover new fossils when they occur in the field, I see these 'winds' exposing past biases and effacing them in favour of paleontological perestroika.

DR MARCEL WUBBOLTS
(DSM; CTO of the Year 2015)

Albert Einstein sitting in the library of the Bern patent office of Switzerland thinking up his ideas and Alexander Fleming discovering penicillin – those were people who were excellent. You could add Louis Pasteur and quite a few more as well. There are many scientific heroes in our history. In those days, scientists were typically able to discover great things by themselves. However, I think there has already been a fundamental change in the last few decades, as most of the big innovations and discoveries are currently done by teams, some of which are very large. If you want to make a breakthrough in science, you can hardly do it alone. Most projects require collaboration and finding people that you can do things with, so that you can strengthen and amplify the output that you generate.

Since I began my professional career, when I did my PhD, I was mostly working on my own. I must say that, especially when I entered DSM, I realised that if you operate in teams and make teams that are very motivated to do things, you can take big steps – and those steps are far bigger than you could do on your own. Our approaches have been guided towards collaborating with others both internally and externally, especially in the last few years, as we have increasingly tried to go outside to find cross-fertilisation between different business areas and value chains.

If we refer to the bio-based economy, we are regularly talking with companies active in the forestry area because they have had loads of experience with processing wood and waste products from agriculture for many centuries, and that knowledge is extremely valuable for the chemistry materials part of the world right now. Reaching out to others is the way to go. Therefore, my approach really changed in the sense that I started looking for cross-fertilisation and thinking about what others are doing that can apply to my own industry.

At the CTO of the Year 2015 event, with all the CTOs coming together, there were a lot of people that suggested we work together from totally different sectors, such as aviation or computing. Unusual combinations of people typically spur quite a bit of fantastic innovation.

JONATHAN O'HALLORAN
(QuantuMDx; CTO of the Year 2015)

To be honest, my approach to progress hasn't changed much; I readily embrace it as I always have done. As a PhD student studying in the fields of genomics, I was taught to embrace an open, multidisciplinary approach to my research problems. The big data 'revolution' for us geneticists started way back in the 90s, when thousands of scientists, including myself, were sequencing humans and other life and sending the data to open databases like the National Center for Biotechnology Information or GenBank. We accessed the data and found trends, and shared that data through peer-reviewed journals and articles. As technology improved and sequencing got better, faster and more ubiquitous, these databases got larger, such that we began understanding life in ways we could only dream about in the past. Other industries embarking on embracing the Internet of Things (Industry 4.0) can learn a lot from the genomics world as we continue to trail blaze open big data, multidisciplinary collaboration and technological advancements.

DR ARTURO IZURIETA
(Executive Director, Charles Darwin Foundation)

The management of biodiversity around the globe has shifted to a participatory approach. My professional and scientific approaches have definitely included and still include a strong participatory focus. The local communities need to be engaged in the decision-making processes about how capital is to be used properly in order to guarantee their own future. Generation of information and the use of technology have been incorporated in research, although decision makers still need to learn about integrating the information provided by science into the formulation of policies and/or decisions that will affect people and nature. Evolution takes place every second; this is the legacy of the thinking of Charles Darwin and we continue to study how nature changes.

the last word:

The next generation of personalised 3D printing for healthcare

International Innovation's Stephanie Spurr investigates how innovative 3D printing is revolutionising the healthcare industry and enabling patients to have highly effective tailored treatments

HOW DIFFERENT WOULD life be if we could receive exactly the type of treatment that we require as individuals – when and where we needed it? What impact would this have on the practice of mainstream personalised medicine? As technology advances, these questions are being answered by the impact of tailored care being provided by researchers and the medical community.

3D printing, known technically as additive manufacturing, involves the application of materials science, engineering and design to create objects through the successive layering of materials. Advancements in this area are of particular interest to the healthcare industry and, more specifically, to patients who require personalised solutions such as prosthetics or surgical implants.

