nature OUTLOOK

Lessons from Australia and New Zealand

nature OUTLOOK

ASSESSING SCIENCE

24 July 2014 / Vol 511 / Issue No 7510

Cover art: Dale Edwin Murray

Society benefits enormously from scientific research. We get new technologies, live longer and healthier lives, and gain deeper knowledge of our planet and the Universe. The issue of how to evaluate the fruits of research confronts scientists and policy-makers all over the world. Every country has its own set of circumstances surrounding its research infrastructure, wealth, and economic, environmental and developmental objectives — so there is no universal solution.

Earlier this year, at a symposium organized by *Nature* in Melbourne, Australia, a group of leading academics, funders and government advisers discussed how research outcomes are measured (see page S57). This Outlook supplement was influenced by these debates, although we at *Nature* take sole responsibility for its content.

As discussed at the symposium, both Australia and New Zealand have research assessment programmes that place heavy emphasis on research excellence (S52) — a qualitative determination that is heavily informed by quantitative metrics concerning, for instance, how often a paper is cited (S64). Both Australia (S67) and New Zealand (S82) have seen their global scientific standings rise in recent years — attributable at least in part to their assessment systems, even though Australia's system offers little financial reward (S81).

Measuring research using academic yardsticks largely ignores the wider impacts of research such as new policies or improved technologies. Academics and policymakers in both countries are considering the benefits and difficulties of trying to measure such impact (S72). Could the creation of 'citation equivalents' enable comparison of non-academic work against peer-reviewed literature (S77)?

We hope that the intense focus on these issues in Australia and New Zealand will inform and stimulate this crucial debate throughout the scientific world.

Philip Campbell, *Editor-in-Chief,* Nature
Michelle Grayson, *Senior Editor, Supplements*

CONTENTS

Nature Outlooks are sponsored supplements that aim to stimulate interest and debate around a subject of interest to the sponsor, while satisfying the editorial values of *Nature* and our readers' expectations. The boundaries of sponsor involvement are clearly delineated in the Nature Outlook Editorial guidelines available at go.nature.com/e4dwzw

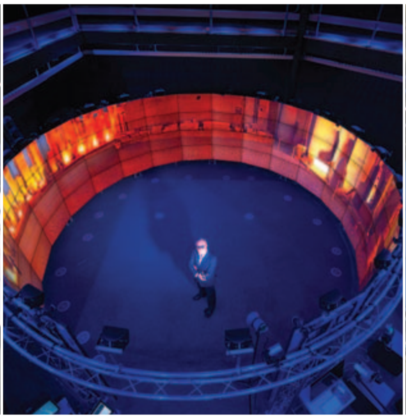
CITING THE OUTLOOK
Cite as a supplement to *Nature*, for example, Nature **Vol. XXX**, No. XXXX Suppl., Sxx–Sxx (2014).

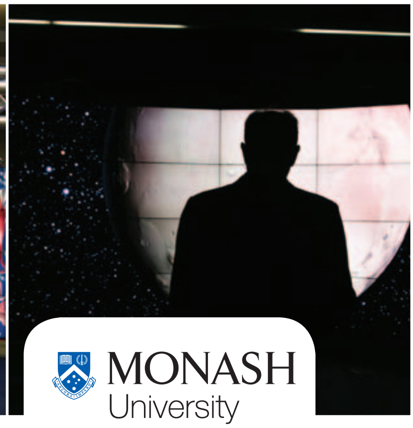
VISIT THE OUTLOOK ONLINE
The *Nature Outlook Assessing Science* supplement can be found at http://www.nature.com/nature/outlook/assessingscience
It features all newly commissioned content as well as a selection of relevant previously published material.

All featured articles will be freely available for 6 months.

SUBSCRIPTIONS AND CUSTOMER SERVICES
For UK/Europe (excluding Japan): Nature Publishing Group, Subscriptions, Brunel Road, Basingstoke, Hants, RG21 6XS, UK. Tel: +44 (0) 1256 329242. Subscriptions and customer services for Americas — including Canada, Latin America and the Caribbean: Nature Publishing Group, 75 Varick St, 9th floor, New York, NY 10013-1917, USA. Tel: +1 866 363 7860 (US/Canada) or +1 212 726 9223 (outside US/Canada). Japan/China/Korea: Nature Publishing Group — Asia-Pacific, Chiyoda Building 5-6th Floor, 2-37 Ichigaya Tamachi, Shinjuku-ku, Tokyo, 162-0843, Japan. Tel: +81 3 3267 8751.

CUSTOMER SERVICES
Feedback@nature.com



THE VIEW FROM INSIDE A MICROSCOPE

Monash University has built the microscope of the 21st century, a cinematic virtual reality environment that gives researchers a new spatial awareness of their subjects.

Dubbed CAVE2™, it comprises a curved room with 80 high-definition LCD screens projecting 3D images that allow a viewer, when wearing special "tracked" control glasses, to not only see their subject but also to manipulate and walk through and around it.

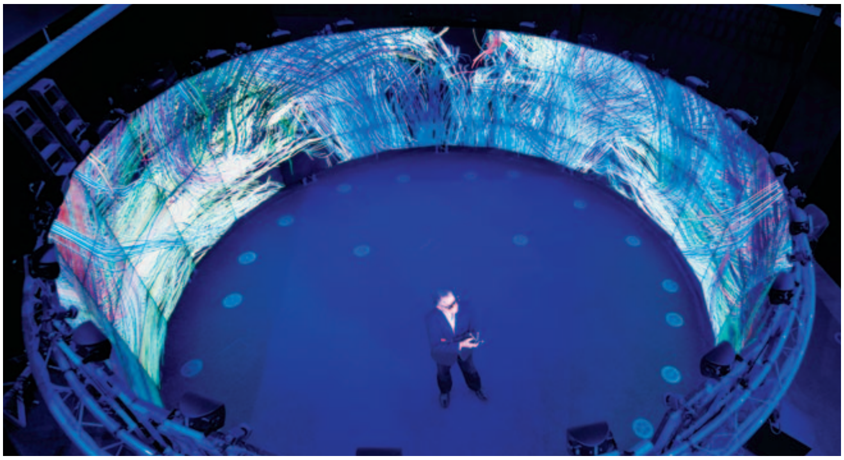
"This opens up new possibilities for insight and discoveries across a range of sciences," says Professor Paul Bonnington, director of the Monash eResearch Centre (MeRC), who has overseen the development of CAVE2 at Monash University's Clayton campus in Melbourne.

For example, the brain's white matter viewed up close in CAVE2 can provide biomedical researchers with new insights into disease—especially when they are able to compare diseased and healthy samples.

Senior research fellow and CAVE2 platform manager Dr David Barnes explains: "If you looked at this on a desktop display it would basically look like a bundle of wool. You don't appreciate the space and gaps between the circuitry and its 3D structure, but CAVE2 lets researchers see the actual structural differences."

The technology behind CAVE2 was developed by the Electronic Visualization Laboratory at the University of Illinois at Chicago in the US, and their experts helped install it in Melbourne, where it's been operating since November 2013.

But it's the additional work by Monash University, integrating CAVE2 with other advanced imaging facilities, that has made it into the modern microscope.



CAVE2 at Monash University displaying brain white matter data courtesy of UIC. Photo: Paul Jones

MORE THAN THE VIEWFINDER

A microscope viewfinder makes a good analogy for CAVE2, according to Professor Bonnington. At the centre of scientific discovery for hundreds of years, a microscope has three key components: at the bottom, a light source to illuminate a sample; in the middle, the focusing dials; and at the top, an eyepiece for viewing.

"Five years ago we set out saying, 'scientific discovery is still going to depend on this concept, but we need a modern equivalent'," he says.

In his 21st century version, the "light source" is the imaging technology that provides the sample. It could be instruments like the Australian Synchrotron, a magnetic resonance imaging scanner or a next-generation DNA sequencer.

The "focusing" components of the traditional microscope are replaced by computational tools that transform and filter the data sample to extract features. These are provided by a purpose-built interactive supercomputer installed at Monash University called the Multi-modal Australian Sciences Imaging and Visualisation Environment, also known as MASSIVE.

The Centre also developed their own data transport, management and storage software called MyTardis, which takes the huge amount of data from the bottom instrument layer of the "microscope" and places it into MASSIVE.

Finally, the modern-day "viewfinder" is a powerful viewing lens—CAVE2 itself—which can reveal features, details and a perspective never before possible.

SEEING WHAT WE'RE MADE OF

These possibilities include building further on the Human Genome Project to

IMAGES: UCSD CALIT2, UIC EVL & PAUL JONES

examine the finer details of the human proteome, the complete set of proteins expressed by our genes.

"Mapping the human genome was really just prep for where the research is going, and that is to understand, not just the building blocks, but how they function," explains Professor Bonnington.

The Human Proteome Project is providing this understanding by mapping proteins to shed light on protein function, and to advance the treatment of disease.

A protein's function is often determined by its shape, and how this shape can change. And there is no better place to analyse protein shape than in CAVE2, where, for example, electron microscopy data converted and modelled through MASSIVE can be studied up close in a super-sized format in three dimensions.

Similarly, CAVE2 could be used to fast-track drug design. "When you know the structure of a target molecule you could come in here with a bunch of drug candidates and literally carry them over to the molecule and see if they fit," Dr Barnes says.

He says the human brain is still the best pattern-recognition tool we have, which is why viewing data in high-resolution, virtual-reality detail in CAVE2 is such an extraordinary opportunity for discovery.

TRANSCENDING TIME AND SPACE

Medicine is not the only field to benefit from CAVE2, and the instrument can display more than just the microscopic world. Planetary scientists are able to step inside a panorama of Mars that has been reconstructed from images originally taken by the NASA rover Curiosity.

As with the biomedical images, seeing the planet's features at scale and looking real enough to touch gives new insight for researchers. "You can deduce a lot more from this perspective," Dr Barnes says.

Dr Barnes also says CAVE2 can assist research and industry across many other fields. Archaeologists, for example, can study fragile historical ruins in detail without disturbing them. And engineers can safely observe how a severe storm would batter infrastructure.

"We have had more than 1500 visitors from research and industry," Dr Barnes says. "People walk away feeling inspired to imagine new uses for the cave in their own fields."

VIRTUAL ENGINEERING

One imaginative new use was modelling crowd flow and bottlenecks at the redeveloped Second Avenue Subway precinct at Fulton Street, the site of the former World Trade Center towers in New York.

"You can actually see people moving around you in their avatar form, and you get a greater understanding of how you can improve the physical operations of a building when people are there," says Peter Bowtell, buildings practice leader of global design and engineering firm Arup Australia. "It is all about being able to visualise big data sets in a meaningful way."

Arup is also using the 3D format of CAVE2 to give clients and practitioners the ability to walk through and around a virtual finished building and experience what it will look, feel and even sound like.

More than just a "wow factor", this lets engineers test the impact of design choices on noise level and identify conflicts with plumbing or electricity conduits, avoiding costly revisions later. Mr Bowtell says "virtual construction" like this is driving anticipated savings of 15 to 20 per cent in the US and the UK.

"You can see new ways in which CAVE2 could really be incredibly valuable for proving building and project concepts before and during their production cycle," he says.

Professor Bonnington says the potential for application and collaboration with research and industry—and as a teaching tool—is boundless.

"The technology itself inspires people," he says. "They see technology used in a way they have never seen before, and they can begin to imagine what the future could be like."

For further information on CAVE2 please email Professor Paul Bonnington: paul.bonnington@monash.edu

To be kept informed of our latest research developments, subscribe to Monash Magazine online. Visit: www.monash.edu/monashmag

MONASH University

Monash University
www.monash.edu

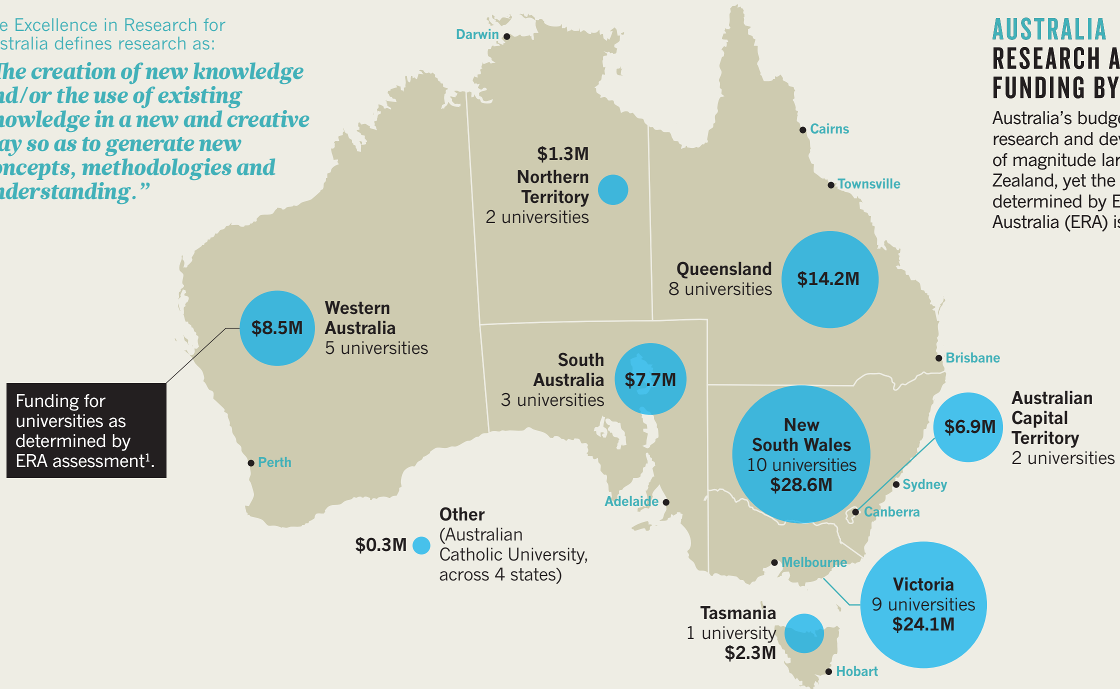
CAVE2 is a trademark of the University of Illinois Board of Trustees.

FUNDING BY NUMBERS

Australia and New Zealand both rely on assessment schemes to improve research quality, yet the money associated with each is very different. By **Julie Gould**.

The Excellence in Research for Australia defines research as:

"The creation of new knowledge and/or the use of existing knowledge in a new and creative way so as to generate new concepts, methodologies and understanding."



AUSTRALIA RESEARCH ASSESSMENT FUNDING BY STATE

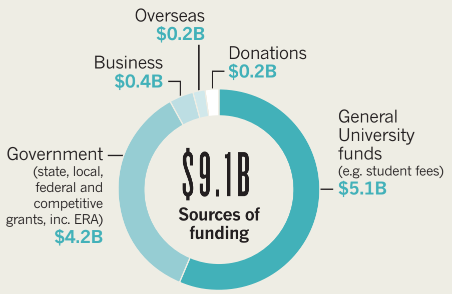
Australia's budget for higher-education research and development is an order of magnitude larger than that of New Zealand, yet the amount of money determined by Excellence in Research for Australia (ERA) is significantly smaller.

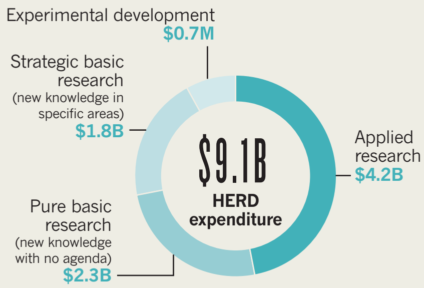
Population:

22M

MONEY MATTERS

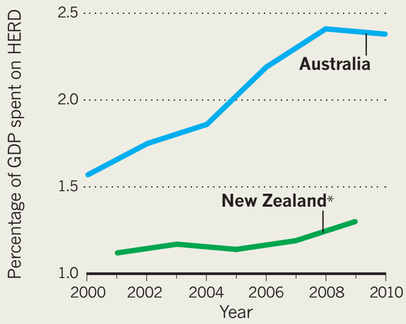
The Excellence in Research for Australia (ERA) assessment comprises only 0.08% of all government funding for higher-education research and development (HERD)[1].





SCHOLARLY SPENDING

New Zealand continues to increase spending on HERD, but Australia is starting to pull back[2].



*Data for Australia are produced on even years; data for New Zealand are produced on odd years.

EXCELLENCE IN RESEARCH FOR AUSTRALIA: TIMELINE

Policy-makers and government officials have changed funding allocations from formula favouring quantity to assessment criteria favouring quality[3].

1990 | 1995 | 2000 | 2005 | 2010 | 2015

- Australian Research Council established.
- Introduction of Unified National System, which was a framework to reorganize and improve higher education in Australia.
- Research block funding became formula based, measuring number of papers published.
- Minister for Education, Brendan Nelson, calls for new Research Quality Framework (RQF).
- RQF abandoned.
- Excellence in Research for Australia (ERA) announced.
- ERA pilot study.
- ERA 2012 report.
- Next ERA evaluation.

References: 1. *Research and Experimental Development, Higher Education Organisations* (Australian Bureau of Statistics, 2010), available at go.nature.com/1obhsa; 2. United Nations Educational Scientific and Cultural Organization Institute for Statistics; 3. Kwok, J. T. *Impact of ERA Research Assessment on University Behaviour and their Staff* (NTEU National Policy and Research Unit, 2013) available at go.nature.com/c2ypxa;

2010

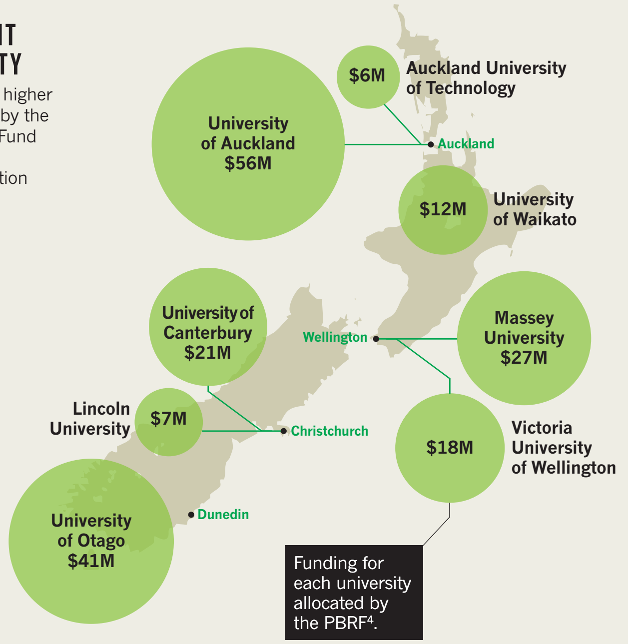
All data are from 2010 unless otherwise stated, because 2010 provides the most recent, reliable, comparable and complete data. All dollar amounts are in US dollars, converted using a 2010 exchange rate.

