UK-Brazil Frontiers of Science Meeting

Itatiba, São Paulo, 27-30 August 2010

EXCELLENCE IN SCIENCE

THE ROYAL SOCIETY

FAPESP

UK-Brazil Frontiers of Science Meeting

Contents

1 Introduction

In August 2010, over 70 outstanding early-career scientists from the UK and Brazil came together in a remote location near Itatiba in São Paulo state. On the agenda was an extraordinarily diverse range of research topics, including biofuels, brain plasticity, the mathematical modelling of populations and disease, science journalism, quantum entanglement, and the effect of climate change on plant development. The meeting was the latest in the Frontiers of Science programme, which brings together future leaders in science from around the world.

© Eduardo Cesar – Revista Pesquisa Fapesp

The Royal Society partnered with FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo - the Research Council for the State of São Paulo) on the meeting, the content of which was devised by an organising committee of 16 scientists from both countries, and which a delegation of 8 scientists from Chile also attended. Following the event, the British Council supported 6 UK scientists to undertake lab and school visits, public lectures and other outreach work while in Brazil.

This report summarises the key issues and findings discussed at the symposium. It is not necessarily an expression of the views of the Royal Society.

2 The Frontiers of Science programme

The Frontiers of Science programme was originally conceived by American geophysicist Frank Press, who was President of the US National Academies of Science from 1981 to 1993[1], and oversaw the inaugural meeting in 1989. It has since evolved into an international franchise of prestigious interdisciplinary meetings of outstanding early-career scientists. Frontiers symposia aim to bring together future leaders in science in all disciplines to forge new links, encourage networking and discussion, and to explore opportunities for collaboration.

The format was adopted by the Royal Society when it co-organised the UK-US Frontiers meeting with the NAS in 2004, and since then meetings have been jointly organised with a number of countries and partners, including Germany (through the Alexander von Humboldt Foundation), China (Chinese Academy of Sciences), India (Indian National Science Academy) and Japan (the Japanese Society for the Promotion of Science).

Notable alumni from the Royal Society's Frontiers programme include 2010 Nobel Laureate Dr Konstantin Novoselov, and Professor Angela McLean FRS, Co-director of the Institute for Emerging Infections at Oxford University.

1 See http://www.kavlifoundation.org/knowledge-connection. Last accessed 19 October 2010.

3 Key Points

- Obesity may be linked to, and exacerbated by, brain inflammation brought on by excessive intake of saturated fats, which kill off neurons and damage the hypothalamus, the part of the brain that controls hunger
- Reinforcing electrical links between different parts of the brain have been shown to help stroke victims recover a significant proportion of lost functions, backed up by a greater understanding of how the brain naturally repairs itself to cope with damage
- The detection and observation of Earth-like planets outside our solar system is likely to become more and more likely over the next few years, underpinned by advances in technology and increasing amounts of data on young planetary systems in our galaxy
- Mathematical models of social networks are yielding important new insights into the spread of infectious diseases through human populations, and are enabling the development of effective policy responses to future outbreaks
- Advances in modelling the earth's geomagnetic field have greatly enhanced our understanding of the behaviour of the earth's core and its relationship with the magnetic field, with potentially significant consequences for understanding plate tectonics and predicting seismic activity
- Public engagement is becoming an increasingly integral part of the role of the modern scientist, driven by heightened public and media interest in science, with scientists spending an increasing amount of their time communicating with non-scientists in government, industry, the media and the general public
- The production of biofuels is increasing, and is a major growth area of research, particularly in Brazil and Chile, where significant advances have been made in the development of high-yield biofuels from sugarcane, pine and eucalyptus trees
- With increasing global temperatures likely to have major adverse effects on future crop yields, the need to develop crops with greater resilience to climate change is driving new and compelling collaborations between researchers in a variety of different disciplines, from biology to engineering – underpinned by increasingly sophisticated modelling of the effects of temperature on all aspects of plant biology
- The bizarre and counter-intuitive phenomenon of quantum entanglement not only holds significant potential for the nascent field of quantum communication, but may also play a significant role in biological systems, particularly in energy transfer processes during photosynthesis

4 The sessions

4.1 Biofuels: new developments, challenges and limitations

Organised by Dr Anamaria Aranha Camargo, *Laboratory of Molecular Biology and Genomics, Ludwig Institute for Cancer Research,* and Dr Araxi Urrutia, *Department of Biology and Biochemistry, University of Bath*

Speakers: Dr Joaquim Eugênio Abel Seabra, *Brazilian Bioethanol Science and Technology Laboratory (CTBE),* Dr Sofia Alejandra Valenzuela Aguila, *Department of Forestry, University of Concepcion,* and Dr Glaucia Mendes Souza, *Chemistry Institute, University of São Paulo*

Reducing the world's dependence on dwindling fossil fuels is essential for geopolitical, economic and environmental reasons. Biofuels are one of the few alternatives identified by scientists that have the potential to displace a substantial amount of petroleum around the world over the next few decades, and a clear trend in that direction has begun. The term biofuels theoretically encompasses any fuel made from living things, or the waste that they produce, but in practice tends to refer to ethanol and diesel made from crops such as corn, sugarcane and rapeseed. Global biofuel production is increasing, with most of it occurring in Brazil and the USA.