HIGH-FUNCTIONING PROSTHETICS

Fully customisable to the wearer, prosthetics enable individuals to regain functionality and independence. The price, however, has been a notorious deterrent; the most technologically advanced prosthetics can cost up to US $100,000. 3D printing is providing a far more affordable solution.

As an example, there are around 2 million hand amputees worldwide, so the creation of a dextrous bionic hand via 3D printing is a pioneering effort to improve daily life. Winner of the UK's James Dyson Award in 2015, the company Open Bionics is working on the creation of a prosthetic that can be ready in just over 42 hours and will cost around $3,000. First, the wearer is scanned, and then both the hand and socket are 3D printed; sensors are placed on the skin that recognise muscle movements and control the hand.

Given that children grow so quickly, prosthetics are rapidly outgrown and need replacing often. The lower cost of 3D printing presents a more viable option for those families. Prosthetics that stretch and expand are also being explored as future options.

TAILORED MEDICATION

Tailoring medication to suit a patient's precise dosage needs, according to their biological and clinical parameters, is set to dramatically boost the efficacy of treatments. This form of personalised care takes into consideration the fact that diseases manifest differently in patients, especially for those suffering from comorbidities. Pills made for the individual will also reduce unwanted side effects, departing from the 'one-size-fits-all' approach to pharmaceuticals.

Approved by the Food and Drug Administration (FDA) in 2015, the first 3D-printed pill on the market is Spritam levetiracetam, a drug designed to control epileptic seizures. As the pill is more porous, it is quickly dissolvable upon contact with liquid and has rapid dissipation properties. Bespoke medication with improved characteristics will also solve problems related to children having difficulties swallowing their medication.

SURGICAL IMPLANTS

Metal-based 3D-printed implants are becoming widely used in some of the world's most innovative hospitals. Patients are being given the opportunity to have implants that meet their exact requirements using materials that are strong and versatile.

For instance, practitioners at the TangDu Hospital in China fitted a woman with the world's first 3D printed titanium sternum in 2015 that exactly matched the patient's own following an operation to remove a tumour.

Success in this area has also been observed in young infants, such as the three babies at the University of Michigan's CS Mott Children's Hospital implanted with3D-printed bioresorable splints to prevent their windpipe from collapsing – a condition known as tracheobronchomalacia. CT scans enabled the development of perfectly customised devices. The successful treatment alleviated suffering and demonstrated that early disease prevention in these cases negated the need for a tracheotomy, mechanical ventilation and prolonged stays in the hospital.

These examples show how affordable digital imaging and design can create innovative devices that not only save, but also change, people's lives.

TRANSPLANTABLE TISSUES AND ORGANS

In the US, there are currently around 123,000 people who need lifesaving organ transplants; 21 people die every day because these organs are not available in time. 3D-printed tissues and organs would therefore save the lives of thousands of people and drastically reduce the number of people on waiting lists.

While scientists have been able to 3D print human tissue for years, enabling the tissue to survive on its own was a necessary step forward. A significant breakthrough in this area came from researchers at Harvard and Sydney universities, who successfully 3D printed capillaries, which provide cells with the nutrients and oxygen they need to survive. This will be essential for growing large, transplantable organs in decades to come.

3D printing is providing exciting new opportunities for researchers and practitioners to innovate while addressing societal needs in personalised and effective ways. Having a blueprint from which to create a 3D-printed solution of the precise shape, size, structural properties, weight and colour required – at a low cost – is life changing.

International INNOVATION

Disseminating science, research and technology

Download the *International Innovation* app for iPad, iPhone* and on the Google Play™ store.

Gain free access to over 200 research articles showcasing cutting-edge developments from across the spectrum of scientific disciplines.

ANDROID APP ON Google play

Download on the App Store

*iPad and iPhone are trademarks of Apple Inc.

Alzheimer's Research UK is the UK's leading research charity aiming to defeat dementia.

Dementia shatters lives and leaves millions heartbroken. But we can change the future. Learn how you can support Research Media's chosen charity and help power our vital research at www.alzheimersresearchuk.org

Alzheimer's Research UK

The Power to Defeat Dementia