NEW ZEALAND RESEARCH ASSESSMENT FUNDING BY UNIVERSITY

The majority of New Zealand's higher education funding is allocated by the Performance-Based Research Fund (PBRF), which spent a total of $168 million on tertiary education organizations in 2010.

Population:

4.4M

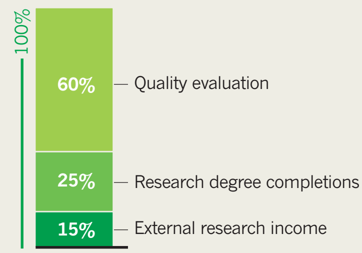


The Performance-Based Research Fund defines research as:

"Original investigation undertaken in order to contribute to knowledge and understanding and, in the case of some disciplines, cultural innovation or aesthetic refinement."

THE GREAT DIVIDE

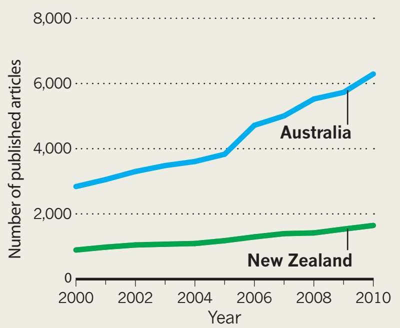
The system used by the PBRF to allocate funds to universities[4].



*The system used to allocate funds by Excellence in Research for Australia is more complicated and relies on a more peer-review structure than New Zealand's system.

PRINTED MATERIAL

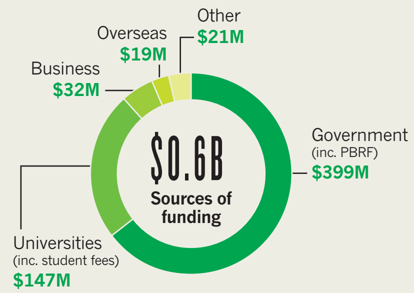
Any published articles* that include at least one author from Australia or New Zealand[5].

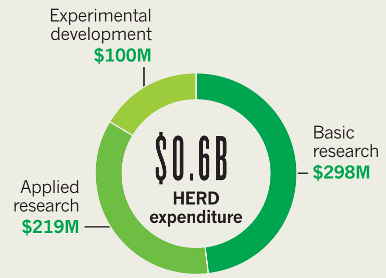


*Journals, conference proceedings, book series, books or trade publications.

MONEY MATTERS

Almost 90% of all funding for higher-education research and development (HERD) in New Zealand is provided by the government and universities[6].





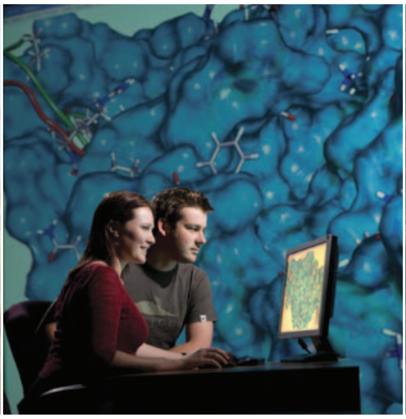
PERFORMANCE-BASED RESEARCH FUND: TIMELINE

Before 2000, funding was provided to tertiary education organizations based on the number of researchers. Now funding is dependent upon individual performance reviews[7].

1990 | 1995 | 2000 | 2005 | 2010 | 2015

- Education Act establishes the Tertiary Education Commission.
- Funding now based on number of equivalent full-time students, weighted by course costs.
- White Paper to assure research quality and accountability.
- Tertiary Education Advisory Commission (TEAC) established to provide advice on strategic direction.
- TEAC introduces the PBRF.
- First Performance-Based Research Fund (PBRF) assessment.
- PBRF reviewed. All funding now allocated through the PBRF.
- Full PBRF assessment.
- Next PBRF assessment is in 2018.

4. *Performance-Based Research Fund Annual Report 2010* (Tertiary Education Commission), available at go.nature.com/s5t6p7; 5. Scopus; 6. *Research and Development in New Zealand 2010* (Statistics New Zealand), available at go.nature.com/c7bbp5; 7. *A History and Overview of the PRBF* (New Zealand Ministry of Education), available at go.nature.com/vwXjbu.



THE UNIVERSITY of ADELAIDE

A CULTURE OF INDEPENDENT THINKERS

Some universities might be content with fostering Prime Ministers and Rhodes Scholars, Nobel Prize winners and astronauts. But the University of Adelaide has its sights set even higher—to be a world-leading research institution, meeting the challenges that will reshape lives and ecosystems.

As one of Australia's most research-intensive institutions, the University has a proud history that goes back to the youngest ever Nobel laureate, Sir William Lawrence Bragg, who attended the University of Adelaide in the early 1900s and who, when aged 25, shared the Nobel Prize in Physics with his father in 1915.

"We have a tradition of exceptional research and a research culture generated by a long history of independent thinkers," says Pro Vice-Chancellor (Research Strategy) Professor Robert Saint. "It is a broad-based institution and we do a wide range of research, from basic through to the applied."

Consistently ranked in the top 1% of the world's universities, Adelaide has 60 research areas rated at or above world standard. It also ranks among Australia's top three universities for contract research and commercialization activity, demonstrating strong connections to external partners.

A HEALTHIER START TO LIFE

At the Robinson Research Institute, researchers are taking a 'bench to bedside' approach to providing children with the healthiest possible start to life. The Institute's transdisciplinary focus is delivering results, particularly in the vexed area of obesity prevention.

"We have a very strong interest in tackling intergenerational transmission of obesity; preventing the obesity epidemic by taking the new strategy of stopping it at its root rather than trying to reverse the situation when people are already overweight," says the Institute's Director, Professor Sarah Robertson.

Bringing together laboratory studies, population-based cohort studies and clinical trials, the Institute's researchers have found that obesity is programmed into a child as early as conception, with both parents contributing equally to a child's metabolic destiny, through their genes and the conditions of the reproductive environment.

"It means that parents have a major effect on the life course of their offspring right from the time of conception, when most people don't even realize they're getting pregnant," Professor Robertson says.

The discoveries offer potent new targets for obesity prevention. Already, principles learned in animal studies are being borne out in large-scale human clinical studies and trials of interventions aimed at breaking this pathway to obesity. Results of some trials have already been published in high-impact journals, while other studies are ongoing.

NEW HORIZONS IN SENSING

The 1966 science fiction film *Fantastic Voyage* envisaged miniaturization technology that could send a medical team traveling around inside the body.

While it might be impossible to send tiny people into the body, scientists at the University of Adelaide's Institute for Photonics and Advanced Sensing are developing sensors at the nanoscale to conduct real-time tests on single cells within living organisms.

In collaboration with Macquarie University, the institute's researchers have developed optical fibers laced with nanocrystals, which are small enough to interact with targets at a cellular level. The aim is to develop a miniaturized laboratory that can operate directly with cells *in vivo*.

The next step will be to use this approach to make meaningful measurements in the brain, the cardiovascular system and even developing embryos, says Institute Director Professor Tanya Monro.

"Any assay that would normally be carried out in the lab could be done at the level of a single cell, without taking it out of the body," Professor Monro says.

PROTECTING A FRAGILE ENVIRONMENT

The global timber industry is worth an estimated $180 billion each year. Yet approximately one-third is illegal. An effective strategy for cracking down on this illegal trade, and thereby reducing associated problems of tropical deforestation and greenhouse-gas emissions, is to empower consumer choice by identifying the source of a piece of timber.

Researchers at the Australian Centre for Evolutionary Biology and Biodiversity have developed a DNA-based tracking method that uses genetic analysis to pinpoint the species and geographic origin of a piece of timber with remarkable accuracy. This technique can reveal whether a piece of merbau timber (*Intsia palembanica*), for example, has been harvested from a certified plantation or whether it has been taken illegally from an uncertified source, even within the same country.




As large-scale DNA screening becomes easier and cheaper, and can be conducted at any stage along the supply chain, a reference database of DNA samples from timber is being compiled to ensure easier and more accurate matching of timber products to their source.

This DNA-based tracking system—the only one of its kind available in the world—has now been commercialized in partnership with the Thünen Institute in Germany and Double Helix Tracking Technologies in Singapore, and it is proving invaluable for verification of sustainably harvested timber products.

"There are a range of certification methods being used, but certification papers can be falsified," says Centre Director Professor Andrew Lowe. "The role of DNA analysis is to verify those certification claims."

CHANGING HUMAN POPULATIONS

We live in an era of unprecedented demographic changes, with migration altering the face of nations, and changing climates triggering the relocation of populations.

The University of Adelaide's Professor Graeme Hugo is one of the world's pre-eminent demographers. As director of the Australian Population and Migration Research Centre, he is at the forefront of exploration into how our global population is changing, evolving and moving, and the economic and social impacts of these shifts.

The University's long established linkages with Asia have helped make it the largest research and training Centre in migration research in the Asia-Pacific region, with more than 50 scholars from countries in the region gaining PhDs in migration and population issues, and more than 20 currently studying.

"The University has become an important regional centre for its holdings of population and migration data from the region, and its staff have high levels of skill in analyzing them," Professor Hugo says.

> "THESE ACHIEVEMENTS EXEMPLIFY THE CAPACITY OF THE UNIVERSITY TO TURN ITS HIGH-QUALITY FUNDAMENTAL RESEARCH INTO OUTCOMES THAT CREATE A BETTER FUTURE"

As well as examining demographic changes at the national and regional levels, researchers are also working with global organizations such as the Nansen Initiative to study the impact of climate change on migration.

"Climate change is going to create massive disruptions and displacements of people," Professor Hugo says. "But in fact there is a much more complex relationship in which the effects of environment and climate change are going to be part of a wider pattern of economic change."

GROWING NEW FUELS

With the twin challenges of climate change and peak oil looming, the race to find viable, sustainable alternatives to fossil fuels has never been more urgent.

In response to this need, the University of Adelaide's School of Chemical Engineering partnered with Murdoch University to establish Muradel Pty Ltd, which has developed Australia's first commercial-scale demonstration plant for the production of green crude from microalgae. It's another illustration of how the University encourages connections that reach from basic research to commercialization.

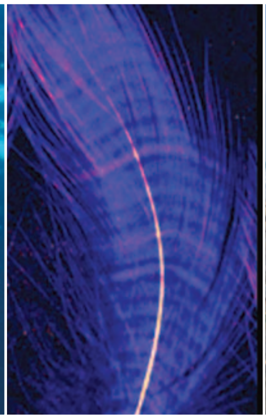
"The challenges with the production of biofuels from biomass are sustainability and high productivity," says Associate Professor David Lewis, one of the project's lead researchers and CEO of Muradel Pty Ltd.

Using a strain of microalgae isolated by Murdoch University, which grows rapidly in saline water, the team has been able to upscale an initial pilot plant, while the University of Adelaide's chemical engineers have developed the vital technologies that allow concentration and extraction of the dilute algae into a commodity product.

A demonstration plant has been built and commissioned in Whyalla, South Australia, with plans to build a larger thousand-hectare plant that will be able to produce around 450,000 barrels of green crude per annum—enough to supply a medium-sized industry such as mining, trucking or a regional airline.

This project, and the many others like it, are proof of the University of Adelaide's capabilities, says Professor Robert Saint.

"These achievements exemplify the capacity of the University to turn its high-quality fundamental research into outcomes that create a better future for local communities and the wider world."



PURSUING PLASTIC POLLUTION AT THE ATOMIC LEVEL

Plastic pollution is finding its way into the tissues of marine wildlife. Although many environmental risks of plastic have long been known, analysis by the Australian Nuclear Science and Technology Organisation (ANSTO) has detected chemicals from plastic pollution in the feathers of seabirds. However, this research is also giving clues to how to manage the problem.

The work is a collaboration between Richard Banati, a biomedical scientist at ANSTO LifeSciences, and Monash University conservation biologist Jennifer Lavers.

They analysed the elemental composition of plastic items collected from the stomachs of flesh-footed shearwaters. These were then compared with the atomic elements in the feathers from birds of the same species—some that had eaten plastics and some that had not.

The plastic and feather samples were analysed first at the Australian Synchrotron light source in Melbourne and then at the country's only operating nuclear reactor, the ANSTO Open-Pool Australian Lightwater (OPAL) research reactor in Sydney. There they were subjected to neutron activation, in which atoms are bombarded with neutrons to make them slightly radioactive.

Each element is then identified by its distinctive gamma-ray spectrum, giving measurements of composition so accurate they've been compared with determining the vintage of a single glass of red wine spilled into Sydney Harbour.

This produced some interesting findings, such as a regular distribution pattern of elements in each feather—much like the rings of trees. It also confirmed the researchers' initial suspicions: trace elements from plastic were found in the feathers of birds that had eaten it.

The health effects of these elements aren't well understood, but their presence in tissues shows the complexity of the pollution problem. Contrary to expectations, plastics that degrade in the environment are not necessarily safer for wildlife, as the increased surface area as they break down can exacerbate the release of toxins like cadmium and mercury.

"A traditional approach to environmental management has been 'the solution to pollution is dilution'," says Richard Banati. "However, we are finding that mass plastic consumption, together with increased degradability of plastics, may actually lead to a steady increase of hazardous contaminants in the environment which would be difficult to reverse."

However, the researchers stress that their aim is not to demonise plastic, but rather to better understand it at an atomic level.

Richard Banati, who has used radioactive elements in pharmaceutical research to track a drug's progress through the body, points to the intriguing possibility that manufacturers, too, could add an isotopic signature of non-radioactive trace elements to plastics to trace their lifecycle.

A combination of non-abundant elements together with a small amount of precious metal like gold—as little as 10 milligrams per tonne—could be detected by ANSTO's instruments and determine the litter's original source.

"Plastics will always have a place in our world," says Richard. "But we need to be mindful that a seemingly 'single-use' throw away item will change form many times and stay in the system at the atomic level for eternity."

ANSTO's Institute for Environmental Research already uses the ability to distinguish naturally occurring isotopes to follow the movement of groundwater and rainwater into the hydrologic cycle, and to examine other human impacts on the climate and environment.

These activities sit alongside ANSTO's long-standing roles in medical research—contributing to new ways of treating conditions like Alzheimer's and Parkinson's diseases, as well as producing 85 per cent of the nuclear medicines used in Australian hospitals—and materials engineering, such as the development of Synroc—tailored ceramic forms for locking up high-level radioactive waste.

Australian Government

ansto

www.ansto.gov.au
www.twitter.com/ANSTO
www.facebook.com/DiscoverANSTO

SDP MEDIA

Multidisciplinary funding and the benefits of research evaluation programmes were hotly debated at an event organized by *Nature*.

RESEARCH METRICS

Calling science to account

Systematic evaluation of scientific research might strengthen public support, but could it also stifle innovation? The issues were debated at a symposium in Melbourne.

BY TIM THWAITES

Since the United Kingdom's first Research Assessment Exercise in 1986, the concept of a national evaluation of publicly funded research has expanded to other countries, including Belgium, France, Italy, Australia and New Zealand. Some assessments are performed specifically to determine allocation of research funds, whereas others are benchmarking exercises of the performance of local research in a global context. Although the overall goals of these assessment systems are well understood, there is doubt as to how well each is working.

Their relative effectiveness was the focus of a symposium in February 2014 in Melbourne, Australia. *Nature* brought together experts from institutes and universities in Australia, New Zealand and Singapore to examine issues surrounding the outcomes and impact of how research is measured.

In his introduction to the symposium, *Nature* editor-in-chief Phil Campbell outlined several of the issues and views that were later discussed. "There is a need for research evaluators to be explicit about the methods they use to measure impact," he said. "Openness is an essential part of earning trust. *Nature* welcomes a diversity of indicators." Relying solely on citations, Campbell added, "absolutely can't be sustained".

The United Kingdom has recently reoriented its research-assessment programme to bring peer review, case histories and metrics into a system called the Research Excellence Framework (REF), which runs for the first time this year (see 'How research benefits the United Kingdom'). The Melbourne symposium examined this approach against various schemes in the Asia-Pacific region, including Singapore's carefully programmed development of knowledge-based industry; New Zealand's proposition that criteria for assessment be laid down even before research starts; and Australia's quantitative evaluation of its research strengths and weaknesses. Two things were clear: there are many reasons for evaluating research, and there are lots of approaches to get results. Perhaps the first hurdle to overcome is deciding what you want to achieve.

VALUING RESEARCH

The symposium's keynote speaker was David Sweeney, the director for research, innovation and skills at the Higher Education Funding Council for England (HEFCE) in Bristol. Sweeney, who managed development of the REF, told delegates there was "no right to research funding". He said, "If, as happened in previous budget proposals in the UK, senior scientists say to government 'Give us the money, and we will deliver the goods', the treasury has a right to say, 'Prove it!'."

Sweeney said that scientists cannot assume that the general public understands the value of their research, so evaluation has become an essential tool for convincing UK government, business and society why they should invest in universities and research. In fact, he said, the UK government wanted to enlist companies to help fund university research — unlocking some of the capital that businesses had put away during the global financial crisis to protect against hard times. The outcomes of the REF, teamed with matched-funding schemes, could help the government release previously hidden private pots of money, he argued.

Sweeney outlined the REF's methodology. "Academic excellence is still the number one objective of public funding," he said. But conventional gauges of merit, such as peer review and citations, should not comprise the whole assessment; it's also important, he said, to reward research that has a positive impact on society. He asserted that the REF did not open the way for government to dictate research direction. Nor did it mean a bias towards funding applied research. Instead, said Sweeney, REF provided a means of validating the contribution of all research: "It's not about favouring one discipline over another." He presented REF not as a perfect measure of impact, but as a first step. "The methodology does the job that needs to be done now, even though it's not perfect," he explained.

Real-world issues, such as water and energy usage, are complex and interconnected, and research addressing these matters needs to draw on expertise from physical and biological sciences, as well as social sciences including economics, behavioural psychology and law. Yet, according to participants in a panel discussion on multidisciplinary research, such crucial work has rarely been valued appropriately in research assessment exercises.