The Brazilian bioenergy research programme (BIOEN) is one of the key players in Brazilian biofuel research, and mainly concentrates on sugarcane, whose high yield and fast growth make it the most successful biofuel crop. Researchers are working on all aspects of sugarcane production, including breeding, selection, gene sequencing, agronomy, expansion to new land areas, and industrial aspects of production, in order to increase the potential yield.

Biofuels are also a major area of research in Chile, where research focuses on the production of treethanol – bioethanol from trees. The demand for this is driven by a number of factors, principal among which are Chile's dependence on energy imports, and its status as the 4th highest pulp exporter in the world. The main commercial species are radiata pine and eucalypts, and studies of the genome of the former have elucidated the factors increasing pulp yield, and the genes involved in wood formation. This has great potential for selecting the best trees for production of pulp or bioethanol in the future.

There is considerable debate over the unintended consequences of biofuel production, mainly its use of land that might otherwise be used to grow food. This debate only serves to highlight the crucial tension between the need to diversify energy supply and the need to preserve the environment, one which is certain to intensify in the years ahead. The definition of a "global sustainable biofuels level" which can accommodate food, feed, fibre, and energy production, has yet to emerge.

4.2 Brain plasticity

Organised by Dr Holly Bridge, *Department of Clinical Neurology, University of Oxford*, and Professor Fernando Cendes, *School of Medical Sciences, University of Campinas (UNICAMP)*

Speakers: Dr Jacinta O'Shea, *Department of Clinical Neurology, University of Oxford,* Dr Martin Cammarota, *Brain Institute, Pontifical Catholic University of Rio Grande do Sul (PUCRS),* and Dr Edson Amaro Junior, *School of Medicine, University of São Paulo (USP)/Brain Institute – Albert Einstein Hospital (InCe-IIEPAE)*

In the latter half of the twentieth century it was discovered that adult brains continue to produce stem cells which mature into neurons. This process, called neurogenesis, underpins the brain's remarkable capacity to re-organise its functional and anatomical properties, which takes place over the course of normal development, and enables the adaptive modification of behaviour during learning, whether through experience or from passively absorbing information.

This brain plasticity, or neuroplasticity, is also fundamental to recovery from brain injury, whether physical, chemical, or psychological. In the last decade, new methods, particularly in neuroimaging, have led to significant advances in our understanding of how the human brain naturally repairs itself to cope with damage (which had hitherto been hindered by experimental limitations). Reinforcing electrical links between different areas of the brain, and shaping patterns of neural activity change that are the result of brain damage, through magnetic brain stimulation have been demonstrated to help stroke victims recover lost functions and thus facilitate behavioural recovery.

Neuroplasticity is also fundamental to our understanding of memory and learning, and in particular why some memories last longer than others. Research on the nature of this process has suggested that after being acquired, memory - the neural representation of the past, undergoes a lengthy process of stabilisation and filtering known as consolidation. The process, which converts unstable short-term memory traces into long-lasting memory, requires gene expression and *de novo* protein synthesis in some areas of the brain, thought to be the hippocampus, amygdala and related cortices. Experiments have hinted that dopamine, the chemical involved in the acquisition and expression of reward/punishment related information in the brain, and which regulates the detection of novelty and salience (the property that makes an individual object or person stand out relative to others or its background), plays a crucial role in the maintenance of memory storage, but not its formation.

4.3 Deep earth system

Organised by Dr Richard Kirby, *School of Marine Science and Engineering, University of Plymouth,* and Dr Ricardo Ivan Ferreira da Trindade, *Institute of Astronomy, Geophysics and Atmospheric Science, University of São Paulo*

Speakers: Dr Carolina Lithgow-Bertelloni, *Department of Earth Sciences, University College London,* Dr Rommulo Vieira Conceição, *Institute of Geosciences, Federal University of Rio Grande do Sul (UFRGS),* and Dr Richard Holme, *School of Environmental Sciences, University of Liverpool*