The intrinsic value of multidisciplinary teams, and the difficulties of their coordination, were well illustrated by the story of the Murray-Darling Basin Plan, set up to manage water resources in Australia's largest and most agriculturally productive area. "It was a wonderful document that told us exactly what we should do," said Robert Saint, pro vice-chancellor of research strategy at the University of Adelaide. The plan was unpopular as it proposed swingeing cuts to water allocation for many farmers. "Its release was closely followed by farmers burning it, and the whole business had to go back to the drawing board." The problem was that the Murray-Darling Basin Authority, which compiled the report, lacked the specific capabilities for incorporating legal, political and social issues alongside the science.

Australia's largest national research body, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), based in Canberra, is no stranger to multidisciplinary research, said its chief executive Megan Clark. CSIRO, she noted, specializes in large-scale, broad, "pan-disciplinary" research groups. "There is an understanding from the minute you walk in that this is not a place to work on personal research," she said. "We work in multidisciplinary teams on mission-directed research." As a result, CSIRO's evaluation of its own research includes traditional outputs, such as patents and journal publications, and quality assessments by independent peer review panels, but crucially also takes into account the impact of its work on end users — including the public, government departments, private companies and environmental organizations (see page S72).

"The methodology does the job that needs to be done now, even though it's not perfect."

CSIRO runs large-scale multidisciplinary research partnerships known as National Research Flagships (see 'Launching flagships'). These focus on issues of national and global importance such as biosecurity, preventative health, manufacturing and sustainable agriculture. In a little more than a decade, the Flagships programme has grown to encompass more than half of all CSIRO research activity.

Many stakeholders, Clark recalled, feared that the Flagships programme would lead to a decline in the quality of the organization's science. But CSIRO's experience has been the reverse, she said. "Last year, we hit a record in the quality of our science and our standing globally." For instance, the citation rate for CSIRO research publications is now 56% more than the global average, according to the organization's latest *Science Health and Excellence* report.

CSIRO's approach differs from multidisciplinary work undertaken at universities, which are the primary training grounds for researchers, said Kim Langfield-Smith, vice-provost for academic performance at Monash University in Melbourne. The academic environment tends to have discipline-focused organization underpinning promotion tracks. This silo structure is not conducive to researchers thinking outside their speciality.

Langfield-Smith spoke of the difficulties in recruiting university researchers for multidisciplinary projects. In particular, mid-career and older researchers found it difficult to justify interrupting their research to join projects that might not yield publications in the top journals of their own fields. What's more, multidisciplinary research is difficult to get underway: it routinely lacks common language, modes of analysis, conceptual frameworks and dedicated journals (many outcomes

HOW RESEARCH BENEFITS THE UNITED KINGDOM

Evaluating research can increase its public support

The Research Excellence Framework (REF) is the new system for assessing the quality of research at UK universities. It aims to demonstrate the benefits of public investment in research; to show accountability for government research funding; and to rate the quality of the United Kingdoms's research efforts on a global scale across all academic disciplines.

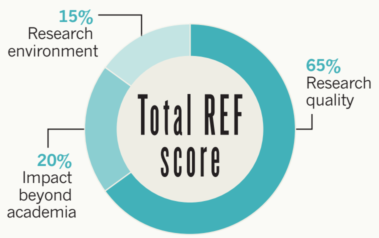
The REF — successor to the Research Assessment Exercise — will produce its first report in December 2014. It will be used to assist the four UK higher-education funding bodies — the Higher Education Funding Council for England, the Scottish Funding Council, the Higher Education Funding Council for Wales, and the Department of Education and Learning in Northern Ireland — to allocate government funding for research, at present about £1.6 billion (US$2.7 billion) a year.

It assesses the efforts of higher education institutions across 36 subject areas, determined by the quality and impact of research as well as what the research environment is like (see 'UK scorecard'). The results will be published in the form of a quality profile in which each submission is ranked as either world-leading, internationally excellent, internationally recognized, nationally recognized or unclassified.

The assessment is made by expert panels, which include representation from people in business or government who use research outputs in their professional activities or who commission or collaborate with academic researchers. T.T.

UK SCORECARD

How a Research Excellence Framework (REF) score is determined.



Research quality (up to four papers per researcher, published between 2008 and 2013).
Impact beyond academia (case studies written by researchers).
Research environment (research strategy, facilities, staffing, etc.).

are instead published as government reports).

Saint observed that peer review could be disadvantageous to multidisciplinary projects at both the funding and publication stage. "I remember the early days of bioinformatics: statisticians would argue that all the theory had been done 40 years ago, and biologists couldn't see anything interesting in statistics." The panellists suggested several ways to promote multidisciplinary work, including setting up dedicated funding streams for such research, and altering the criteria of assessment so that work published in government reports is eligible for consideration.

Hugh Durrant-Whyte, chief executive of NICTA, Australia's largest information and communications technology research organization, suggested that the solution lay in removing disincentives. Funding agencies, he said, should foster a research culture that encourages scientists to undertake projects because they were "cool and exciting, not because there is a paper at the end". Young scientists, he said, should be urged to "find something interesting and get on with it". This would naturally stimulate collaborations and multidisciplinary work, he added.

WHEN OPTIONS ARE LIMITED

The value of research to government can be very different from its value to business, or to academia or the public. That's why it's critical to set the criteria for evaluation from the very beginning, said Peter Gluckman, chief science adviser to the prime minister of New Zealand. This approach "changes the way research is done", said Gluckman. "It influences how scientists work and think."

Gluckman was mainly referring to government-directed projects that account for a large portion of the science budget of small countries such as New Zealand. Perhaps the most compelling argument for this principle can be seen in Singapore, which has taken little more than a decade to generate a biomedical industry from a low starting point (see 'How to grow an industry').

David Lane is chief scientist of Singapore's Agency for Science, Technology and Research (A*STAR) which, with the country's Economic Development Board, was responsible for implementing the Biomedical Sciences Initiative to develop the industry. He said that determining impact was a major part of the government's strategy. "Our budget was increased," he said, "but 30 to 40% was set aside and would only be released if we could show we were doing work aligned with industry." The yardstick by which the effort was measured was the level of corporate investment in Singapore's biomedical industry.

Such a utilitarian view of science by governments, said Gluckman, differs enormously from the academic perspective, which focuses on accumulation of knowledge. Governments, he said, were typically concerned with research impact on the economy, the environment, defence and public health. Such priorities were greater in small economies that cannot so easily spare money for blue-sky research.

One of the purposes of the Excellence in Research for Australia (ERA) programme at its inception was to determine in which research fields Australia had world standing, said Margaret Sheil, provost of the University of Melbourne and a former head of the Australian Research Council (ARC). Sheil, who was heavily involved in the design and operation of the ERA (see page S67), pointed out that although Australia had a small population, it was competing globally in many disciplines.

Representing these different viewpoints in one assessment tool is not easy. Science entrepreneur and chancellor of Monash University, Alan Finkel, suggested that funding bodies needed a framework where activities such as working in industry, contributions to government reports or communication of research outcomes to audiences other than a researcher's peers could be converted into a "citation equivalent" for the purpose of improving the measurement of research impact (see page S77).

METRICS ARE NOT THE ANSWER

Assessing a country's research enterprise is not an end in itself. And when it comes to acting upon the outcomes of research assessment, funders have vastly differing viewpoints. The one issue on which they tend to agree is

LAUNCHING FLAGSHIPS

Restructuring CSIRO to tackle national problems

The National Research Flagships are large-scale, multidisciplinary research partnerships between the Commonwealth Scientific and Industrial Research Organisation (CSIRO; Australia's largest national research body), universities, other publicly funded research institutions, the private sector and international organizations. There are 11 current Flagships tackling significant national challenges (see table, below).

The initiative began with three Flagships in 2003 and has grown into one of largest scientific research programmes ever undertaken in Australia. Together, they account for more than half of CSIRO's budget of about AUS$1.5 billion (US$1.4 billion), expected to increase to 65% by July 2015.

Setting up the Flagships required a substantial organizational shake-up. Initially, CSIRO retained its 11 traditional discipline-based divisions across the country, with the Flagships able to draw staff from any division or partner organization. From July 2014 they will merge into nine Flagships.

Since 2005, a Flagship Collaboration Fund has committed more than AUS$130 million in grants to encourage partnerships between universities, CSIRO and other research agencies. **T.T.**

FLAGSHIP TITLE	YEAR LAUNCHED	DESCRIPTION
Energy	2003	Investigating low carbon alternative energy sources and the future of transport.
Food Futures	2003	Transforming the global reach of the Australian agrifood sector.
Preventative Health	2003	Improving well-being through research into prevention, detection and health interventions.
Wealth from Oceans	2003	Investigating the network of resources, capacity and sustainability of the oceans and developing appropriate technologies.
Water for a Healthy Country	2004	Developing technologies to improve the social, economic and environmental outcomes around water access and use.
Future Manufacturing	2007	Developing cleaner advanced materials and technologies.
Minerals Down Under	2007	Growing Australia's resource base, increasing productivity of the minerals industry and reducing its environmental footprint.
Climate Adaptation	2008	Supporting Australia's efforts to adapt to climate change.
Sustainable Agriculture	2010	Addressing productivity and food security in a carbon-constrained world.
Digital Productivity & Services	2012	Developing and delivering improved online services and changing the way people engage with technology.
Biosecurity	2013	Helping to protect Australia from biological risks posed by exotic and endemic pests and diseases.

that any worthwhile evaluation of research — whether it be for disbursing grants or encouraging excellence — needs to be based on a range of measures, not just the quantity of publications and how often they are cited by others. In the final panel of Melbourne symposium, representatives of four significant funding organizations discussed how best to incorporate the information gained from assessments.

Traditionally, research assessment evaluates completed projects. But, in an ever-changing research environment, a scientist's past successes might not be a predictor of how well they will perform in the future, said Tony Peacock, chief executive of the Australian Cooperative Research Centre (CRC) Association in Canberra, which runs the nation's 40 CRCs — collaborative partnerships between publicly funded researchers and industry. In fact, Peacock argued, rewarding only those strategies that were successful in the past would tend to discourage new approaches and stifle innovation, the essence of successful science. Relying solely on citation and peer review metrics was opposed for similar reasons by Warwick Anderson, chief executive of Australia's National Health and Medical Research Council (NHMRC) in Canberra, which dispenses more than AUS$750 million (US$700 million) of government money in research grants each year (see page S52).

"It's not only the research that's important, but also how it is used," he said. Health researchers typically wish to influence decision-makers and medical practitioners as well as other scientists, which means they need to publish in areas outside academic literature. To properly evaluate their work, he said, you needed to consult sources other than scientific journals, such as government reports and health-care experts. Government has a huge interest in health care because of its enormous cost. Australia's AUS$140 billion health-care industry — comprising vaccine manufacturers and medical device developers, among others — is also the nation's second largest exporter of manufactured goods, Anderson said.

Australia's other major research funding body is the ARC, responsible for disbursing more than AUS$900 million a year. It also administers the ERA, which aims to determine areas of Australia's research strengths. ERA assessments are made by internationally recognized researchers, organized by discipline and clustered into eight Research Evaluation Committees. They use traditional measures of quality, such as citation analysis or peer review, but also incorporate a broader view, considering income from commercialization and measures of esteem — for example being admitted to a learned society such as becoming a fellow of the Australian Academy of Science.

ERA ranks research quality against a global scale and is "a rigorous and robust measure across all discipline domains", ARC's chief executive Aidan Byrne told the symposium. It aims, he said, to get researchers to change their focus from quantity of work to quality. "In that, the ERA exercise has been spectacularly successful. And it did it without tying the exercise to financial rewards."

Furthermore, despite its reliance on metrics, ERA results for academic excellence correlate with other real-world outputs, Byrne said. For instance, 95% of industry investment in research in Australia is in the same areas in which researchers performed at world-class or better. And the same is true for 98% of the research that was commercialized and for 97% of the work that was patented.

HEFCE's Sweeney's take on various methods of assessment was straightforward. No system will be perfect, he said, but you have to start somewhere: "You can propose alternatives, and spend five years discussing them, but that's not going to solve today's problems." ■

Tim Thwaites *is chief science writer for Science in Public, a science communication agency based in Melbourne.*

HOW TO GROW AN INDUSTRY

Singapore becomes a biomedical powerhouse

BLOOMBERG/GETTY

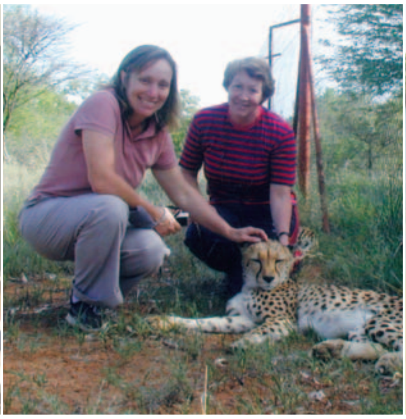
Singapore's impressive bioscience research hub, Biopolis, which opened in 2003.

In little more than a decade, Singapore has established a thriving biomedical industry from scratch. The country, with few natural resources, set itself a goal in the early 1990s to become a knowledge-based, innovation-driven economy. The government identified biomedical sciences as an area with tremendous growth potential and decided to try to grow its own industry. In 2000, it started to invest in a Biomedical Sciences initiative and, by 2012, this industry had grown to more than SG$30 billion (US$24 billion), comprising more than 50 manufacturing plants, 50 R&D centres and 30 regional headquarters of biotechnology and pharmaceutical companies.

The first phase of the initiative (2000–05) concentrated on rapidly expanding Singapore's basic research capabilities and infrastructure as well as attracting industry R&D laboratories from other countries. The government also constructed an R&D hub, the Biopolis — seven buildings of 185,000 square metres at a cost of SG$500 million — next to the National University of Singapore.

The second phase (2006–10) bolstered Singapore's capacity to undertake translational and clinical research and turn it into health-care products and applications. Large biomedical corporations, such as Lonza and Genentech, were attracted by favourable business and investment terms including generous tax rates and access to a flexible and skilled labour market.

The current phase (2011–15) focuses on encouraging international investment and links with industry. An Industry Partnership Office has been set up to facilitate collaborations with private enterprise. The five-year budget was increased by 16% to nearly SG$16 billion, with a substantial portion channelled into industry-oriented research. T.T.

SAVING SPECIES WITH BIG DATA AND APPLIED STATISTICS

Kerrie Mengersen, Professor of Statistics at the Queensland University of Technology (QUT), knows she has the best job in the world. Studying everything from the effect of chemotherapy on the brain to the efficient management of airports, Mengersen applies the tools of Bayesian statistics to some of the world's most important problems.

A Bayesian statistician views the world as an opportunity for adaptive learning, Mengersen explains. "We create new mathematical and statistical methods and computational solutions," she says. "Then we apply these new approaches to help solve important problems across diverse areas including health, environment, conservation, business and industry."

"As statisticians we find the stories in the data, and then convey these insights to people who make decisions to address some of the world's grand challenges."

Recently, Mengersen and co-authors caused a stir when they used this approach to study the number of living species that exist on coral reefs around the world. They found that despite decades of study, scientists appear no closer to understanding how many species are alive today. Existing estimates vary wildly, seemingly with little reference to previous findings.

They called for a more systematic and statistically based approach to this important topic. It's work that illustrates how statistical analysis can not only provide solutions, but also raise questions that can motivate discussion and generate new insights.

For Arun Sharma, QUT's Deputy Vice-Chancellor, Research and Commercialisation, Mengersen's work epitomises the university's focus on supporting high-impact research with a view to achieving significant public and practical benefit. "We're known as 'a university for the real world' because of our close links with end users," he says.

In 2013, the success of that strategy saw QUT ranked by The Times Higher Education as Australia's top university under 50 years in its 100 under 50 ranking. In recent years, QUT has built critical mass in the fields of robotics and automation, big data and personalisation—technological trends that are advancing disciplines, transforming professions and disrupting business models. These technological capabilities, coupled with an interdisciplinary culture and a desire to solve real-world problems, differentiate QUT's research.

The diversity and importance of Mengersen's work have led her to be named one of QUT's most successful researchers. In the past year alone, she was an integral leader in the consortium securing $20 million in funding over the next seven years to establish a new Australian Research Council Centre of Excellence for Mathematical and Statistical Frontiers of Big Data, Big Models, New Insights.

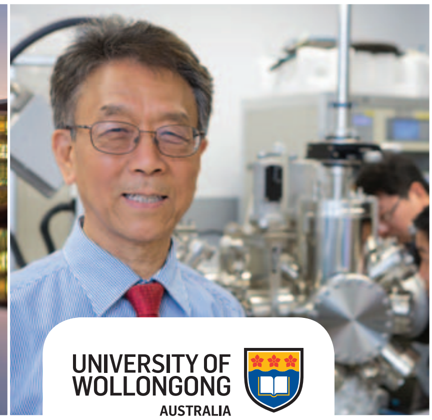
The aim of the Centre is to bring together researchers in mathematics, statistics and machine learning to create innovative models and make vital contributions to society, business and government. Its work is organised into three research programs—*Big Data Analytics* will focus on innovative methods for extracting and communicating information from big and complex data; *Big Models* will study new theoretical and methodological approaches to modelling large, complex systems; and *New Insights* will consider new ways of using the modelling and analytic approaches to inform our understanding of issues in the areas of health, the environment and societies.

"All our work involves engaging with great researchers and the expert clinicians, conservationists, managers and others who are doing amazing things in their own fields," Mengersen says. "It is humbling and very rewarding to be able to help them do their jobs better."

"One of the great things about working at QUT for me is its very strong support for maths and statistics," she adds. "The University encourages cross-disciplinary collaboration, which means that I actively work with people from social science, engineering, environmental science, health and business."

On top of all that, Mengersen is particularly proud of her group of researchers and students, known as the Bayesian Research and Applications Group, or BRAG. "What more could I ask of a workplace?"

www.qut.edu.au



FROM HEAVY INDUSTRY TO NOVEL MANUFACTURING AND SUSTAINABLE SEAS

We live in an age of uncertainty, a world with a population that is both ageing and growing. It is a world of climate change, of rapid economic transformation and of immense technological advances.

Most cities and regions have developed slowly—over many decades, if not centuries. But in order to survive in this fast-changing world, communities must now be able to adapt quickly.

So says Professor Chris Gibson, leader of the Global Challenges Program at the University of Wollongong, one of a small number of universities around the world that is harnessing research strengths to target the global challenges of the 21st century.

TRANSFORMING LIVES AND REGIONS

Ranking in the top 2% of universities worldwide, we are especially qualified to tackle these challenges having played a leading role in the transformation of our home town of Wollongong, one hour south of Sydney, to a city of the future.

Throughout the last century, Wollongong was Australia's heavy industry heartland, best known as the home of the nation's largest steel mill. The University was established to train the industrial chemists, metallurgists and engineers needed to keep these factories working.

But, although these traditions continue, our research is now helping turn Wollongong into a 21st century centre for technology. This includes innovations like the BioPen, which lets surgeons "draw" on damaged bone with an "ink" containing live cells.

Professor Chris Gibson, Global Challenges Program Leader, University of Wollongong

Developed at the Australian Research Council Centre of Excellence for Electromaterials Science (ACES), which is headquartered at the University, the BioPen uses techniques similar to 3D printing to extrude cellular material between layers of gel. By delivering this material directly to the site of an injury, it can accelerate the regeneration of functional bone and cartilage.

The University of Wollongong was the first in Australia—and remains one of only five labs in the world—to fabricate silicene, a new two-dimensional material. Structurally similar to graphene, but made of silicon instead of carbon, silicene has intrinsic semiconductor properties that graphene lacks.

These properties could help it revolutionise materials science, leading to smaller, faster computer chips and more practical and efficient solar cells, as well as improvements in medical technologies and vehicle and aircraft parts.

Having demonstrated our expertise through achievements like these, we are now focusing our efforts on three Global Challenges—areas in which we can make the greatest impact: the ageing population, the growing pressure on marine and coastal environments, and the changing nature of manufacturing and industry.

"We have taken an innovative approach to our research, concentrating on three challenges and then marshalling multidisciplinary resources and expertise from across the University to work on research projects under each challenge," Professor Gibson says.

MANUFACTURING INNOVATION

Taking advantage of Wollongong's history as a region of industrial creativity, we're already tackling the puzzle of what we should be making in Australia and how we should be making it. This means exploring the potential of the broadband-powered digital economy and the possibilities of smart materials, robotics and automation, as well as innovative medical devices.

It's also where we use our strengths in 3D printing and additive manufacturing to create results that were previously not feasible—such as custom-printed flutes that can play microtonal scales, or the notes between notes.

After bringing together economists, planners, social marketers, creative artists and designers to work on projects, we have initiated a global benchmarking exercise to ensure we are operating at best practice in these novel manufacturing techniques in our local region.

SUSTAINING COASTAL AND MARINE ZONES

Through our international collaborations we're seeking to improve the sustainable management of fish stocks, like bigeye and yellowfin tuna, that are under pressure from fishing fleets. This project, run through the Australian National Centre for

Ocean Resources and Security, will help to deliver the food security needed for social stability in Pacific island nations that face declining fisheries.

We're also harnessing social media technology to build resilience to climate change-induced extreme weather events in South-East Asian megacities. PetaJakarta uses real-time data from 150,000 Twitter users in Indonesia's capital to track and analyse flooding and inform emergency services and residents.

Our SMART Infrastructure Facility, which runs the project, was one of only six research institutions in the world to receive an inaugural Twitter Data Grant and gain access to this vital information.

LIVING WELL, LONGER

By taking a holistic approach to the problem of an ageing population—considering physical and mental health as well as access to services—we're discovering the physical and mental requirements for a long, healthy and high-quality life.

Our research is making a real impact on dementia, which is expected to affect one million Australians by the middle of the century. Two dementia-friendly communities that we're designing and piloting will not only accommodate but also actually welcome people who suffer from this debilitating illness.

And we're bringing together doctors, psychologists, geneticists, paediatricians, obstetricians and social scientists to follow three generations of local residents to understand their patterns of mental health and wellbeing as they age.

Professor Gibson says these collaborations capture the power of the University's multidisciplinary research capacity.

"Regions all over the world are facing common challenges, and it is important that from an empirical basis we develop tailored outcomes that have a global impact," he says.

The Global Challenges Program shows how we're playing a significant role in transforming lives and regions for the better.

To learn more, visit **globalchallenges.uow.edu.au.**

UNIVERSITY OF WOLLONGONG

A dynamic Australian university with a strong research focus, located just an hour from Sydney's International Airport.

CURRENT RANKINGS

- Top 2% of world universities (The Times Higher Education, QS, Leiden and Academic Ranking of World Universities)
- Top 100 for global graduates (QS Graduate Employers Survey)
- Five stars (QS World University Rankings)
- 1st in Australia for Educational Experience and Graduate Outcomes (Good Universities Guide)
- 22nd and 33rd in The QS and Times Higher Education rankings respectively for the world's Top 100 Universities under 50 years of age.
- 2nd (relative to size) and 8th on total research funding awarded nationally.

CAMPUSES

- Two campuses each in Wollongong and Sydney, and regional campuses in the Shoalhaven, Batemans Bay, Bega and Moss Vale
- University of Wollongong in Dubai.

KEY NUMBERS

- 31,500 students
- 12,800 international students
- 1,520 higher degree research students (893 domestic; 627 international)
- 138 nationalities represented in student body
- 2,350 staff
- 476 degree courses.

RESEARCH AND COLLABORATION OPPORTUNITIES

- Record $49.1 million in Australian Research Council (ARC) funding announced in 2013
- Postgraduate scholarships
- Multidisciplinary PhDs
- Vice-Chancellor's Postdoctoral Fellowships
- Visiting academic appointments
- Study leave and sabbaticals
- Financial assistance for international exchanges
- Joint PhDs with overseas universities.

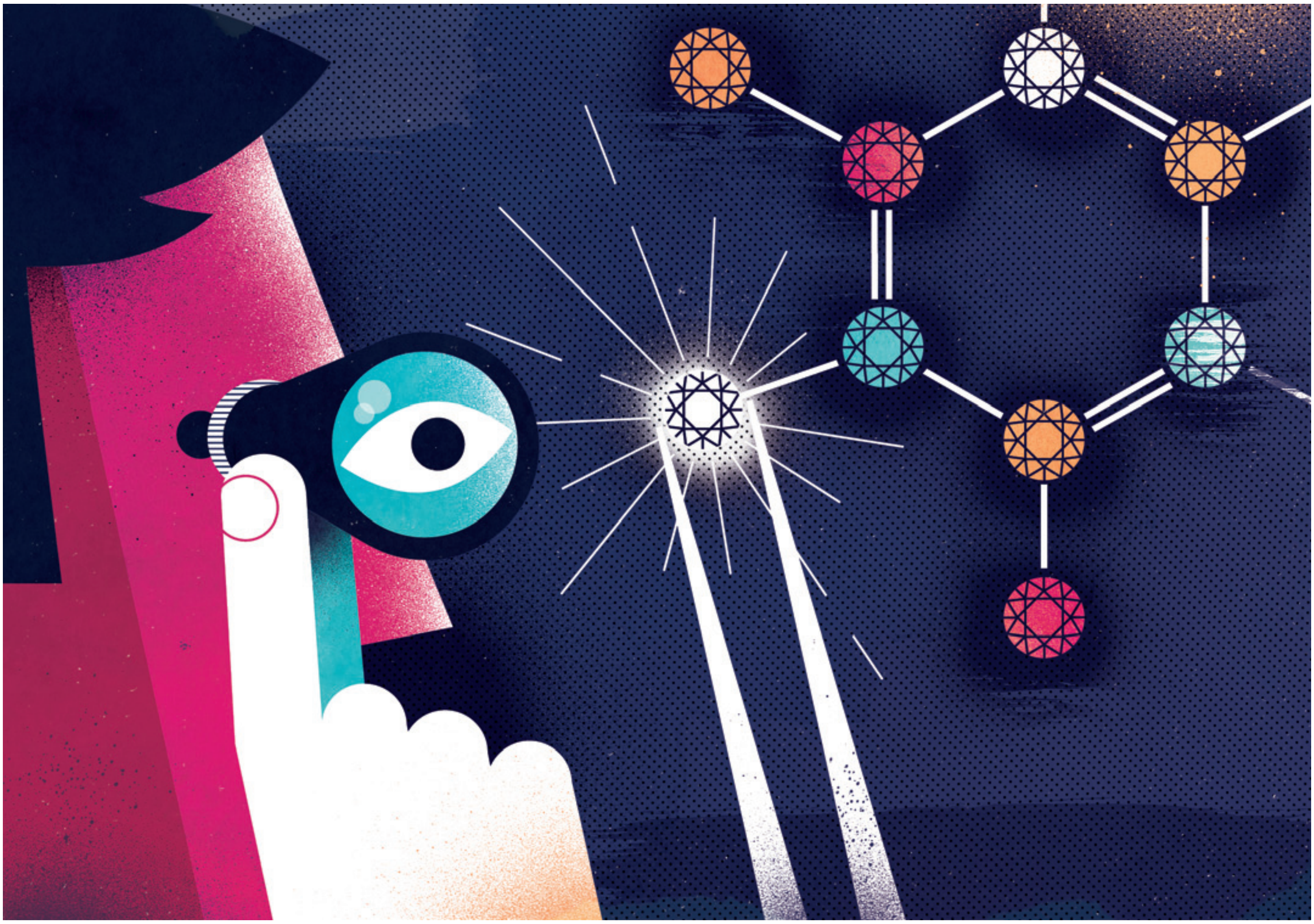
LEARN MORE

Visit: www.uow.edu.au
www.uow.edu.au/research
Facebook.com/UOW
Twitter.com/UOW

Phone: +61 2 4221 3555

UNIVERSITY OF WOLLONGONG
AUSTRALIA

University of Wollongong



DALE EDWIN MURRAY

RESEARCH ASSESSMENT

The limits of excellence

Young researchers and interdisciplinary science might be getting short-changed by research assessment in Australia and New Zealand.

BY ANNABEL MCGILVRAY

The day before he and I speak, Jonathan Boston receives an email on a familiar theme. It is from a colleague concerned about a junior researcher whose career decisions are "being twisted in an uncomfortable way" by the demands of New Zealand's Performance-Based Research Fund (PBRF). "I have had many such messages over the years — which reflect the good and the bad of the PBRF," says Boston.

Boston holds a personal chair in public policy at Victoria University of Wellington, and was one of the architects of the New Zealand system. He says that research paths can become conflicted by one of three scenarios: compulsion to publish articles in high-impact international journals rather than working on a book with a domestic publisher; pressure to change research focus to better align with mainstream or more highly esteemed fields; or encouragement to accept a position as a non-PBRF-eligible teaching fellow and move away from active research. Each of these outcomes can be traced to the way in which the PBRF measures research excellence, and so its influence on the country's research funding environment.

At its conception in 1999, explains Boston, the PBRF was an ambitious undertaking to measure research excellence andraise standards at institutions across New Zealand. It was intended to remedy years of neglect of the research sector through which the bulk of funds, dubbed research top-ups, had been linked to postgraduate student numbers. The flaws of that arrangement had become evident in the mid-1990s when non-university higher education providers — such as polytechnics and institutes of technology — began offering postgraduate degrees. The research pot was suddenly being split between ever more institutions, many of which had limited research capacity. When Helen Clark's Labour government came to power in 1999 with five former academics — including Clark, a lecturer in political studies — among its senior ranks, it vowed to strengthen the process of research funding and increase accountability. "The only option was some sort of performance-based regime," says Boston.

The PBRF is based on the individual, making it unique among measures of national research excellence. Every six years, it gauges and reports the standard of research of each of New Zealand's approximately 6,000 researchers in universities and colleges (so-called tertiary educational establishments). These rankings — A, B, C and R — are provided to the institutions; a researcher can apply to receive his or her own rating. The outcomes are then weighted by quality and subject area, in line with the resources required for different fields. The individual results are aggregated by institution and are the major determinant, alongside external income and research degree completions, of the distribution of research funding. The PBRF is now the largest single source of tertiary research funding in New Zealand, worth NZ$262.5 million (US$224.2 million) in 2013 (see page S52).

Across the Tasman Sea, the Australian Research Council (ARC) is gearing up for the third round of its own national measure of research quality, the Excellence in Research for Australia (ERA) evaluation, which takes place for every three years for the country's 41 universities. The forthcoming ERA2015 will categorize and evaluate the nation's entire higher education research output, comprising more than 400,000 publications. The ERA assesses work by discipline, and the initiative directly influences only a small portion of university research funding.

Results suggest that the overall quality of research has increased in both countries since the introduction of national assessments. More New Zealand researchers are achieving an A rating, and more Australian disciplines are classed at 'above world-standard'[1,2]. But the PBRF and ERA prompt passionate reaction in their respective research communities. With increasing awareness of the need to assess the societal impact of research, merely weighing academic excellence makes less sense. There is concern that subject-focused assessment programmes don't adequately recognize the value of interdisciplinary research. And, as Boston's recent email correspondence implied, there are fears that the way excellence is measured — in particular the focus on high impact publications — may be hindering the careers of young researchers.

THE FOLLY OF YOUTH

PBRF and ERA both use metrics of quality and peer review to determine ratings. The same indicators are used in different forms in research assessment schemes around the world. However, for the PBRF, all nominated publications and other research outputs are rated by selected reviewers — a qualitative process that depends on individual judgements.

The ERA, by contrast, places more emphasis on citation analysis. "The number of people who are citing and making reference to work is a pretty good indicator of the significance and impact it has had in the academic community," says Aidan Byrne, ARC chief executive officer.

But these measurements of excellence are creating obstacles for young scientists, says Attila Brungs, deputy vice-chancellor for research at the University of Technology, Sydney (UTS). "Narrow metrics can drive some bizarre behaviours. People don't publish as much with PhD students because PhD students are often published in lower-ranked journals."

More broadly, the strengths of early-career researchers aren't readily demonstrated by reference to an objective publication review, a particular flaw of the individual-centred PBRF. Assessment encourages institutions to employ staff with established research records rather than emerging researchers who are doing excellent science but who are yet to amass publications. There is early evidence of this reluctance to engage young researchers, with one study showing a 14% drop in research staff aged 35 and younger between the first and second rounds of the PBRF[3].

There are fears that the way excellence is measured may hinder the careers of young researchers.

Indeed, a 2008 independent review of PBRF found that morale of otherwise high-achieving young researchers was being hurt by low ratings. The review, commissioned by the body that oversees PBRF, the Tertiary Education Commission (TEC), stated that "the assignment of a 'C' grade was seen by rising stars to undermine morale and to stigmatize their position". Boston says that when the PBRF scheme was designed there was no intention to reveal individuals' ratings. Not until after the system was established did Boston and his colleagues realize they were compelled to impart that information to researchers. "We simply failed to fully realize the implications of the Privacy Act and Official Information Act," he says. "If I had known we would end up with a regime in which individuals had their scores reported to them, and that other people could potentially know what they were, I would not have supported it."

The TEC has created a specific 'new and emerging researcher' category to counter disincentives to employ early career researchers when evaluation rounds loom. Researchers in this category can qualify for C(NE) rating and contribute to their institution's funding allocation. Their evidence portfolio assessment is weighted against their time as a researcher, with a minimum of two research outputs generally expected.

But many people, including Boston and Peter Gluckman, chief science advisor to the New Zealand prime minister, believe that the individual judgements inherent in the PBRF reviewing process continue to place undue pressure on emerging researchers to publish in high-impact journals. "I've seen several young researchers quite compromised by this drive to produce the one paper that will get into *Nature*," says Gluckman, "when their career would have been much more developed had they focused on getting solid, excellent papers in the appropriate journals".

TOGETHER YET APART

Researchers undertaking interdisciplinary work are also feeling compromised. Campuses across New Zealand and Australia are bringing together researchers from multiple disciplines, from the hard sciences to the humanities, to look at societal problems in a holistic way. These fields include environmental sustainability and medical research and, in many cases, work is carried out under the auspices of a centre or an institute within a university.

Despite this big-picture approach, assessments such as the PBRF and the ERA continue to view research through a mono-disciplinary lens. The final report from the 2012 PBRF conceded that the 42 subject areas under which all research is assessed "do not accurately reflect the way research activity is organized and conducted". Despite this acknowledgment, there are no plans for a review, says Marny Dickson, chief policy analyst for tertiary education at the New Zealand Ministry of Education.

The story isn't much more encouraging in Australia. The Australian Council of the Learned Academies (ACOLA) — representing the four Australian academic societies: the Australian Academy of Science, the Academy of Social Sciences in Australia, the Australian Academy of the Humanities and the Australian Academy of Technological Sciences and Engineering — seeks to inform policy specifically related to multidisciplinary research. In a 2012 report, ACOLA found that the ERA "has difficulty in evaluating and reporting interdisciplinary research". And the situation is likely to be exacerbated as universities base their internal benchmarks around the ERA, which, like the PBRF, focuses researchers on higher impact journals — few of which are interdisciplinary.

For instance, the Centre for Cosmopolitan and Civil Societies at UTS, does a lot of applied research related to policy, and frequently produces work for the local, state and federal governments. When the centre's researchers publish, they have to do so in the journals of their individual expertise, whether marketing, business and economics, or social science and the humanities. The university is then rated separately for each of these fields, rather than for the centre's projects as a whole. "In an exercise like ERA, their work disappears, it doesn't exist," says Brungs.

Brungs says that the distortion doesn't yet affect the university's research priorities, because the funding linked to ERA is very small. In 2014 it was just AUS$69 million, or 4% of the research block grants made by the Department of Education. But, an increase in

INTERNALIZING TARGETS

Measurements used by the Excellence in Research for Australia system are finding their way into internal targets set by research institutions. Here is one example of 2011 targets from a leading Australian university.

Research outputs	Laboratory-based sciences: minimum (Min) and aspirational (Asp) targets							
	Lecturer		Senior lecturer		Associate professor		Professor	
	Min	Asp	Min	Asp	Min	Asp	Min	Asp
Nº publications	1.5	4	3	6	4	8	7.5	15
Impact factor	4.5	16	9	24	12	32	22.5	60
Proportion in A/A* journals †	35%	55%	45%	65%	55%	80%	55%	80%
Research income (AUS$)	$5,000	$40,000	$30,000	$125,000	$150,000	$500,000	$500,000	$1,000,000

† Ranking of journals as a proxy for quality (A/A* being the two highest) was abandoned by the ERA in 2011.

the proportion of ERA funding would make future collaborations harder to justify. "Universities are not allowing the drivers to distort their behaviour too much," says Brungs. "But if we continue to go down that path it does have real danger for the interdisciplinary sector."

PLAYING GAMES

If PBRF and ERA become more significant, recruitment policies at universities will inevitably be coloured by how a candidate might affect a pending evaluation. Some fear this will lead to a widespread gaming of both systems as institutions try to improve their scores.