The interior of the Earth has long been a subject of fascination for scientists and in popular culture, which can partly be explained by the fact that it is inaccessible to direct observation. Although spacecraft have been sent to the edge of the solar system and beyond, covering distances of over 6 billion kilometres, the deepest hole humans have ever dug reaches 12 kilometres below ground, less than a quarter of a percent of the Earth's radius. The centre of the planet, 6,380 kilometres below us, thus remains even less well explored, a fact underlined by the fact that the existence of the earth's inner core was only established, using seismological data, in 1936, six years after the discovery of Pluto.[2]

Much of what is known about the earth's interior is therefore derived from indirect observation. The Earth's geomagnetic field has been measured and studied for over four centuries, and varies on timescales from milliseconds to millions of years, and stretches from near-Earth space to the deep interior. The larger-scale (3000km) and longer (between one and many millions of years) variations are driven by a hydromagnetic dynamo in the Earth's core. Motions in the core bend and stretch the magnetic field, and therefore the structure of the field at the core surface is particularly interesting.

Although what is happening in the core cannot be observed directly, modelling of the geomagnetic field can probe the deep earth on timescales going back for thousands of years. By combining these models with other geophysical data, powerful insights into the structure and evolution of the deep Earth, and from that the whole Earth system, can be obtained. These findings may be significant in helping us to understand how plate tectonics, and thus seismic activity, are driven. They suggest that the deep mantle has a strong influence on the Earth's core. Experimental evidence has shown that potassium plays a crucial role as a substantial radioactive heat source in planetary cores, although researchers have speculated that its distribution in the Earth's mantle may be complicated, as the composition of this mantle may have varied considerably over time.

4.4 The mathematical modelling of populations and disease

Organised by Dr Henrique Bursztyn, *National Institute for Pure and Applied Mathematics (IMPA),* and Dr Jonathan Dawes, *Department of Mathematical Sciences, University of Bath*

Speakers: Professor Claudio Jose Struchiner, *Department of Scientific Computing, Brazilian School of Public Health, Fiocruz,* Professor Vincent Jansen, *School of Biological Sciences, Royal Holloway, University of London*, and Dr Ivana Gudelj, *Department of Mathematics, Imperial College London*

The use of mathematical models to illuminate our understanding of infectious diseases was pioneered by Sir Ronald Ross FRS, whose seminal work elucidating the role of mosquitoes in the transmission of malaria won him a Nobel Prize in 1902. Significant progress has taken place in the century following his discovery. Advances in molecular biology and genetics have enabled better monitoring of diversity among pathogens and hosts. With an unprecedented amount of data available in the modern era on DNA sequences, population genomics, health insurance and complex networks, researchers are able to build increasingly sophisticated models for use in mathematical epidemiology.

One of the most promising areas of research is in network analysis, and in particular how populations are structured in terms of social networks, and how diseases can transmit on these networks. The complexity of these networks is underlined by the changes in human behaviour when a disease is present. For example, this can include vaccinations, wearing of face masks (as with SARS), or taking prophylactic drugs, which then has a further effect on the spread of the disease, which modelling needs to take into account.

Mathematical modelling has also enabled a much more sophisticated understanding of how pathogens such as *E coli evolve*, and conversely the evolution of resistance to those pathogens. A number of system level models have made accurate quantitative predictions of interactions between bacteria and bacteriophages (viruses that infect and kill bacteria) in the laboratory. Some of these approaches can be generalised to other forms of microbial systems, and have shed new light on the dynamics of the evolutionary arms race between predator and prey at the microscopic level, with a number of beneficial applications in the area of disease prevention and control.

Research in Brazil has also suggested that genetic manipulation of mosquitos could help in the fight against malaria and other mosquito-borne diseases such as dengue fever, by spreading genes that confer resistance to these parasites to the mosquitoes. However, the delivery of these genes to the mosquitoes themselves remains a major logistical hurdle.

2 Hirose K (2010). *The Earth's Missing Ingredient.* Scientific American, June 2010.

4.5 Planet formation and evolution

Organised by Dr Silvia Helena Paixão Alencar, *Department of Physics, Federal University of Minas Gerais (UFMG)*, and Dr Dalia Chakrabarty, *Department of Statistics, University of Warwick*

Speakers: Dr Jane Greaves, *Department of Physics and Astronomy, University of St Andrews,* Dr Douglas Galante, *Institute of Astronomy, Geophysics and Atmospheric Science, University of São Paulo*, and Dr Ken Rice, *Royal Observatory, Edinburgh*

The first discovery of another planet orbiting a star outside our Solar System was made in October 1995.[3] Since then, 473 exoplanets have been discovered, and 43 multiple planet solar systems. Many of these planets exhibit properties that are markedly different from those encountered in our own solar system, with a number of them taking the form of "hot Jupiters" – gas giants with orbits very close to their own parent stars, and with these orbits displaying a wide range of eccentricities.