Australia's National Tertiary Education Union has found that ERA gaming already occurs, as individuals, departments and institutions strive for results needed to influence funding decisions that last for three years. In the case of the PBRF, the equivalent decision influences six years of funding, a magnitude which further incentivises manipulation. The problem is likely to persist, says Frank Larkins, former deputy vice-chancellor for research at the University of Melbourne. "Universities have a lot of smart people and they can learn pretty fast how to optimize their performance," says Larkins.

The ERA peer-review panels are asked to look closely for idiosyncrasies in the research performance of institutions, and the ARC is now able to cross-reference dubious submissions against previous rounds. However, there is nothing to stop universities taking on researchers, and sometimes whole research departments, in order to boost output prior to an ERA round. The Australian newspaper described the "churning" of researchers this year in the lead-up to the 31 March 2014 census deadline. Any staff hired after this date are not eligible for assessment in ERA 2015. But, during the preceding Australian summer, research groups and even whole departments were poached by the Australian Catholic University, Central Queensland University and Charles Sturt University, among others.

ARC leader, Byrne, doesn't endorse such activities, but says that calculated reallocation of resources for the purposes of ERA ranking is not necessarily a bad thing. "We don't want to stop institutions from making strategic decisions about what research they wish to pursue." The importance placed on the ERA rankings by Australian university management has been evident, not only in the tendency for researcher churning, but also in the tailoring of internal research benchmarks to better meet the terms of the ARC system (see 'Internalizing targets'). Consequently, universities have set departmental and school-wide targets regarding quantity and quality of publications.

Despite this, Byrne does not accept that ERA is forcing institutional change. "It does get used by institutions in various ways, but we are providing an evaluation against the best possible standards we can come up with", he says.

Perhaps the most egregious example of an attempt to game the system occurred in New Zealand in 2006. One leading university reclassified dozens of staff members, notably those who were PBRF-eligible but performed little active research. By reclassifying inactive researchers away from subjects such as economics and biology to fields such as philosophy and religious studies, the university would improve its standing in the former fields. The surge in the number of New Zealand philosophers piqued the curiosity of PBRF reviewers who eventually reversed the classifications.

MEASURING A MOVING TARGET

The objectives and the structure of ERA and PBRF have changed little, but the status quo may be threatened by demand for the explicit inclusion of research impact as a quality indicator within the assessment exercises (see page S81). At UTS, Brungs says that more focus on impact might bring much-needed formal recognition of interdisciplinary work within the system. For example, work that has valuable outputs concerned more with policy than scholarship. "Publishing in *Nature* is one way of demonstrating excellence in research," he says. "Changing the way that a nation drinks water is another way."

The ARC is considering the inclusion of impact measurements, but Byrne says the organization does not want to just graft these on to the existing system and does not have the resources to develop an independent measurement of impact. The Australian government's current aversion to any increase in red tape does not help.

In New Zealand, the 2008 review of PBRF cautioned against diluting its focus on excellence by aligning it with government innovation policy. However, a re-evaluation has seen a number of alterations, including an increase in the significance of investment from industry in determining overall funding awards, coupled with a moderate reduction on the emphasis of the research quality assessment. According to the Ministry of Education, these changes reflect the fact that external research income is a "strong proxy indicator" for the transfer of knowledge between academia and industry and the change will encourage "research of relevance to end-users". It is a tangible shift towards reward for research impact.

But Boston is not satisfied that, even with such changes, assessments like the PBRF and ERA will continue to be relevant. He refers to Goodhart's law, which states that once a measure becomes a target it ceases to be a good measure. "I don't see the logic of running the same assessment process every six years ad infinitum, with only minor tweaks," he says. "It sets up a particular set of incentives and a particular kind of process within institutions, some of which is undesirable."

To keep improving research excellence, Boston says, the government needs to increase funding and other resources, or make bigger changes to the assessments, for instance by introducing new criteria. Continual re-allocation of finite resources can only do so much. "I don't know how you're going to squeeze more drips out of the orange." ■

Annabel McGilvray *is a freelance science and medical writer based in Sydney.*

1. *Performance-Based Research Fund: Evaluating Research Excellence — the 2012 Assessment, Final Report* (Tertiary Education Commission, 2013); available at go.nature.com/gprpet.
2. *Excellence in Research for Australia 2012, National Report* (Australian Research Council, Commonwealth of Australia, 2012); available at go.nature.com/q8sxiw.
3. Çinlar, N. & Dowse, J. *Staffing and Performance Trends in Research Subject Areas* (Tertiary Education Commission, 2008).

PERSPECTIVE

CASAMENTO PHOTOGRAPHY

On the verge of a new ERA

Despite its limitations, Excellence in Research for Australia was the right assessment tool at the right time, says **Margaret Sheil**.

In the early part of this century, the Australian government made a decision to improve the country's research effort. It made targeted investments in research agencies, built infrastructure and created a number of world-class centres of excellence. Yet some argued our research efforts were spread too thinly and performance was uneven. By 2007, only two of Australia's 40 universities were in the top 100 of the Academic Ranking of World Universities (ARWU). That same year, an Australian Productivity Commission report on public support for science and innovation identified several areas of the innovation system requiring improvement, which included a lack of effective support for industry-based research and development, deficiencies in the scientific workforce and inadequate methods of evaluation.

The government determined that Australia's dual funding system, comprising individual competitive grants and block grants to institutions, was not providing the right incentives. In particular, block funding was distributed according to formulae that took into account only the number of scholarly publications, with no consideration for their quality. The results were, in hindsight, predictable: the number of publications increased but not their overall quality. The government needed a new framework: one that would encourage universities to focus their endeavours and build on their strengths; to address weaknesses in research performance; and to provide researchers with an incentive to target quality. All of that had to happen within a system that was streamlined and cost effective.

CITATION ANALYSIS CAN BE USED AS A PRINCIPLE INDICATOR OF QUALITY.

CORE VALUES

From 2007 until 2012, I was chief executive of the Australian Research Council (ARC), the body tasked with developing the new framework. We weren't starting from scratch; the previous government spent nearly four years working on a new design, and we could draw inspiration from other assessment systems, including the United Kingdom's Research Assessment Exercise (RAE), and New Zealand's Performance-Based Research Fund (PBRF).

None of the approaches, however, were entirely appropriate for Australia. The proposed design from the last government relied on case studies to assess research impact. Case studies are expensive and time-consuming to prepare and assess, yet were not, the new minister felt, sufficiently robust to inform funding allocations. Similarly both PBRF and RAE — to different degrees — are selective exercises, focusing on just the best output, allowing universities to hide poor performance. RAE used panels of experts to assess the quality of publications — a costly and lengthy process. And the units of assessment for both schemes were unsuited to Australia: PBRF evaluates individual portfolios, making it difficult to scale up; RAE evaluates departments. But our universities have varied and complex organizations of departments, schools, faculties and/or research centres which do not lend themselves to a simple comparison.

These schemes did, however, provide useful leads. In particular, the 21 years of the RAE saw a growing correlation between the quality ratings assigned to departments and their citation performance. This suggested that metrics alone could be used as indicators for many scientific disciplines, although less so for others, such as the humanities and mathematics where citation data were less reliable or books were more important than journal articles.

In coming up with our own solution, the ARC consulted widely with institutions, learned academies, research leaders and bibliometric experts. We settled on 'discipline' as the best unit for evaluation because it avoided focusing on either university structures or individuals (thereby minimizing the value and prospect of poaching individual stars). Where citation analyses were not appropriate, peer review of selected publications or outputs was used instead. This approach also had the benefit of enabling evaluation of the creative arts — important for Australia where most conservatoria and visual and performing arts schools had been incorporated into universities.

Excellence in Research for Australia (ERA) was born in 2010. By including all outputs within a discipline, rather than just the premier efforts of a select group of researchers, ERA ensured that the attention of every researcher was on quality rather than quantity. And because its discipline-specific measures of achievement accorded with established academic practice, the results were largely accepted with only a small number of disputed outcomes.

There have been difficulties. ERA initially ranked around 22,000 journals in four bands (A*, A, B and C) to provide another set of indicators for the committees to use. However, some institutions used the journal ranks out of context, potentially harming the careers of young academics and those working in cross-disciplinary areas, since both groups are unlikely to publish in top tier journals. Bandings were removed in 2012.

Overall, ERA has been of considerable value — despite the fact that it drives only a small proportion of the block funding allocations. Crucially, it has demonstrated that citation analysis can be used as a principle indicator of quality in many disciplines, producing finely grained information about research strengths and weaknesses. Governments, universities, industry and the academic disciplines themselves have welcomed this information and make regular use of it. This success shows in our international standing: Australia now has 5 universities in the ARWU top 100, and 19 in the top 500.

Any comprehensive evaluation system is bound to have its critics. But widespread consultation and the use of discipline-based solutions has helped minimize opposition to the ERA. Though there is widespread acceptance that there are benefits in competitive processes for teams and individuals that have winners and losers, the political dimensions associated with 'losing' loom larger when applied to institutions, for example, negatively affecting newer institutions in areas serving growing and diverse populations. These considerations are beyond the control of the ARC and are unrelated to the ERA itself, which, while not perfect, has nonetheless achieved its goals. ■

Margaret Sheil *is the provost at the University of Melbourne.*
e-mail: provost@unimelb.edu.au

RMIT UNIVERSITY: SMARTER TECHNOLOGY SOLUTIONS

With an international reputation for excellence in applied and outcome-oriented research, RMIT University in Melbourne, Australia, is a global university of technology and design and one of Australia's leading educational institutions.

Founded in 1887, RMIT has a proud history of strong links with industry. Under the leadership of RMIT Vice-Chancellor and President, Professor Margaret Gardner AO, the university has continued to foster connections between research and the private sector. At present, RMIT has over 200 active research collaborations with industry and overseas partners.

With a student body that includes more than 10,000 postgraduate students, 5,000 staff comprising 2,500 academic and teaching staff, and campuses in Australia and Vietnam — plus a recently opened center in Barcelona, Spain — RMIT boasts a rich portfolio of teaching and research partnerships that cover every continent.

As part of its strategic plan for 2015, RMIT has set itself three goals: to be global, urban and connected. Entwined with this is the university's desire to develop innovative solutions to tackle the complex, technical challenges of today. In particular, researchers at RMIT are developing smart-technology solutions in the areas of energy, health and computing.

SMART SOLAR SOLUTIONS

Solar, or photovoltaic, cells are a common feature in today's cities and the electricity they generate from sunlight can make a significant contribution to meeting everyday power requirements. An even simpler idea is to take sunlight and convert it directly into heat. Gary Rosengarten (pictured, top left), professor of sustainable systems engineering at RMIT's School of Aerospace, Mechanical and Manufacturing Engineering, is doing just that — by applying smart technology solutions to the field of solar thermal energy.

"Solar thermal energy is fundamentally more efficient than photovoltaics," explains Rosengarten. While photovoltaics struggle to reach 20 per cent sunlight conversion efficiency, solar thermal energy can easily achieve 70 per cent efficiency. Plus, heat is also easier and cheaper to store than electricity.

Rosengarten leads the MUSIC (Micro Urban Solar Integrated Concentrators) project, which aims to revolutionize the use of solar collectors in urban environments. The thin and lightweight concentrators being developed will share the look and placement of conventional photovoltaic panels. However, by using a clever combination of vacuum insulation to keep the heat in and mirrors or lenses to concentrate the light, the concentrators will be able to reach temperatures of up to 400 degrees Celsius, without the need for expensive systems that track the Sun.

Another of Rosengarten's projects combines solar thermal and photovoltaic technologies to efficiently create both electricity and hot water. This system employs a collector to appropriately siphon off solar wavelengths that can be efficiently absorbed by photovoltaic cells, allowing the remaining light to reach a solar thermal collector, generating temperatures of up to 150 degrees Celsius.

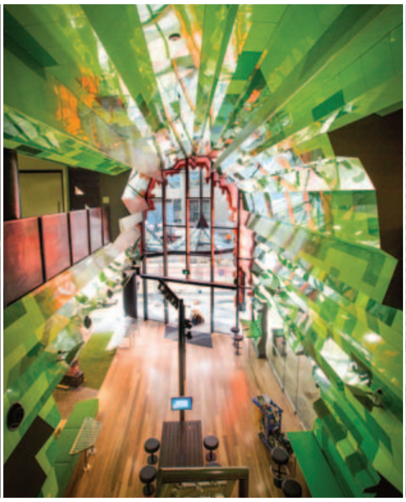
For Rosengarten, RMIT's mission of tackling key issues that affect communities and the environment is important. "I like to know that I am contributing to society by helping industry develop new products for market and that I am doing it in an environmentally sustainable way." He is also impressed by the atmosphere that the university has created for its researchers. "RMIT has invested considerably in people and infrastructure in targeted areas to ensure there is critical mass to achieve world-class outcomes," he says.

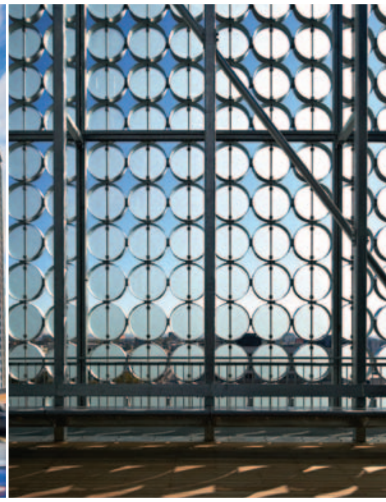
CONNECTING MEDICINE, PHYSICS AND ENGINEERING

RMIT's location in the city of Melbourne places the university within easy reach of 19 major research hospitals and facilities, meaning researchers are ideally positioned for immersion in the medical community. Consequently, smart technology solutions to meet biomedical needs are constantly evolving at RMIT, as are the facilities in which they are being developed.

"At RMIT, world-class facilities are being set up and a growing group of leading researchers are working together to publish their research in leading journals," says James Friend (pictured, top middle), director of the flagship AUS$30 million MicroNano Research Facility (MNRF) at RMIT and a professor at the RMIT School of Electrical and Computer Engineering.

LEFT & CENTRE IMAGES: CARLA GOTTGENS; RIGHT IMAGE: JOHN GOLLINGS





LEFT IMAGE: CARLA GOTTGENS; CENTRE IMAGES: JOHN GOLLINGS; RIGHT IMAGE: EARL CARTER

2014 will see the completion of the MNRF, a significant upgrade of RMIT's existing fabrication and metrology capabilities. The new facility will meet the needs of research at the nanoscale and integrate biomedical research activities. Research at the facility will span the traditional disciplines of physics, chemistry, engineering and medicine.

Much of Friend's own research lies at the boundaries of medicine, physics and engineering, and his development of miniaturized motors, or microactuators, for the retrieval of blood clots from deep within the brain is a prominent example of this union. The use of tiny actuators capable of navigating weakened blood vessels will enable minimally invasive neurological intervention in people affected by strokes or aneurysms, who might otherwise be unsuited to treatment.

Friend's background in microfluidics and micro- and nanofabrication is also contributing to substantial improvements in the delivery of drugs via the lungs. By employing acoustic waves that travel along a material's surface, his group can atomize large biomolecules — including drugs, DNA and antibodies — and even cells into suitably sized droplets, while avoiding the damage that conventional methods of nebulization can cause.

The technology has already proven effective for the delivery of a DNA vaccine in sheep, and has the potential to be used to convey gene therapy or stem cells to inaccessible sites, deep within the lungs. "Our work promises to overcome fundamental problems neurosurgery, drug delivery and microfluidics," explains Friend. "This is a huge motivation for conducting my research."

COMPUTING WITH DIAMONDS

RMIT is a university focused on both design and technology. For Andrew Greentree (pictured, top left), an associate professor at the RMIT School of Applied Sciences, "it is the technology part that is key".

Greentree is guiding RMIT's efforts to bring computing into the quantum age. A quantum computer stores information as qubits — the equivalent of bits in classical computing. But unlike classical bits, qubits can exist simultaneously in multiple states, a feature that can be exploited to allow new and more powerful forms of computing. And while a classical computer uses only one aspect of quantum mechanics — barrier tunneling — a quantum computer also uses the quantum phenomena of superposition and entanglement to harness the power of quantum states. "This provides greater control, allowing computation to be carried out in new ways," observes Greentree. "Simply put, a quantum computer is the ultimate computer."

For information to be transmitted, qubits must travel from one location to another. Although wires serve this purpose in classical computing, they are incapable of preserving quantum information. Before joining RMIT, Greentree conceived an elegant solution to this problem, called coherent tunneling adiabatic passage (CTAP), which continues to inform his current research. CTAP will likely play a key role in facilitating the on-chip transport of quantum information.

At present, quantum computing devices that employ a small number of qubits already exist. But scaling the technology up remains a challenge — albeit one that Greentree is willing to embrace. "I want to ensure that my research is important and relevant," he says, "and to transition my research into real world applications and devices."

Greentree is also an expert in the use of diamond for quantum purposes. In particular, he hopes to use diamond to create hybrid quantum–classical computers that boast solid-state quantum memories. Beyond computing, Greentree's interests in diamond are shaping part of the research programme at the upcoming Australian Research Council Centre for Nanoscale BioPhotonics, in which RMIT is a partner institution.

RMIT is a university that is excited by change and isn't afraid to back key ideas from its researchers, he notes. "If quantum technology is as important as we think, soon we will need to be educating quantum engineers who are ready to design and build practical quantum devices," he says. "It's my aim that RMIT will be at the forefront of this revolution."

RMIT UNIVERSITY

RMIT University
www.rmit.edu.au/research

INGENIO *et* LABORE

By natural ability and hard work

The University of Auckland

MAKING OUR MARK IN LASER SCIENCE AND OPTICS

Information processing and advanced telecommunications technology are just some of the disciplines that laser science and optics have the potential to impact in the future.

Temporal cavity solitons – as persistent light pulses – demonstrate the beauty of laser science and constitute the most fundamental example of self-organisation in optics. They are an ideal information carrier to store data and create an all-optical buffer, a critical function for high-speed routing technology.

University of Auckland Associate Professor Stéphane Coen has contributed to the first-ever capture of these pulses of light using nothing more than a continuous-wave laser and an unamplified loop of standard optical fibre. Now his team at Auckland can retain pulses for more than one hour, equivalent to a propagation distance of close to one billion kilometres, and has evidenced their ultra-weak long range interactions. These pioneering achievements have implications for many disciplines, from life sciences to ocean physics.

Published in Nature Photonics, the research has revealed the rich physics of these little-known objects. It also has deep practical significance, as temporal cavity solitons provide key insights into new microscopic light sources that have the potential to provide ultra-accurate measurements on a chip.

Associate Professor Stéphane Coen is one of a team of award-winning scientists achieving international recognition for their work in our world-class laser laboratory.

To find out more, visit

LEADINGRESEARCH.*ac.nz*

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

KingS12580/NAT/A




University of Western Sydney

UNIVERSITY OF WESTERN SYDNEY: TACKLING BIGGER, UNANSWERED QUESTIONS

Experimental psychologists, neuroscientists, engineers, computer scientists, linguists, composers and dancers — few people might guess what kind of research projects would require such a diverse team of professionals, but Kate Stevens from the MARCS Institute of the University of Western Sydney (UWS) knows. She is the leader of Music Cognition and Action, a research program that uses behavioral and neurophysiological approaches to study the temporal dynamics of perception and creativity, as well as individual and group performance.

"We are trying to understand how innovation and knowledge emerge from a group," says Stevens, "However, these are difficult and complex questions that require an interdisciplinary team to answer."

Stevens has joined forces with a professional dance company and built a research team of internationally recognized scientists, choreographers and dancers. They analyze behavioural and brain processes as people interact and create. Every week, Stevens holds seminars and specialist group meetings where other research groups at the institute join and contribute to the discussion. "Here at the MARCS Institute we have experts in, for example, perception, language development, neuromorphic engineering and human-machine interaction," says Stevens. "We all come together for one purpose: to answer those big and risky questions."

IMAGES 1-3 SALLY TSOUTAS

FOCUSSING ON IMPACT

Scott Holmes, the Deputy Vice-Chancellor of Research and Development at UWS, says Stevens' story is reflective of the university's emphasis on research excellence. "Our big goal is to make sure all of our research is high impact, not only in terms of citations but also the effects on professions and our communities," he says.

Indeed, UWS has come a long way since its founding in 1989. Over the past 25 years, the institution has evolved into a vibrant, modern, outer-metropolitan university where students receive professional training in science, health and medicine, technology, engineering, humanities, education, business and law. UWS is now home to over 3,000 staff and 42,000 students, most of whom are residents of Western Sydney — one of the fastest growing and most culturally diverse regions in Australia.

UWS places a strong emphasis on research and development. It has invested heavily in areas including neuroscience, infrastructure engineering, complementary medicine, education and humanities. 70% of UWS research reviewed by the Excellence in Research for Australia assessment in 2012 was rated as "world standard" or above.

BIG INFRASTRUCTURE, BIG ANSWERS

Environmental sustainability is a core area for UWS. The university has invested heavily in the Hawkesbury Institute for the Environment, which focuses on the impacts of environmental change on terrestrial ecosystems. "Our research spans from the molecular and microbe level through to plants, animals and entire ecosystems," says Ian Anderson, Director of the institute. "The findings from our research are aimed towards helping us better manage both Australia's native forests and intensively managed landscapes in the future."

One of the largest projects conducted at the Hawkesbury Institute for the Environment is EucFACE, a free-air CO_2 enrichment field experiment that examines the response of a native Australian eucalypt forest to an atmospheric CO_2 concentration of 550 ppm, which is expected later this century. "We really stand out internationally in terms of our research programs and our extensive array of world-class research infrastructure to study climate change impacts," says Anderson. "We run a lot of large-scale, comprehensive experiments and the university has been very supportive."

While EucFACE is still in its infancy, preliminary findings indicate that mature eucalyptus trees may not respond to future concentrations of CO_2 as predicted by findings from experiments in other parts of the world. "A significant difference is the poor nutrient status of most Australian soils and the fact we have very long dry spells where there is not a lot of water. So the ability of these tree species to respond to increasing CO_2 level is limited," says Anderson.

DALE EDWIN MURRAY

RESEARCH IMPACT

Income for outcome

Australia and New Zealand are experimenting with ways of assessing the impact of publicly funded research.

BY BRANWEN MORGAN

When it comes to research, governments the world over are asking more questions about whether they are getting value for money — and there is nothing wrong with that, says Peter Gluckman, chief science adviser to the prime minister of New Zealand. "It is what the whole of a nation's science policy process is about: how much to allocate to public sector support; how much to industry sector support; how much to invest in heath versus relative amounts for environment, for instance," he says. "Whether it is done implicitly or explicitly, everyone in that process is thinking about impact."

And whereas large economies have the capacity to invest in a wide range of scientific endeavours, from nanotechnology to cosmology, smaller countries such as Australia and New Zealand do not have that luxury. "The smaller the country, the more limited the choice," says Gluckman. "So when looking at science and innovation systems, you start to be more conscious in the prioritization process; it becomes a much more strategic issue."

Determining the impact of research on wider society has the potential to assist decision-makers within organizations and institutions. But what is troubling people like Gluckman are the definitions. "You have to be really clear about the word: there are many different kinds of impact and perceptions differ," he says. "Governments have to decide what impacts they are looking for." Questions surround what constitutes impact and at what point during or after the research process it should be evaluated. Can something that is subjective and qualitative ever be appropriately measured?

VALUE JUDGEMENT

Gluckman's office in Auckland serves as the administrative headquarters for the science, technology and innovation stream of the Small Advanced Economies Initiative (SAEI) — a network for the discussion of challenges, opportunities and policies that are of particular relevance to small developed nations. For these countries, prioritizing the areas of science and innovation in which they invest is crucial to economic prosperity.

The SAEI has begun to develop an 'impact taxonomy' to help categorize the range of impacts that can arise from research. These include not only the direct economic effects but also intangible factors — for example, a Nobel prizewinner's role in enhancing a country's scientific reputation. Gluckman says that a holistic science system has to consider all the different kinds of impact that matter to people; a taxonomy, he contends, will facilitate that discussion. "What is the 'value' of doing the kind of biosecurity research that makes foot and mouth disease less likely or a country more resilient to an earthquake?" he asks. "This type of research could easily get forgotten if you focus on only one form of impact."

But measuring the breadth of impacts arising from research that often takes place over many years poses tough challenges. Assessors need to identify proxies and intermediate outcomes to gauge the direction a study is taking. That is where Adam Jaffe, director of New Zealand's Motu Economic and Public Policy Research think tank in Wellington, comes in. Jaffe is working on an evaluation framework covering five categories of impact: financial, social, environmental, public policy and

NATURE.COM
More on measures quantifying research available at:
go.nature.com/kpjgf7

capability. The purpose of this framework is to give decision-makers an idea of the full range of potential outcomes and help them decide which to track — and how.

Many scientific discoveries are serendipitous, and critics suggest that such a goal-oriented approach could lead to less blue-sky research funding. Gluckman disagrees, saying that knowledge advancement is in itself a goal. "To say impact assessment moves you away from basic science is to narrowly use the term 'impact'." Jaffe, an American, uses a baseball analogy to defend impact assessments. "The fact that sometimes you strike out and sometimes you do well doesn't stop us from thinking about who is better on average," he says. "We can look at which models on average generate the greatest outcomes and impacts across a number of different measures." The inevitable randomness in the process, he adds, "doesn't invalidate this approach". Using a framework such as his, which incorporates multiple measures across many dimensions, will minimize the chance of missing important effects.

No single group of measures may indicate both excellence and impact.

Such a framework will probably be attractive to New Zealand's recently launched National Science Challenges (NSCs), which provides designated pots of money to research areas deemed to be of national significance. The NSCs have a funding horizon of ten years — part of the government's move to support science over a longer term than most other funding bodies, which typically give three- to five-year grants. In their proposals, applicants are required to describe their ten-year vision, anticipated outcomes and impact.

Auckland University physicist Shaun Hendy and his team have recently submitted an application for one NSC, called Science for Technological Innovation, which covers work that "enhances the capacity of New Zealand to use physical and engineering sciences for economic growth". Hendy, who is also the director of the Te Pūnaha Matatini Centre for Complex Systems and Networks, hosted by Auckland University, found the requirement to discuss impact hampered his application. "Our proposal covers a very broad range of disciplines and industry stakeholders," he says. "Manufacturing technologies are changing so rapidly that we've struggled to design a research programme that will deliver short-term impact but will also be relevant in a decade."

Research teams that are awarded NSC funding will be required to develop a 'pathway to impact' plan, complete with monitoring and evaluation procedures. Hendy does not believe this sort of assessment is particularly helpful in the long run, because it does not measure the opportunity costs. "To determine the real benefits of the National Science Challenges, an economist would need to know what we chose not to fund as well as what we did," he explains. "These sorts of exercises are much more about bureaucratic box-ticking than any real attempt to measure the value of science to society".

AUSSIE RULES

The Commonwealth Scientific and Research Organisation (CSIRO), whose headquarters is in Canberra, is the largest of the Australian government's portfolio-funded research agencies. CSIRO is one of the few public research and development entities in Australia — and possibly the world — that formally and transparently plans, monitors and evaluates the impact of its research, according to CSIRO's Mark Johnson. He is project manager of Impact 2020, launched four years ago with the aim of developing a framework to assess the economic, environmental and social impacts of CSIRO's Flagship programmes for use across the organization. For CSIRO, impact is used to influence its "4As": allocation (of resources), advocacy, accountability (to government and other key stakeholders) and analysis (for performance improvement).

CSIRO uses an impact pathway model that describes a project's inputs, activities, outputs, expected outcomes and eventually impact — for example, the adoption of new research protocols that improve productivity (See 'Pathway to impact'). Within the Flagship programme, project leaders can modify these pathway stages depending on changes in resources and goals of either CSIRO or its clients and partners.

CSIRO's research impact planning is a dynamic process; the organization is continually evaluating changes beyond the bounds of a study to see whether the focus of that study is still appropriate. This eye to the wider world also helps with internal engagement. "A lot of people get hung-up on the long-term nature of most impacts, which they see as so far removed from their actions today that they are reticent to engage," says Mark Bazzacco, CSIRO's executive manager of performance and evaluation. He says that "monitoring progress towards impact" as opposed to "monitoring impact" helps scientists to keep an eye on their project's goals and get a greater sense of the role they play in effecting change.

Bazzacco gives an example. Some research impacts are the culmination of decades of work. The Murray-Darling Basin management plan was a large collaborative research project that aimed to measure and model water flows within this vital river basin. In addition to collecting data, the researchers involved also helped policy-makers understand the modelling and the plan's findings to enable creation of new regulations concerning water usage. But once the new policy had been developed, it was up to state and federal governments to adopt it — and then for many other actors to implement it. It will take another decade at least for the final impacts (environmental, agricultural, social and economic, for example) to be realized; in the meantime, the researchers have moved on to other projects. Monitoring progress towards impact recognizes where the researcher's role is important (for example, in conducting the work and helping communicate the results) and avoids any negative implications of assigning responsibility for behaviours that influence the final impact yet are beyond the researchers' control (in this example, the implementation of the policies).

MAPWORK PROJECT

Over its lifetime, CSIRO has conducted tens of thousands of projects. Johnson is working on ways to show these in an easy to appreciate, visual manner. They have come up with an impact map, shown on page S74, designed to be a conversation starter rather than a precise diagnostic tool. It shows 286 projects — only those that meet a minimum realized or projected financial return criterion and where data are available to evaluate the delivered or intended impact. Impacts can be social, environmental and/or economic. Projects are assigned a primary impact category based on the same 17 socioeconomic objectives used by the Organisation for Economic Co-operation and Development.

The size of the bubbles is based on a four-point scale that allows projects with different types of outcome to be compared with each other. The placement of the bubbles are indicative of when projects have delivered, or will likely deliver, a significant milestone. From 2004, the timescale changes from five- to two-yearly, as there are more data are available for recent projects. Here are some examples, highlighted on the image.

Wireless LAN: CSIRO scientists solved the main problem impeding fast wireless networking of electronic devices — that of reverberation within rooms. The organization applied for several patents and, in 1996, was granted a US patent for wireless local-area network (WLAN, or wifi). This outcome has led to major social and economic impacts and has revolutionized communication. The technology is now used in an estimated five billion devices worldwide. CSIRO has licence agreements, worth more than AUS$430 million (US$400 million) with more than 20 international companies.

Murray-Darling basin plan: The Murray-Darling is the largest river system in Australia. It supplies water to approximately 10% of the population and produces 40% of national agricultural output. Growing demands on its increasingly variable flows have caused widespread concern among communities and industry. CSIRO scientists measured the available water within the basin and created a model. In 2011 they produced a report on resource planning, management and investment, as well as modelling scenarios for future catchment development, groundwater extraction and climatic conditions out to 2030. The report and models directly informed government investment; the project's impact has been an estimated saving of at least AUS$2.8 billion (US$2.6 billion) through better use of funds and water infrastructure efficiencies.

Tiger prawn and Aquaculture feeds: In 2010, CSIRO announced that its ten-year collaboration with Australian prawn farmers had led to successful selective breeding of Black Tiger prawns with improved growth and survival rates that could be sustainably farmed in salt-water ponds. The estimated economic impact on the industry is AUS$120 million (US$112 million) per annum. Simultaneously, another CSIRO research team developed a new aquafeed ingredient (Novacq), derived from marine microbes, which increases Black Tiger prawn growth rates by 30%. The combined value of the increase in prawn yield is estimated to be AUS$430 million (US$400 million).

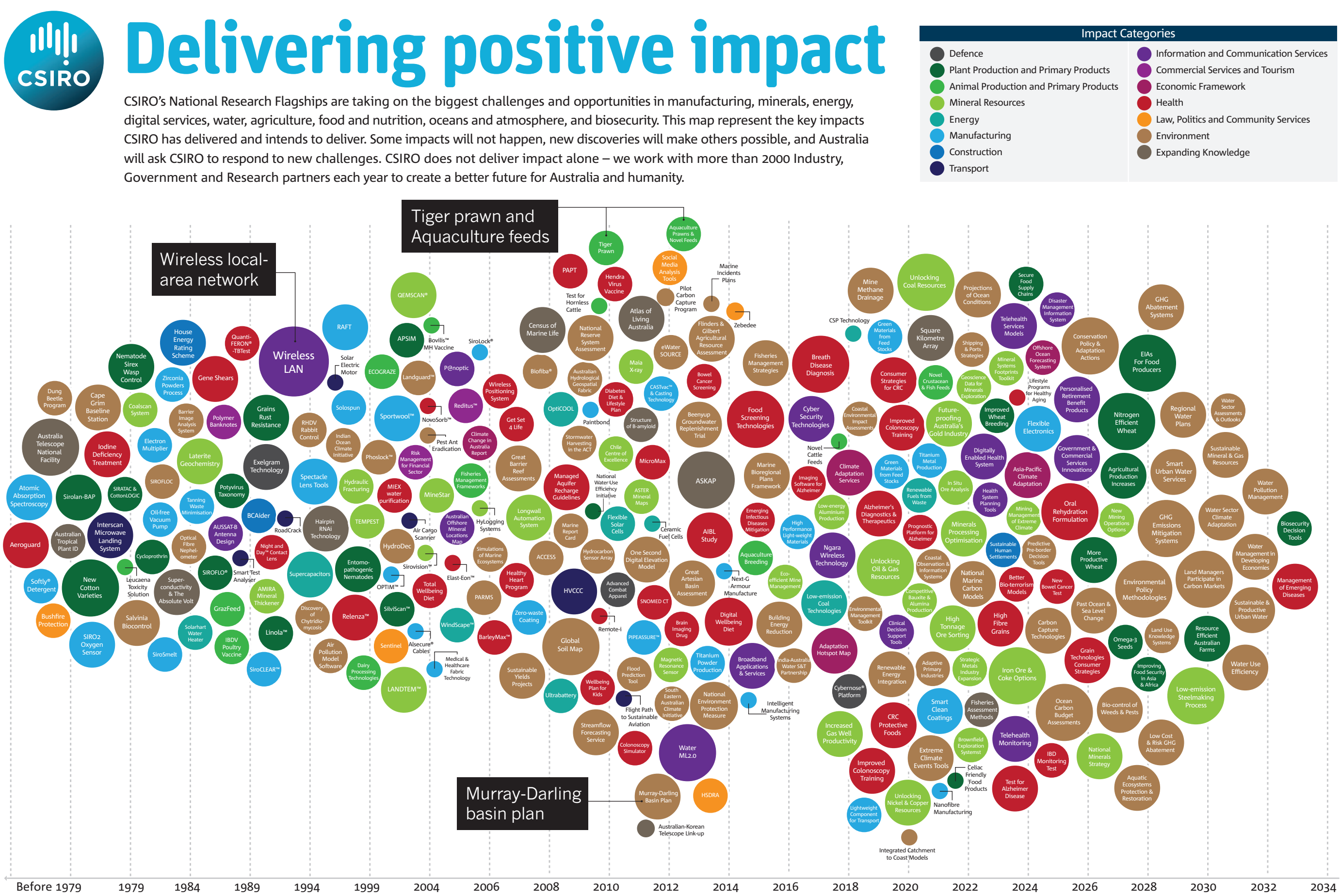
The Cooperative Research Centres (CRCs) programme in Canberra, set up in 1990 by the federal government, also looks at the broader impact derived from its applied research. CRCs support multidisciplinary teams, which often include groups from CSIRO, and are carefully managed to deliver impacts, says Tony Peacock, chief executive of the CRC Association, the CRC umbrella advocacy body. All CRCs include participation of end-users from the outset, ensuring that projects are always addressing real-world situations. Any proposal for CRC funding involves completing an impact tool similar to CSIRO's impact pathway approach.

Over the past decade, there have been three independent retrospective analyses of the CRC programme. The methodologies were agreed up front with government officials and use a counterfactual point of view — that is, they compare the impact of the CRCs with a scenario in which each project had not taken place. All three studies showed that CRCs have had a positive impact, including on economic indicators such as GDP. Peacock is open about the intended target audience. "There is no problem convincing the public of the value of research — they want to hear our stories," he says. "These retrospective studies were directed solely at those who were likely to determine whether the CRC programme continues to get money."

UNIVERSITY CHALLENGE

Australia's higher, or tertiary, education sector, which includes all the country's universities and almost two-thirds of its scientists, does not routinely conduct research impact assessments. These institutions are, however, compelled to monitor research quality through the Excellence in Research for Australia (ERA) initiative (see page S64).