Our understanding of how planets such as these form has been greatly enhanced by recent developments in astrophysics. With new stars forming in our galaxy all the time, in regions within a few hundred light years of the Sun, there is ample opportunity to observe very young stars of a few million years old or less; this is the stage when giant planets tend to form from gas and rocks not collected into the nascent star. Data on a number of these systems has enabled predictions to be made as to how common different types of planetary systems are, and suggest that conditions around young stars could be suitable for solar systems similar to our own to exist within around 50 light years. These may contain 'Earth-like' planets of similar size and distance from their sun, which moderate advances in technology may enable us to observe in the near future.

The possibility of detecting planets such as these has helped to increase interest in the new field of astrobiology, which seeks to understand the fundamental nature of life on our planet and how it could manifest itself on others. Brazil has recently seen the opening of its first ever laboratory devoted to the subject – AstroLAB at the University of São Paulo, which has four main objectives: to understand biodiversity in the Earth's most extreme environments (by examining so-called 'extremophiles' which live at extremes of pressure or temperature); to test biological and chemical samples under extraterrestrial conditions; theoretical simulations of planetary formation and atmospheric conditions; and public outreach. A simulation chamber is currently being constructed which will form the main focus of much of this work.

4.6 Plant development and climate change

Organised by Dr Kerry Franklin, *Department of Biology, University of Leicester,* and Dr Mariana Cabral de Oliveira, *Bioscience Institute, University of São Paulo*

Speakers: Dr Anthony Hall, *School of Biological Sciences, University of Liverpool,* Professor Carlos Alberto Martinez y Huaman, *Ribeirão Preto School of Philosophy, Sciences and Literature, University of São Paulo,* and Dr Philip Wigge, *Department of Cell and Developmental Biology, John Innes Centre*

It has been estimated that every 1°C increase in seasonal temperature causes a 2.5-16% decrease in crop yields.[4] As global temperatures continue to rise, with consequent knock-on effects on food production, it has therefore become imperative to understand the effects of temperature on plants. It is clear that there is a non-linear relationship between temperature and crop yield, with yield dropping dramatically at certain levels of temperature.

The effort to develop crops with greater resilience to climate change will be a complex and difficult process, requiring collaboration between researchers in a variety of disciplines from biology to engineering. Sophisticated models have already elucidated important insights into the mechanisms by which plants perceive and relay temperature signals, adjust their physiology in response to temperature change, and the effect on processes such as flowering. Increases in global temperature over the last century have already altered the phenology (recurrent life cycle events) of various wild plants.

A related breakthrough in this field was announced in August 2010 by a team of UK researchers, who publicly released the first sequence coverage of the wheat genome, a crucial first step towards a fully annotated genome,[5] which could be a crucial contribution to addressing global food security by enabling the development of new strains with greater yields. Other approaches have sought to document how circadian clocks - which temporally regulate physiological, biochemical, metabolic and development processes in a variety of living organisms – maintain their rhythms in plants over a broad range of physiological temperatures.

Another crucial question is to what extent plants are able to absorb and sequester increasing levels of CO^2 from the atmosphere. It has been shown that some trees and plants are growing larger and more quickly in response to these changes,[6] but in some species the photosynthetic response decreases at certain levels of CO^2 concentration.

3 Mayor M and Queloz D (1995). *A Jupiter-mass companion to a solar-type star.* Nature 378, pp 355 – 359.
4 Battisti D and Naylor R (2008). *Historical Warnings of Future Food Insecurity with Unprecedented Seasonal Heat.* Science 323, 5911, pp. 240-244.
5 See http://www.jic.ac.uk/corporate/media-and-public/current-releases/100827wheatgenome.htm Last accessed 22 November 2010.
6 Lewis S et al (2009). *Increasing carbon storage in intact African tropical forests.* Nature 457, pp 1003-1006.

4.7 Quantum entanglement

Organised by Professor Marcelo Knobel, *Gleb Wataghin Physics Institute, University of Campinas (UNICAMP)*, and Professor Peter Vukusic, *School of Physics, University of Exeter*

Speakers: Dr Paulo Alberto Nussenveig, *Institute of Physics, University of São Paulo,* Dr Daniel Felinto Pires Barbosa, *Physics Department, Federal University of Pernambuco,* and Dr Libby Heaney, *Department of Physics, University of Oxford*

Quantum entanglement is one of the most bizarre and counter-intuitive features of quantum mechanics.

The term was originally coined by Erwin Schrödinger ForMemRS[7] to describe the remarkable phenomenon whereby two or more quantum subsystems are intrinsically connected in such a way that measurements on one subsystem instantaneously affect the other, regardless of distance. For example, if someone measures a physical property, such as spin, position, or momentum, of a particular particle, then another 'entangled' particle will change its behaviour accordingly, even if the particles are separated by distances which exceed the space that light could traverse in the time required to make the measurement. Albert Einstein ForMemRS referred to it as "spooky action at a distance". Hence the correlations of entanglement are described as 'non-local'.