In 2003, the then Liberal government started developing an assessment system — called the Research Quality Framework (RQF) — that looked at the impact of research as well as its quality. But in December 2007, just weeks before the RQF was due to be implemented, an incoming Labor government scrapped it (see page S52). Matt Brown, senior policy analyst in research at the Australian Technology Network of Universities (ATN), in Adelaide, believes that an opportunity to provide a useful decision-making tool was lost. "We've seen



CSIRO

Organizations worldwide wrestle with the issue of how to show and compare the impact of their projects. Australian national science agency CSIRO is working on an impact map. Each of the 286 bubbles represents one project with one primary category. The four sizes of circle relate to size of impact (economic, social or environmental), centred on when projects met, or will meet, a significant milestone. Larger version: go.nature.com/bduk6p. Website: csiro.au/impact.

CSIRO

car manufacturing suddenly disappear from Australia and now the country is asking what its future industries will be," he says. "Research impact assessment would have helped guide today's decisions."

Another attempt to push the research agenda came in 2012, when 12 Australian universities took part in the Excellence in Innovation for Australia (EIA) trial. The EIA demonstrated how a case-study approach could be used to systematically assess the impact of university research across a wide range of disciplines and areas. "The time was right to have another go at putting impact on the agenda," says Brown. "And when trying to convince policy-makers, you need proof by demonstration." In the EIA trial report, the authors note that they met their objective to "measure the innovation dividend of research generated by Australian universities" and advanced the methodology to do so.

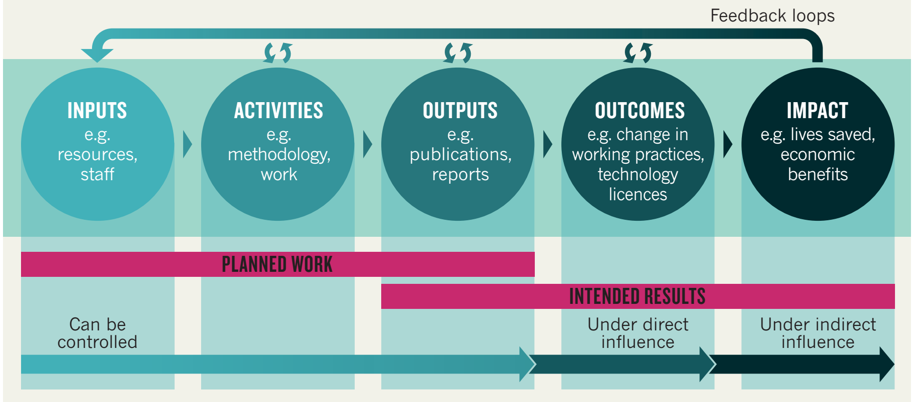
Australia's chief scientist, Ian Chubb, seems undecided as to the benefits of an impact assessment system for the tertiary sector and has concerns around the retrospective case-study approach, as recently implemented in the United Kingdom's new Research Excellence Framework (which, ironically, was influenced by the aborted RQF). This approach is also highly selective, with universities submitting only those studies that demonstrate the best results. Chubb echoes Gluckman in the need to articulate the goal of any assessment system. "If the purpose of measuring impact is to show politicians just how much scientific research underpins sectors of the economy, then we should own up to it," he says. "But if impact evaluation is to be tied to funding, then you have to be careful that you're not just being fashionable. You're not going to give a university funding because 15 years ago someone had an idea that turned out to be profitable."

"If the purpose of measuring impact is to tell politicians the value of research, let's own up to it."

In an effort to ensure better coordination of activity and investment, without succumbing to the whims of fashion, the Australian Research Committee (ARCom), based at the Department of Industry in Canberra and chaired by Chubb, put together a national research investment plan to guide government. The plan was released in November 2012. As part of its plan, ARCom, which includes the Canberra-based chief executives of the Australian Research Council (ARC), the National Health and Medical Research Council (NHMRC) and CSIRO, recommended the development of a university-focused impact assessment mechanism as a companion to the ERA. ARCom released a discussion paper in June 2013 and the submissions window was closed in August — just in time for another change in government. The incumbent Liberal party has not endorsed the plan.

PATHWAY TO IMPACT

Each of CSIRO's Flagship projects is guided by this framework, which gives project leaders a way to think about their work so they can plan and monitor for impact.



In the absence of government leadership, one Australian university has decided to go it alone. "We are in a different political environment now," says Warren Payne, pro vice-chancellor in research and research training at Victoria University, Melbourne, "and we need to be ready for a measure of impact that might come on top of the current ERA framework."

Individual research programmes at Victoria University are assessed for retrospective and prospective impact; economic, social and environmental outcomes are combined with qualitative surveys that gather the views of people who are socially or financially invested in the project on potential future impacts. The university is currently trialling the system and has brought in an independent assessor to evaluate progress. So far, 11 projects from Victoria University's social science and science technology departments have been successfully assessed via a rating scale that considers the significance and reach of each of the impact claims.

Payne sees Victoria University's impact tool as a useful way to guide its research decisions. But he says that perhaps the greatest attribute of the system is to focus the minds of researchers as to what expectations they are raising and whether they are delivering on them. And, as an added benefit, they are more motivated because they understand how their work feeds future impacts.

GROUP EFFORT

One of the strongest arguments for assessing impact is the inclusion of research that falls outside the traditional criteria for academic excellence. "Work that previously might have been seen as highly applied — almost in a pejorative sense — might then be recognized as being important," says Tim Wess, executive dean of science at Charles Sturt University in Wagga Wagga. Wess gives the example of research into changing a nursing procedure that reduces post-operative mortality, compared with fundamental research in particle physics. Assessing both types of research by their excellence and impact "would level the playing field", he adds. University promotion committees and grant application reviewers could also take this information into consideration.

Unfortunately, no single group of measures may be able to indicate both the excellence and the impact of research. Publishing a paper, even an 'excellent' one, may not have an impact outside academia without additional effort — often undertaken by others — to translate that knowledge into practice. This raises the issue of timeframe. The wider benefits of research might not appear for years or decades, by which point many individuals and organizations may have contributed. How can an impact measure tease out separate contributions?

Indeed, coming up with a suitable methodology is a big sticking point. Payne has discussed Victoria University's approach with the ARC, which administers the ERA assessment exercise and is the larger of Australia's two research-funding councils. "ARC feels that although our method can probably be scaled quite nicely within the university, it isn't sure it can be done systemically," he says. The other funding body, the NHMRC, requires some mention of impact in its grant proposals, but the guidelines are not explicit and vary by scheme. "Consensual views as to what can be claimed as impact and what evidence should be provided would be very helpful," says NHMRC chief executive Warwick Anderson.

So far, it is a discussion that has been disparate — and one that, given its membership, ARCom seems well placed to continue. "I'm not saying it shouldn't be done — or that a whole bunch of smart people can't find a way," says Chubb. "We just can't afford to be simplistic about it." ■

Branwen Morgan *is a freelance science writer based in Sydney, Australia.*

PERSPECTIVE

BRETT D'ELTON

Powering up citations

Changing the way we measure and reward research could enrich academia and improve outcomes for society, says **Alan Finkel**.

Australian science suffers from a fundamental misalignment. Publicly funded researchers at universities face considerable pressure to generate academic papers. Taxpayers, however, would prefer to see more significant commercial and social benefits from their research investment.

At the national level, the Excellence in Research for Australia (ERA) process, through which the federal government evaluates universities, is driven by assessment of the quality of research publications. In the science, technology, engineering and mathematics (STEM) disciplines this assessment is based on citations — a score measuring a published paper's influence by the number of other papers in which it is cited. In the humanities and social sciences (HASS), the assessment is based on academic peers reading selected papers to determine quality. The ERA does credit other accomplishments[1], including fellowships of learned academies, patents and registered designs, plant-breeders' rights and research commercialization income, but there is little evidence that assessments have given much weight to such achievements.

Because faculty members, departments and universities want to be judged as being world class or better in the ERA assessment, they pursue research for academic publications that are likely to be well cited — almost to the exclusion of other activities. And since evaluation programmes such as the ERA affect funding and student demand, they drive academic behaviour.

Individual researchers realize that the path to promotion is paved with academic papers, and so rarely spend time working on anything else. For example, academics have little incentive to join in industry programmes such as the successful Cooperative Research Centres (CRCs) if participation limits their ability to publish extensively. Universities and research institutes considering the appointment of an academic who has spent years in industry often worry that the applicant's grant-winning ability might be compromised by his or her time away from academia. Similar issues dog researchers within government research institutes such as the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

These problems thwart engagement with industry, thus depriving researchers of useful commercial skills. In Australia, more than twice as many PhDs are employed in universities than in industry, whereas in Germany the ratio is the other way round[2]. As a result, Australia was rated last in the recent ranking from the Organisation for Economic Co-operation and Development (OECD) of university–industry collaborations[3]. Without such collaborations, industry does not fully benefit from the fundamental research undertaken in academic settings, and academic researchers are not as aware as they should be about market and societal needs and trends.

One way to encourage academics to collaborate more with industry would be to award 'citation equivalents' to various activities that advance the practical impact of science through means other than peer-reviewed publication of academic papers. In STEM disciplines, citation equivalents could be calculated for issued patents, commercial contracts and licence fees. More broadly, citation equivalents could be awarded for activities including writing books, opinion pieces and government submissions, PhD student supervision, and development of new approaches to teaching practices or novel training courses.

Citation equivalents earned could be counted in the same way as normal citations, even contributing to higher order measures such as the H-index (a measure of a researcher's impact and productivity) or institutional-level evaluations such as the ERA. Each contributing activity would count as equivalent to a paper with an agreed number of citations. For example, an Australian patent might be rated as equivalent to a paper with a small number of citations, say five. On the other hand, a triadic patent (which covers the US, Europe and Japan) might be rated as equivalent to a paper with 50 citations; patents taken up and used would be rated more highly than ones that lie dormant.

TAXPAYERS WANT TO SEE COMMERCIAL AND SOCIAL BENEFITS FROM THEIR RESEARCH INVESTMENT.

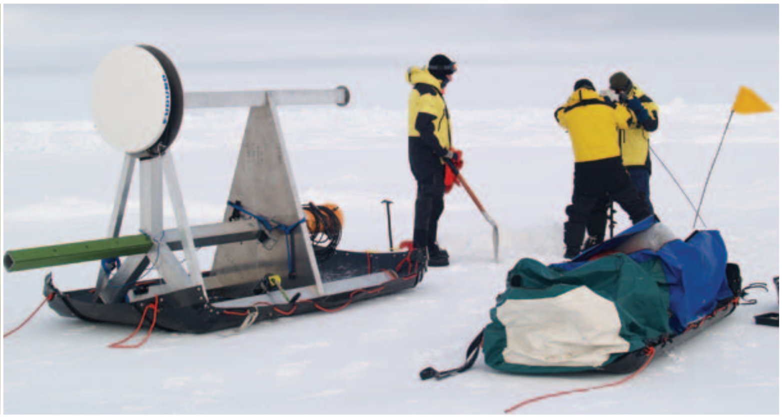
A system such as this, aiming to provide impact measures for individual effort, would be cheaper and faster than the labour-intensive methods that are needed to gauge institution-level impact. Case studies and expert evaluation panels take a long-term view, in some cases considering outcomes a decade or more after publication. The proposed citation equivalents, by contrast, would measure near-term achievements as soon as the impact activity is definitive, for example, the issue of a patent.

Because traditional citations are global in extent, citation equivalents could be considered for adoption not only in Australia, but worldwide. To be successful, citation equivalents would have to be embraced by research institutes, universities, national granting agencies and, ideally, international evaluation programmes and databases such as Scopus, Google Scholar and Web of Science.

Citation equivalents could be tested on a small scale and rolled out as experience is gained. With a little funding and some determination we could broaden the existing publications-focused metrics to achieve a better balance — acknowledging the best basic research while also promoting the STEM research that delivers the greatest impact for the society that is paying for it. ■

Alan Finkel *is president of the Australian Academy of Technological Sciences and Engineering and chancellor of Monash University.*
e-mail: alan@finkel.net

1. *Excellence in Research for Australia 2012, National Report* (Australian Research Council/Commonwealth of Australia, 2012); available at go.nature.com/fcunry
2. Pettigrew, A. G. *Australia's Position in the World of Science, Technology & Innovation.* Occasional Paper Series, Issue 2 (Australian Government, 2012); available at go.nature.com/x4yp7g
3. *OECD Science, Technology and Industry Scoreboard 2011* (OECD, 2011); available at go.nature.com/n914ae.


AN ISLAND LABORATORY HELPING TO SAVE LIVES AND SPECIES ACROSS THE WORLD

The University of Tasmania has a growing reputation as one of Australia's foremost teaching and research institutions, ranking in the top two per cent of universities worldwide and in the Australian top ten, and leading the world in our distinctive research themes.

While maintaining our island identity, we undertake research of international scope, thanks to collaborative partnerships we've built across the globe, strengthened by a network of more than 90,000 alumni spanning more than 120 countries.

BETTER HEALTH: FOR BABIES AND FOR GROWN-UPS

Beginning in the late 1980s, University researchers investigated why Tasmanian babies had a relatively high risk of sudden infant death syndrome (SIDS). Their discovery that sleeping on the stomach is a major risk factor saves the lives of hundreds of babies every year.

This was one of the first of many successes of what is now the Menzies Research Institute Tasmania. Recently, its scientists have discovered genetic markers for prostate cancer risk, and how vitamin D helps prevent multiple sclerosis relapse.

ENVIRONMENT, RESOURCES AND SUSTAINABILITY: DEFEATING DEVIL'S DISEASE

Medical scientists from the Menzies Research Institute Tasmania are helping our zoologists study the facial tumour disease that's devastating Tasmanian devil populations. They've found a genetic mutation in the contagious cancer that makes it invisible to the devil's immune system, meaning that cancer cells pass to a new devil without triggering a protective response.

This discovery raises hope for a future vaccine, but in the meantime we are protecting populations of healthy devils on isolated islands and peninsulas, as well as in captive breeding facilities throughout Australia.

CREATIVITY, CULTURE AND SOCIETY: UNDERSTANDING CONVICT LIFE

University historians gained new perspectives on Australia's convict history and other aspects of colonial life from records of the 73,000 people transported to Van Diemen's Land, gathered with the help of Oxford, Sussex and Liverpool universities.

"It's about using Tasmania as an island laboratory to look at national and international problems," says Hamish Maxwell-Stewart, leader of the Founders and Survivors project.

These insights have led curators of heritage sites like Port Arthur to replace stereotypical blood-soaked interpretations with a more complete picture of colonial life.

MARINE, ANTARCTIC AND MARITIME: PRESERVING FUTURE FISH

Marine parks must be more than just boundaries on a map if they're to conserve biodiversity, our researchers found with the help of recreational divers. Their survey of 87 marine protected areas in 40 countries found that many were no more diverse than non-protected areas nearby.

Most successful were parks with a well-enforced ban on fishing; also those more than 10 years old, relatively large and some distance from fished areas.

"It's these kinds of areas that we need to create and at the same time retrofit the existing ones that are unlikely to ever reach their conservation goals," said the study's lead author, Graham Edgar.

ENABLING TECHNOLOGIES AND PLATFORMS: BACKWARDS IN TIME

For a billion years of Earth's history, life stopped evolving and remained little more than a layer of slime. University geologists used a technique developed for studying mineral ores to determine that the pause was due to a shortage of oxygen and other elements essential for life.

The team at the Centre for Ore Deposit and Exploration Science vaporised ancient mineral samples and measured the levels of trace elements present when they formed.

"The fluctuations in these levels may help explain events like the emergence of life, mass extinctions, and the development of gold and other ore deposits," says geologist Ross Large.

Our publication Research to Reality has more stories of research from University of Tasmania, at: www.utas.edu.au/research-to-reality.

UNIVERSITY *of* TASMANIA
AUSTRALIA

University of Tasmania
www.utas.edu.au

SMART IDEAS FOR CANCER RECOVERY, SAVING ENERGY AND FIGHTING CRIME

Edith Cowan University in Perth, Western Australia, is recognised for research that tackles real problems, concentrating our efforts in areas where we have a proven track record.

Our research institutes—including Health and Wellness, Electron Science Research and Security Research—and our close links with nine other Australian universities are part of our commitment to a vibrant research culture and strong support for our staff and student researchers.

WORKING OUT BETTER LIFE FOR CANCER PATIENTS

Toxicity in cancer treatment leads to a number of well-established musculoskeletal deficits, as well as osteoporosis and bone fractures that can substantially reduce quality of life, physical function and independence. But research by the University's Health and Wellness Institute has shown that exercise can act as medicine to significantly reduce these risks and help cancer survivors recover.

Their studies on prostate cancer patients found clinical benefits of resistance training for reversing muscle loss and improving physical function and quality of life.

This approach is a big change from historical practice, in which clinicians advised cancer patients to rest and avoid activity. However, exercise guidelines co-authored by the Institute have now been adopted as the prescribed model for cancer management in North America and much of the world.

WINDOWS FOR A CLEAN ENERGY FUTURE

The vast area taken up by windows on buildings could soon become a source of electricity, by using technology that turns them into transparent solar panels. TropiGlas, being developed commercially by a Perth company using research from the University's Electron Science Research Institute, is an "intelligent glass" technology that converts the ultraviolet and infrared components of sunlight into electricity while allowing visible light to pass through.

A hair-breadth, nano-engineered film sandwiched between two sheets of glass selectively diverts the energy of this radiation to photovoltaic cells at the edge of the pane. Although not yet as efficient as traditional solar panels, TropiGlas is able to cover a much larger area than a rooftop installation, effectively turning buildings into power plants.

"We believe that within a couple of years we should be able to double the efficiency, which is very good considering we're not using visible light," says Institute director Kamal Alameh.

The first commercial trials of the product are taking place in South Africa, where TropiGlas is being installed in a new government office building in Pretoria.

SIMPLE SOFTWARE FOR CYBER SLEUTHING

Some of the most serious modern crimes are also the most technically challenging to police, requiring the analysis of suspects' computers for illegal images such as child pornography. But the University's Security Research Institute has produced software that lets police view photos and videos on hard drives without damaging their integrity as forensic evidence.

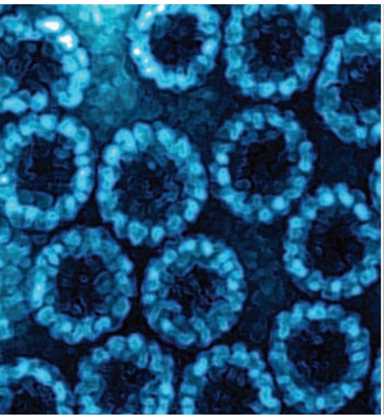
Called SImPLE—short for Simple Image Preview in Live Environment—the software was designed to be both effective and easy for officers to use with only minimal training. This contrasts with the currently used sophisticated, multi-purpose software, which can be operated only by a central unit of expert technicians.

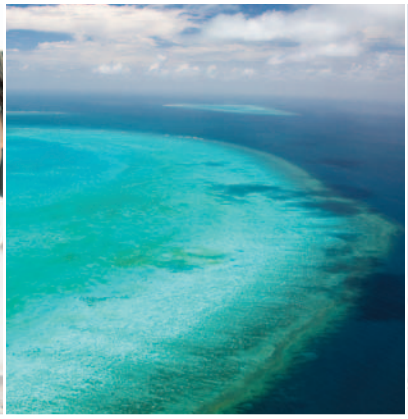
Doing the analysis on-site also enables a quicker response for identifying and rescuing victims of abuse, as well as providing evidence needed to bring a suspect into custody or elicit a confession.

In addition to harnessing the expertise of the Institute's researchers, the development of SImPLE used the skills of University students, giving them the chance to contribute to a project with substantial community benefits. As the project moves into its beta stage, the students will continue to support the software and keep it up to date in a rapidly changing field.

Find out more about our work in all fields at www.ecu.edu.au/research.

AUSTRALIA ECU EDITH COWAN UNIVERSITY





KNOWLEDGE LEADERSHIP FOR A BETTER WORLD

Ranked in the world's top 100, The University of Queensland (UQ) is one of Australia's leading teaching and research universities, and has educated more than 210,000 alumni—including over 11,000 PhDs—who have made and continue to make positive impacts throughout the world.

UQ's excellence in research has been translated into positive impact for people and communities worldwide, with many economic, environmental, health and social benefits. Leading outcomes include:

- the world's first vaccine against cervical cancer, which has benefited tens of millions of women worldwide, and has the capacity to save an estimated quarter of a million lives annually
- the Triple P – Positive Parenting Program, which has reached more than seven million children and their families in approximately 25 countries, and has been translated into more than 20 languages
- signal correction technology used in approximately two-thirds of the world's magnetic resonance imaging (MRI) machines
- genome mapping studies that have greatly increased our understanding of the genetic causes of chronic, debilitating conditions such as ankylosing spondylitis, osteoporosis, tuberculosis, leukaemia and rheumatoid arthritis
- mine safety technology (GroundProbe) used to preserve lives in some of the world's largest mining companies as best practice for active slope monitoring
- conservation planning software (Marxan) used in more than 100 countries to support the design of marine and terrestrial reserves
- innovative treatments for diseases linked to autoimmune, neuropathic and inflammatory conditions, which are being translated by UQ biotechnology start-ups including Spinifex and Dendright.

To bring these and many other innovations to the global market, UQ's excellence in research has been enhanced by the University's commercialisation companies: UniQuest, which ranks in the world's top 10 per cent of such companies, and JKTech, which specialises in commercialising resource industry-related innovations.

This translation of research excellence to real impact for society defines the "excellence-plus" culture embedded at UQ. We particularly seek to partner with industry, government and non-government organisations to enhance these outcomes. In 2012, UQ received more research funding from non-government sources than any other Australian university, and UQ consistently features among the top few Australian universities for research funding from government.

UQ's success is underpinned by the quality of its people and research excellence, which is evidenced by the Australian Government's Excellence in Research for Australia (ERA) 2012 assessment. In this benchmarking exercise, all of UQ's research fields were ranked as world standard or above.

With a focus on excellence in discovery, learning and engagement, UQ's record of success has far-reaching impacts. We are committed to "excellence-plus" to enhance UQ's positive worldwide impact.

Research conducted at UQ by Professor Ian Frazer AC (pictured) and the late Dr Jian Zhou on virus-like particles led to the development of the world's first cervical cancer vaccine.

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

www.uq.edu.au

TOP RIGHT IMAGE COURTESY OF GROUNDPROBE ®

PERSPECTIVE


BELINDA PRATTEN/ANU

If not funding then teaching

The lack of financial reward from Australia's national system of research assessment is obscuring the real issue, says **Brian Schmidt**.

When he announced the formation of the Excellence in Research for Australia (ERA) initiative in 2008, Kim Carr, then minister for innovation, industry, science and research, said that it would provide a "transparent, workable system to assess the quality of home-grown research". Carr strongly hinted that future funding decisions affecting higher education institutions would be informed by outcomes of the ERA, which would collect data and rate the quality of their research output.

For a comparable model, Australian universities looked to the equivalent system in the United Kingdom, the Research Assessment Exercise (RAE), which allocated significant fractions of the available research money to universities on the basis of their RAE scores. The implication for Australia was that a poor score would lead to financial disadvantage.

Six years later the sector is gearing up for the third instalment of the assessment process. But during this time, the money that was supposed to be tied to ERA outcomes has all but vanished. The incentive structure to award the money is in place: on a scale of one to five the two lowest ratings attract nothing, whereas the top rating (five, or 'well-above world-standard') earns seven times that of the middle rating (three, or simply 'world-standard'). But the total amount of money available is trivial compared to the overall budgets of the participating universities. In fact, ERA financial reward accounts for only 1.2% of Australia's investment in higher education research and development (HERD), or just over AUS$116 million (US$109 million).

Given that the government has spent AUS$43.5 million on the ERA, and universities themselves have outlaid substantial sums to undertake the ERA evaluations since 2008, one might question the value of this exercise that awards so little money.

> A FAR MORE **SENSIBLE** SYSTEM IS ONE THAT PROVIDES THE **FULL COST** OF RESEARCH IN THE GRANTING PROCESS.

NON-FINANCIAL INCENTIVES

Nonetheless, it is clear that ERA has helped influence the AUS$9.6 billion invested annually in HERD. By focusing its assessment on research quality, rather than quantity, the ERA has helped elevate the research at many of Australia's universities (see page S67). The sector is now strategizing about research quality — and these plans are manifested in new initiatives across various universities. There is evidence that excellence is being recognized and rewarded as one of a series of outcomes.

ERA's impact has gone beyond universities and helped to measure Australian capabilities against benchmarks across the breadth of the HERD sector. This is a useful exercise that should help Australia invest more strategically in research in the future — a necessity thrown into sharp relief by the 2014 budget, which introduced big changes for the higher education sector. Among other items, the budget removed the cap for university tuition fees bringing potentially profound implications for the higher education sector. In this instance the ERA process can provide a benchmark to gauge the effect on research quality. The results, positive or negative, can be used to inform policy decisions around the impact of the decision to deregulate fees as well as other reforms proposed in the future.

But how much influence can the ERA continue to wield once the HERD sector realizes that the total pool of money on the table is tiny? Some commentators have said that, without significant funding flowing from ERA rankings, the programme is not worthwhile — but this is not where the problem lies with funding for HERD.

A far more sensible system is one that contributes towards the full cost of research as part of the granting process, as happens in the United Kingdom, United States and Canada, for example. An assessment system like ERA would then give additional strategic money to help institutions do even better research, at a level in line with current funding. Unfortunately, Australian grants provide nowhere near the full cost of research; significant cross-subsidization is required from student fees. This undesirable method of research funding is unfair to students who believe they are paying for their education but are in fact paying for the country's research.

As a fraction of GDP, Australia spends more on research within higher education than most of the countries in the Organisation for Economic Co-operation and Development (OECD), but its overall rate of R&D investment is well below the OECD average. It is therefore important that Australia maximizes its returns from research within the higher education sector. ERA has successfully emphasized research quality, but this is against a dearth of assessment on how our universities interact with industry (see page S77). Given this set of incentives, it is perhaps unsurprising that although our universities' research outputs are ranked eleventh in the world, Australia was ranked last for business collaboration with higher education and public research agencies within the OECD. Australia needs to invest more in R&D, but without a strategic plan to achieve educational and business outcomes in tandem with excellence in research as captured by ERA, our country will not fully benefit from its investment.

The next round of ERA evaluations is scheduled for 2015. And although the ERA has been worthwhile, it is unclear how much is to be gained by undertaking this formidable exercise again so soon. Not much has changed in the past three years in the Australian HERD sector, so this triennial exercise — as it stands — seems too frequent. On the other hand, if ERA can spur the government to strategically plan its research agenda, then supporters and naysayers alike would rejoice in being assessed as often as is deemed necessary. ■

Brian Schmidt *is professor of astronomy at the Research School of Astronomy & Astrophysics, Australian National University, Weston Creek, Australian Capital Territory.*
e-mail: brian@mso.anu.edu.au


JESSIE CASSON

Q&A Jane Harding

Individual approach

Jane Harding is deputy vice-chancellor for research and professor of neonatology at the University of Auckland, which is New Zealand's most well-funded university under the Performance-Based Research Fund. She discusses the country's approach to assessing science and measuring impact, and describes why she prefers a model that grades the individual not the research group.

What do researchers in New Zealand think about the Performance-Based Research Fund (PBRF)?

Most researchers see the PBRF as an inevitable chore. Still, although they find it time-consuming and distracting to prepare a portfolio, they see some advantages in having something that provides an external validation of research performance on a regular basis — in our case, every six years.

Although many researchers believe that the PBRF is a rather imperfect measure of research quality, it is, by and large, a useful thing. It would be difficult to find an alternative way to distribute the money to the most research-intensive groups. And there is evidence that the PBRF has improved the quality of research.

What is your involvement with the PBRF?

I am responsible for running the whole process within the University of Auckland. The early stages are mostly about preparation and education — making sure that everybody knows what they have to do. Then we get into the phase of assembling individual portfolios. We run an internal review of the draft portfolios before they get polished for final submission, and when the assessment is completed, we manage the results and make sure that they get to the right people.

It is a very big, complicated and continuous process involving a lot of human resources work: we have close to 2,000 portfolios to submit by a specific date. At its peak it can occupy about half of my time for two to three weeks.

This seems like a significant investment for the university.

Yes — but it is also very important to us. The PBRF contributes about 8% of our total budget, which is a significant chunk of funding. Universities in New Zealand did a rough approximation after the last PBRF round on the costs of the process to universities; our best estimate was less than 3% of the total PBRF income over the six-year period, which is not a huge overhead.

What is the grading experience like for researchers?

From an institutional point of view, the distribution of individual grades — A, B, C or R (for research inactive) — has little overall effect on us in terms of dollars. If one of our researchers is awarded a B instead of an A, that is usually balanced somewhere else in the institution by somebody getting an A instead of a B. Such variations don't make much of a difference to the profile of the institution, but they make a huge difference to the individuals. Getting an assessment of a B when you thought you might have been eligible for an A is a huge disappointment. People will inevitably interpret the grades as defining something about themselves; you can't stop them from taking it personally.

Have any categories of researchers been disadvantaged by the assessment?

The assessment is experience-dependent, which makes it difficult for a junior researcher to get an A grade. A brand-new postdoctoral researcher is not going to have a strong research portfolio. The PBRF has a category for new and emerging researchers, in which the threshold for getting a C is much lower, and this does mitigate some of the disparity.

You could even argue that researchers with less experience benefit more from the PBRF because there is assistance at an institutional level: the PBRF provides institutions with funds to specifically support supervision for research degrees. In our university, the PBRF has contributed to an increase in support for less-experienced researchers.

Does the PBRF have a bias against specific research fields or types of output?

That is what everybody worries about, but I don't think it is a reality. You have to trust that the reviewers can assess the different kinds of research in an appropriate way. A few concerns have been raised about the criteria for 'world-class' research, which could disadvantage disciplines focused on indigenous research in local communities. But any bias would result from a misconceived equating of world-class research with international research. You can do world-class research on New Zealand topics.

There is also a minor concern that some types of research, for example those involving commercially relevant work with private companies, might be discouraged because it doesn't necessarily result in a report that can go into a portfolio.

But overall, I don't think that the PBRF has changed the nature of scientific inquiry. It does create pressure to produce outputs, which means that people who would like to sit and spend 15 years writing a book are not going to do well in the PBRF, but they won't do well in any environment that is focused on research quality.

Overall, more than 10% of funding to universities in New Zealand comes from the PBRF. This is much lower than the 25% allocated by a similar programme in the United Kingdom, but higher than the 2% allocated in Norway. Do you think that enough money is distributed through the PBRF?

The amount distributed through the PBRF — NZ$262.5 million (US$224.2 million) in 2013 — is enough to provide a significant incentive but not enough to cover the costs of the research that it is designed to support or to ensure the highest quality research. However, the international comparison comes down to how other components of the system are funded. Universities in New Zealand are seriously underfunded by any measure. We have one of the lowest funding rates per student compared to other OECD [Organisation for Economic Co-operation and Development] countries. And our expenditure on research and development as a proportion of GDP is about half the OECD average.

As a result of this shortfall, researchers in New Zealand spend a substantial amount of time seeking funding. We also face difficulties in recruiting and retaining good researchers. Even though a world-leading professor may be interested in coming to New Zealand and accepts our salary levels, he or she is often discouraged by the lack of research funding and so might choose not to come here. That is a major disadvantage. More funding through the PBRF would help to support more research, but would not make up for the serious underfunding across the sector.


UNIVERSITY OF AUCKLAND

The University of Auckland was allocated more than NZ$72 million from the PBRF in 2010.

How does New Zealand's approach compare with other peer-review-based models such as in the United Kingdom?

The difference in New Zealand is that the assessment is done at the level of the individual as opposed to the research group. Arguably, an individual-based system could lead to selfish behaviour because there is no direct incentive to work collaboratively and to support a team or more junior researchers.

In New Zealand, this is counterbalanced by requiring that portfolios include not only research outputs, but also evidence for the section called Contribution to the Research Environment — a category that covers activities such as engaging in peer review activities, leading collaborative groups, supervising postgraduate students and mentoring early career researchers. It would be very difficult to apply the individual portfolio model to a larger system because of the scale of the assessment.

I prefer the individual model. The UK process requires gathering all of the individual material and then assembling that into an aggregate submission, so it seems to be a lot of additional work for not a lot of additional gain. My colleagues in the UK talk about their universities employing people full-time just to write the submissions.

And how does it compare with indicator-based models like those in Denmark and Australia?

Any peer-review process is vulnerable to the vagaries of individuals. Assessments can vary based on who is on the panel, how well they know the subject, their own personal prejudices, as well as many other unquantifiable factors such as how well the portfolios have been written. The system is also expensive, because each individual portfolio in New Zealand needs to be prepared and assessed.

A metrics-based system is much cheaper and simpler to run and would come out with almost the same outcomes if one was simply talking about allocation of the money and alignment of institutional goals to research quality objectives. But New Zealand's approach of submitting individual portfolios brings the incentives back to each individual staff member in a much more direct way than does submission of metrics at the institutional level. There is also the issue that the metrics themselves, rather than research quality, can become the target — and the lack of peer review means that different disciplines might be differentially treated.

"Researchers with less experience benefit because the PBRF provides funds to support supervision."

Should the PBRF include measurements of impact, similar to the United Kingdom's new Research Excellence Framework?

It is challenging to get a single system to measure two different things. If you consider research quality and research impact to be separate things, then you need separate processes. It is difficult to measure impact — and expensive in terms of the effort required to assemble the evidence.

Introducing new measurements would be useful if they created incentives for academics to increase the impact of their research, but impact is so closely related to research quality that I am unconvinced as yet that a separate assessment is worth the enormous cost. We will learn from the UK's attempt to assess impact on a national scale. ■

Interview by **Smriti Mallapaty**, *assistant editor for Macmillan Science Communication in Tokyo.*


CSIRO'S NATIONAL RESEARCH FLAGSHIPS: AGRICULTURE | BIOSECURITY | DIGITAL PRODUCTIVITY & SERVICES | ENERGY
Achieving positive impact together
At CSIRO we shape the future. We do this by using science to solve real issues. Our research makes a difference to industry, people and the planet.
Connect with us:

FOOD & NUTRITION | MANUFACTURING | LAND & WATER | MINERAL RESOURCES | OCEANS & ATMOSPHERE

CSIRO

An open letter from Dr Megan Clark, Chief Executive CSIRO

Dear valued members of the international research community,

Responding to the major scientific challenges of our time takes an agile and considered approach, as well as the ability to change and evolve.

Indeed, embracing change is essential for CSIRO to continue to be one of the top ten applied research agencies in the world and Australia's most trusted name in science and technology.

In order to make it easier to achieve common goals for long-lasting benefit we have streamlined CSIRO into nine National Research Flagships.

These National Research Flagships allow us to focus on the biggest challenges that face our nation and the globe. By taking a multidisciplinary approach, we can bring to bear the expertise we need to undertake groundbreaking scientific research.

We're creating an operating environment where we can work with you, the international research community, to create positive impact within and across our areas of specialty, and on the world around us.

This is an exciting time for our research. Our doors remain open for researcher exchanges and visits, joint ventures, collaboration agreements, joint publications, joint forums for knowledge exchange and co-investment. We want the best minds in Australia working with the best minds in the world to solve the greatest challenges of our times.

We look forward to continuing to make a positive impact together.

Dr Megan Clark

CSIRO

collaborate@csiro.au | csiro.au

ACHIEVING SUCCESS IN COOPERATIVE RESEARCH CENTRES

As Australia's University of Enterprise, the University of South Australia (UniSA) engages meaningfully and creatively with our peers, industry and the community in areas that are aligned with key state, national and international priorities.

We are proud of our collaborative and solutions-focused research through our successful involvement in the Commonwealth's Cooperative Research Centres (CRC) scheme, where we currently lead and headquarter three CRC's and partner in eight more.

CRC's in the areas of Contamination Assessment and Remediation of the Environment (CRC CARE), Cell Therapy Manufacturing (CTM CRC) and Data to Decision (D2D CRC) place UniSA at the forefront of industry and academic research collaboration, as we bring together our breadth of research expertise to focus on end-to-end approaches and solutions.

From areas of cancer, through to energy and the environment and the development of future industries, our enterprising research is delivering rich, robust and multifaceted outcomes that make a difference to the world.

To learn more about our collaborative research success, please visit **unisa.edu.au**

University of South Australia Senior Research Fellow Dr Mohammad Mahmudur Rahman is performing CRC CARE-supported research on arsenic toxicity, bioavailability and detoxification. This work will help minimise the risk of arsenic exposure at contaminated sites such as disused mines.

University of South Australia

nature

http://www.nature.com/nature/outlook/assessingscience