Quantum entanglement has a number of useful applications. For example, the entanglement of two particles can be used for teleportation and encoding information in a compact manner, opening up new avenues for quantum communication.[8] Recent research has offered a tantalising glimpse of how a quantum computer might work in practice,[9] while other work has suggested that quantum entanglement may play a crucial role in biological systems, specifically in energy transfer processes during photosynthesis.[10]

4.8 Regulation of energy metabolism

Organised by Dr Saif Haque, *Department of Chemistry, Imperial College London,* and Dr Alicia Juliana Kowaltowski, *Department of Biochemistry, University of São Paulo*

Speakers: Dr Nadja de Souza Pinto Lardner, *Chemistry Institute, University of São Paulo,* Dr Andrew Murray, *Department of Physiology, Development and Neuroscience, University of Cambridge,* and Dr Licio Augusto Velloso, *School of Medical Sciences, University of Campinas (UNICAMP)*

All living organisms have to adapt and respond to changes in their environment, and particularly in the availability of energy supply, which requires changes to the organism's metabolism. Organisms and cells deploy a number of strategies to integrate their metabolic pathways, and to properly respond to changes in their environment.

Two major challenges in current research in energy metabolism and metabolic control were outlined. One is the public health cost of obesity and obesity related illnesses. Obesity significantly increases the risk for development of a number of other highly lethal diseases, such as artherosclerosis, hypertension, diabetes and cancer. However, researchers have shown that obesity is not exclusively caused by consumption of increased calorific food and insufficient exercise. They have made use of neuroimaging technology to demonstrate that an inflammatory process induced in the hypothalamus, the part of the brain that controls food intake and energy expenditure, may also play a crucial role in creating an imbalance in energy metabolism. This process is itself triggered by excessive intake of saturated fats, and is therefore self-reinforcing.

The second, which is often related, is in treating heart failure, which is becoming an ever more urgent public health issue, with hospitalisation rates in the US showing a dramatic increase.[11] Novel approaches seek to understand the cellular mechanisms which lead to energetic abnormalities in cardiac and skeletal muscle, and have led to the modelling of stresses such as lack of oxygen and high-fat diets in humans and animals. These have led to the identification of novel pharmacological agents which can improve the oxidative capacity of heart and skeletal muscle, and thereby alleviate many of the symptoms associated with heart failure.

7 Schrödinger E (1935). *Discussion of Probability Relations Between Separated Systems.* Proceedings of the Cambridge Philosophical Society, 31, pp 555–563.
8 Heaney L and Vedral V (2009). *Natural mode entanglement as a resource for quantum communication.* Physical Review Letters 103, 20, pp 200502-1-4.
9 Coelho A, Nussenveig P et al (2009). *Three-Color Entanglement.* Science 326, 5954, pp. 823 – 826.
10 Engel G et al (2007). *Evidence for wavelike energy transfer through quantum coherence in photosynthetic systems.* Nature 446, pp 782-786.
11 Liu L (2008). *A New Epidemic of Heart Failure in the United States.* Presented at the Scientific Sessions of the American Heart Association, in New Orleans, LA, on November 9, 2008.

4.9 Science journalism and the public perception of science

Organised by Dr Richard Kirby, *School of Marine Science and Engineering, University of Plymouth,* and Professor Marcelo Knobel, *Gleb Wataghin Physics Institute, University of Campinas (UNICAMP)*

Speakers: Dr Yurij Castelfranchi, *School of Philosophy and Human Sciences, Federal University of Minas Gerais (UFMG)*, Tim Hirsch, *Independent journalist and former Environment Correspondent, BBC News,* and Dr Mariluce Moura, *Revista Pesquisa FAPESP Magazine*

Public engagement is becoming an ever more critical and unavoidable aspect of modern science. An increasingly empowered public is demanding greater scrutiny of the science that it funds through its taxes, and with an increasing number of outlets such as blogs and social networking, has reinforced the need for scientists to be able to describe, defend and to discuss their work, what it can and cannot tell us, and the implications for policy makers and the wider public. Many scientists and scientific institutions spend more and more of their time communicating with non-scientists, such as government, industry, funders and foundations, civil society, journalists and the general public.

However, many scientists fear their work will be distorted, misrepresented and 'dumbed down' by the mainstream media, as evidenced by coverage of stories (particularly in the UK media) such as the MMR vaccine, the debate over genetically modified crops, swine flu and climate science. However, when scientists make the effort to communicate their work in language which non-specialists can understand (a key principle of the Frontiers of Science meetings), and when journalists properly convey accurate nuances of risk and uncertainty, relationships of trust can be built to the benefit of all stakeholders, and to the greater understanding of scientific research. With Brazil's astonishing rise to scientific prominence in the last decade, and the consequent interest in Brazilian science by its media, FAPESP has had to get to grips with these challenges in a relatively short space of time, and has already made remarkable progress in communicating major advances in Brazilian science such as those in biotechnology.

5 Horizon scanning

Participating scientists were asked to identify what they perceived as the emerging scientific challenges in the next five to ten years in their field. These included:

- The study of epigenetic effects, beyond simply looking at DNA sequences, in order to provide novel insights into all aspects of biology.
- Discerning the relationship between genetic data and the biophysical properties of cells, which lead to the development of organisms, thus offering the possibility of better understanding diseases, engineering more optimal food crops, and shedding insights on fundamental questions regarding self-organization and the evolution of development.
- To search for more quantum effects in biological systems - to understand how they can exist for so long and what additional function they give to the system.
- Developing a greater understanding of 'complexity science', where the connectivity between objects is constantly changing at the microscale, but somehow constant at a macro scale (for example, how do disease contact networks change when people are fearful of infection; how do individual birds/locusts behave within flocks or swarms, how should we best reorganise power delivery over grids as demand changes, or people plug in/unplug their electric cars?)
- Building a scalable quantum computer, that can perform tasks that cannot currently be performed efficiently on classical computers, in order to gain increasing knowledge about the subtleties of quantum entanglement in systems of increasing complexity.
- Understanding molecular-level interactions in biological materials, especially those involving water, which is essential for many biologically-related applications such as tissue engineering, drug delivery, biosensing, and artificial organs.
- Elucidating the links between the interior of the Earth and the development of the atmosphere/hydrosphere (e.g. spatial and temporal variations in the oxidation state, or the amount of oxygen in the Earth's mantle).
- The study of population dynamics on complex networks through epidemiology, evolutionary dynamics, game theory and other related disciplines.
- Deciphering how perceptual (eg economic and social) decisions are formed by the human brain, what underpins decision making, and how to reliably study the neural activity underlying such decisions.
- Modelling plant life history and evolution, and to understand how to breed plants with high yields in the presence of lower inputs of fertiliser, water and chemicals.
- The ageing population, and how to keep it healthy as it ages despite rising levels of chronic diseases such as obesity.
- Mapping the ocean ecosystem and exploiting its resources effectively and sustainably at a time of increasing global temperatures.
- Developing an appropriate methodology to integrate the massive amounts of data generated by the various disciplines that underpin modern science.
- Detecting Earth-mass planets in extrasolar systems, deciding on robust biosignatures of life of various kinds, and putting in context the formation of our planetary system.
- Understanding the Palaeozoic 'Snowball' earth, and its implications for the modern climate.

6 Feedback

Participants were also invited to provide their thoughts on the symposium as a whole. Responses were overwhelmingly positive, with participants welcoming the chance provided by the Frontiers of Science format to discuss cross-cutting themes above and beyond disciplinary boundaries, and to forge new links with their overseas counterparts. A number of participants also indicated that they had established promising links with potential collaborators, and in many cases had already begun to discuss joint projects, seminars, and other collaborations. A selection of their comments is provided below:

" I was enormously impressed by the Brazilian researchers I met [...] The financial investment in science is terrific, especially in Sao Paulo state."

"As a direct result of the visit I have established a collaboration that will see the establishment of a new molecular laboratory in Brazil."

"I already have plans to further the links I have made by hosting students from Brazil in my laboratory in the UK."

"All [speakers] were clear, presented their work in an accessible and understandable way which led to questions and interesting discussion. They seemed to invite interaction, rather than closing down discussion with definitive answers. "

"I believe [..] that the most important contacts were with the young scientists of the other fields, since this is one of the few opportunities we have for such close discussions among us. In many aspects, this kind of meeting builds a sense of scientific community beyond our specific subjects. In this way, this meeting [helped] to build cross disciplinary scientific networks."

"From the different [subject] areas, there were many interesting computational modelling techniques which I am now keen on applying to my own area".

"The meeting has made me think about how my research is perceived by scientists outside my field. This will prove valuable when writing papers for multidisciplinary journals and applying for funding to panels of mixed expertise."

"I was able to introduce a speaker to a relevant - related field of research that they were unaware of, and where we plan to collaborate."

"[One particularly valuable aspect of the meeting was] being able to discuss research that is tangential to your own, that I would never normally have time to read about, and to therefore glimpse avenues of research/ technical possibilities that I was unaware of."

"This meeting enlarged my vision as a scientist".

"Everyone seemed very positive about the future of Brazilian science and I think we in the UK could learn a lot from that kind of attitude."

"The meeting was an enjoyable, stimulating and thought provoking experience. It was fascinating to have the opportunity to interact with such a diverse group of leading researchers."

"It was absolutely marvellous and I enjoyed the science and the company more than at any other meeting I have ever been to."

"I thought this was a thoroughly enjoyable meeting and didn't really want to leave. I met tons of interesting people (most doing very interesting things outside my field of expertise). The enthusiasm that many people have for their research is very infectious."

Appendix 1: List of participants

Name	Affiliation
Dr Sofia Alejandra Valenzuela Aguila	Department of Forestry, University of Concepcion
Dr Luciane Carla Alberici	Ribeirão Preto School of Pharmaceutical Sciences, University of São Paulo
Dr Silvia Helena Paixão Alencar	Department of Physics, Federal University of Minas Gerais (UFMG)
Dr Edson Amaro Junior	School of Medicine, University of São Paulo (USP)/Brain Institute – Albert Einstein Hospital (InCe-IIEPAE)
Dr Daniel Felinto Pires Barbosa	Physics Department, Federal University of Pernambuco
Dr Nicolás Walter Franck Berger	Faculty of Agronomic Science, University of Chile
Dr Claudia Blindauer	Department of Chemistry, University of Warwick
Dr Holly Bridge	Department of Clinical Neurology, University of Oxford
Professor Carlos Henrique de Brito Cruz	Scientific Director, FAPESP
Dr José Antônio Brum	Gleb Wataghin Physics Institute, University of Campinas (UNICAMP)
Dr Henrique Bursztyn	National Institute for Pure and Applied Mathematics (IMPA)
Dr Mariana Cabral de Oliveira	Bioscience Institute, University of São Paulo
Dr Anamaria Aranha Camargo	Laboratory of Molecular Biology and Genomics, Ludwig Institute for Cancer Research
Dr Martin Cammarota	Brain Institute, Pontifical Catholic University of Rio Grande do Sul (PUCRS)
Professor Lorna Casselton FRS	Foreign Secretary, Royal Society
Dr Yurij Castelfranchi	School of Philosophy and Human Sciences, Federal University of Minas Gerais (UFMG)
Professor Fernando Cendes	School of Medical Sciences, University of Campinas (UNICAMP)
Dr Dalia Chakrabarty	Department of Statistics, University of Warwick
Dr Carolina Chavero	Department of Astronomy, Brazilian National Observatory
Luke Clarke	Science Policy Centre, Royal Society
Dr Hannah Clarke	Department of Experimental Psychology, University of Cambridge
Dr Veronica Laura Oliveros Clavijo	Department of Earth Sciences, University of Concepcion
Dr Rommulo Vieira Conceição	Institute of Geosciences, Federal University of Rio Grande do Sul (UFRGS)
Dr Maria Elena Lienqueo Contreras	Department of Biotechnology and Chemical Engineering, University of Chile
Dr Antonio José Roque da Silva	National Laboratory of Synchrotron Light
Dr Ricardo Ivan Ferreira da Trindade	Institute of Astronomy, Geophysics and Atmospheric Science, University of São Paulo
Dr Jonathan Dawes	Department of Mathematical Sciences, University of Bath
Dr Max Oliveira de Souza	Fluminense Federal University (UFF)
Dr Nadja de Souza Pinto Lardner	Chemistry Institute, University of São Paulo
Professor Claudio Andres Hetz Flores	Institute of Biomedical Sciences, University of Chile
Dr Kerry Franklin	School of Biological Sciences, University of Bristol
Dr Douglas Galante	Institute of Astronomy, Geophysics and Atmospheric Science, University of São Paulo
Dr Jane Greaves	Department of Physics and Astronomy, University of St Andrews
Dr Veronica Grieneisen	Department of Computational and Systems Biology, John Innes Centre
Dr Ivana Gudelj	Department of Mathematics, Imperial College London
Dr Anthony Hall	School of Biological Sciences, University of Liverpool
Dr Saif Haque	Department of Chemistry, Imperial College London
Dr Libby Heaney	Department of Physics, University of Oxford
Dr Adriana Silva Hemerly	Medical Biochemistry Institute, Federal University of Rio de Janeiro (UFRJ)
Tim Hirsch	Independent journalist and former Environment Correspondent, BBC News

Name	Affiliation
Dr Richard Holme	School of Environmental Sciences, University of Liverpool
Professor Vincent Jansen	School of Biological Sciences, Royal Holloway, University of London
Dr Richard Kirby	School of Marine Science and Engineering, University of Plymouth
Dr Jolanta Kisielewska	Institute for Cell and Molecular Biosciences, University of Newcastle
Professor Marcelo Knobel	Gleb Wataghin Physics Institute, University of Campinas (UNICAMP)
Dr Paula Kover	Department of Biology and Biochemistry, University of Bath
Dr Alicia Juliana Kowaltowski	Department of Biochemistry, University of São Paulo
Dr Cristina Lazzeroni	School of Physics and Astronomy, University of Birmingham
Dr Carolina Lithgow-Bertelloni	Department of Earth Sciences, University College London
Dr Guilherme Mallmann	Research School of Earth Sciences, Australian National University
Dr Mariluce Moura	Revista Pesquisa FAPESP Magazine
Dr Andrew Murray	Department of Physiology, Development and Neuroscience, University of Cambridge
Dr Adrian Muxworthy	Department of Earth Sciences and Engineering, Imperial College London
Dr Maziar Nekovee	Centre for Computational Science, University College London and BT Research, British Telecom
Professor Osvaldo Novais de Oliveira Junior	São Carlos Institute of Physics, University of São Paulo
Dr Paulo Alberto Nussenveig	Institute of Physics, University of São Paulo
Dr Jacinta O'Shea	Department of Clinical Neurology, University of Oxford
Dr Steven Penfield	Department of Biology, University of York
Dr Katia Jasbinschek dos Reis Pinheiro	Brazilian National Observatory
Dr Olivier Restif	Department of Veterinary Medicine, University of Cambridge
Dr Ken Rice	Royal Observatory, Edinburgh
Dr Patricio Rojo	Department of Astronomy, University of Chile
Dr Salomé Minerva Angélica Martínez Salazar	Department of Engineering Mathematics, University of Chile
Dr Denis Schluppeck	School of Psychology, University of Nottingham
Dr Peter Alexander Bleinroth Schulz	Gleb Wataghin Physics Institute, University of Campinas (UNICAMP)
Dr Joaquim Eugênio Abel Seabra	Brazilian Bioethanol Science and Technology Laboratory (CTBE)
Dr Glaucia Mendes Souza	Chemistry Institute, University of São Paulo
Dr Fabio Squina	Brazilian Bioethanol Science and Technology Laboratory (CTBE)
Dr Dimitris Stamatellos	School of Physics and Astronomy, University of Cardiff
Professor Claudio Jose Struchiner	Department of Scientific Computing, Brazilian School of Public Health, Fiocruz
Dr Antonio Lucio Teixeira Junior	School of Medicine, Federal University of Minas Gerais (UFMG)
Dr Araxi Urrutia	Department of Biology and Biochemistry, University of Bath
Dr Hamilton Varela	São Carlos Chemistry Institute, University of São Paulo
Dr Licio Augusto Velloso	School of Medical Sciences, University of Campinas (UNICAMP)
Dr Sascha Wallentowitz	Department of Physics, Pontifical Catholic University of Chile
Dr Philip Wigge	Department of Cell and Developmental Biology, John Innes Centre
Dr Helen Williams	Department of Earth Sciences, University of Oxford
Professor Carlos Alberto Martinez y Huaman	Ribeirão Preto School of Philosophy, Sciences and Literature, University of São Paulo
Professor Daniela Zanchet	Institute of Chemistry, University of Campinas (UNICAMP)

The Royal Society

The Royal Society is a Fellowship of more than 1400 outstanding individuals from all areas of science, mathematics, engineering and medicine, who form a global scientific network of the highest calibre. The Fellowship is supported by over 140 permanent staff with responsibility for the day-to-day management of the Society and its activities. The Society encourages public debate on key issues involving science, engineering and medicine, and the use of high quality scientific advice in policy-making. We are committed to delivering the best independent expert advice, drawing upon the experience of the Society's Fellows and Foreign Members, the wider scientific community and relevant stakeholders.

We are working to achieve five strategic priorities:

- **Invest** in future scientific leaders and in innovation
- **Influence** policymaking with the best scientific advice
- **Invigorate** science and mathematics education
- **Increase** access to the best science internationally
- **Inspire** an interest in the joy, wonder and excitement of scientific discovery

For further information

The Royal Society
Science Policy Centre
6–9 Carlton House Terrace
London SW1Y 5AG

T +44 (0)20 7451 2500
F +44 (0)20 7451 2692
E science.policy@royalsociety.org
W royalsociety.org

Issued: March 2011 DES2075

Founded in 1660, the Royal Society is the independent scientific academy of the UK, dedicated to promoting excellence in science

Registered Charity No 207043

Cover image: Map of Equatorial South America showing Richard Spruce's routes, from *Notes of a botanist on the Amazon & Andes*, by Richard Spruce, 1908. From the Royal Society library and archives