



MACQUARIE
University

World-leading research World-changing impact

MACQUARIE UNIVERSITY



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From the Deputy Vice-Chancellor

RESEARCH



Macquarie University was formed with two propositions in mind: service and engagement. Through this proud tradition, we serve the world in discovery, innovation, cooperation and partnerships. From our unique location, in the heart of Australia's largest high-technology precinct, we have the perfect platform for engaging with, and making an impact on, the world through our outstanding research and innovation.

In 1964, the pioneers who created our University challenged the educational establishment of the time, and it is this ethos that is embedded at Macquarie: challenge the status quo and be audacious, bold and daring. This University has made its most powerful impact as a training ground

for engaged world citizens and community leaders.

I often hear people talk of the accelerating rate of change occurring across society and culture; Macquarie is neither immune nor separate from this world. We investigate this world, we contribute to the scientific, technological and cultural change taking place, and we train the next generation of business, government and academic leaders. All of this takes place within a world-leading research-informed campus, a campus with one eye on tomorrow, and one eye on the past.

The 2018 Excellence in Research for Australia (ERA) ratings and its companion Engagement and Impact (EI) results showcase Macquarie's strengths as a comprehensive research-intensive university. The results confirm Macquarie's status as a university of world-leading research excellence, research engagement and research impact.

Macquarie is not only a locus of discovery, we communicate that discovery, and we cooperate with academic and non-academic partners on that discovery – and through this we change the world.

I commend to you the outstanding research described in these pages and the stories of impact that have flowed from this research. This book shines a light on the high-quality research that has been a hallmark of Macquarie since it was established in 1964.

Professor Sakkie Pretorius

DEPUTY VICE-CHANCELLOR (RESEARCH)
MACQUARIE UNIVERSITY

From the Pro Vice-Chancellor

RESEARCH PERFORMANCE AND INNOVATION



Macquarie University is a place of purpose, with a mandate of discovery and a belief that our discoveries exist to change the world. As the 2018 ERA ratings show, Macquarie is a hub of research excellence with four broad disciplines rated as well above world standard. This is a remarkable feat for a university of Macquarie's size and shape, and it speaks to the multidisciplinary and interdisciplinary nature of research that flourishes on our campus.

The greatest discoveries often occur at the fault lines between disciplines, where the edges of multiple disciplines touch. Macquarie's culture encourages this type of discovery, our structure enables this, and our

mantra of service and engagement empowers us to take our world-leading research and translate it into real-world scenarios.

This is the first time a university in Australia has completed the EI exercise, and I encourage you to read the impact case studies we have included. Storytelling is not something academia often does, yet it is something that holds great power.

Macquarie's stories of research impact reflect that we are a university with world-changing impact across every discipline in which we undertake research. Not only can we affirm our basic research is world leading, but we can show you how our basic research is applied to the real world, and we can show you how Macquarie cooperates with non-academic partners to translate our discoveries around the world.

I commend the 2018 ERA and EI ratings to you, but more importantly, I commend to you Macquarie's stories of research excellence, research engagement and research impact. In these stories, I hope you will find not only inspiration but also ideas for how you could collaborate with Macquarie. We are always ready to work with you.

Professor Peter Nelson

PRO VICE-CHANCELLOR (RESEARCH PERFORMANCE AND INNOVATION)
MACQUARIE UNIVERSITY

Introduction

WORLD-LEADING RESEARCH, WORLD-CHANGING IMPACT

In 2015, Macquarie University launched its Strategic Research Framework 2015–2024 World-Leading Research; World-Changing Impact, which charts a clear course for the University over 10 years.

In this book are stories of research impact that took decades to manifest and change the world. These stories show the Macquarie way of research excellence and research engagement. They show off Macquarie's proven ability to build unique research concentrations that bring together end users, industry and policymakers with our emerging and mature domains of research excellence.

Macquarie's achievements arise from our researchers' drive to improve the quality and influence of their discovery and to accelerate their world-leading research performance and the scale of their world-changing impact.

This book is an overview of those achievements and of Macquarie's research excellence, research engagement and research impact. This book tells a few of the stories that lie behind our 2018 Excellence in Research for Australia (ERA) and Engagement and Impact (EI) ratings.

BACKGROUND TO THE 2018 ASSESSMENT RATINGS

The Australian Research Council (ARC) is responsible for administering Excellence in Research for Australia (ERA), Australia's national research evaluation framework. ERA identifies and promotes excellence across the full spectrum of research activity in Australia's higher education institutions.

Through ERA, the ARC is tasked with identifying excellence in research by comparing Australia's university research effort against international benchmarks, creating incentives to improve the quality of research and identifying emerging research areas and opportunities for further development.

The first full round of ERA occurred in 2010, and the results were published in early 2011. This was the first time a nationwide stocktake of discipline strengths and areas for development had ever been conducted in Australia. There have been three subsequent rounds of ERA in 2012, 2015 and 2018.

In 2015, the Australian Government launched its National Innovation and Science Agenda. One of the measures in the agenda was for Australia to introduce an Engagement and Impact (EI) assessment framework to assess the engagement of researchers with end users, and show how universities translate their research into economic, social, environmental and other impacts. EI 2018 was undertaken as a companion to ERA 2018.

FIELDS OF RESEARCH CODES

For the purposes of ERA and EI, disciplines are defined as two- and four-digit Fields of Research (FoR) codes as identified in the Australia and New Zealand Standard Research Classification (ANZSRC) 2008 released by the Australian Bureau of Statistics and Statistics New Zealand. The ANZSRC provides 22 two-digit FoR codes, 157 four-digit FoR codes and an extensive range of six-digit codes.

ERA undertakes evaluation at both the two- and four-digit FoR code levels, whereas EI undertakes an evaluation at a curated two-digit level. Macquarie submitted data to ERA at the four-digit level and this data was aggregated to form the two- and four-digit Units of Evaluation (UoEs).

The two-digit FoR code is the highest level of the ANZSRC hierarchy; it relates to a broad discipline field; for example, Physical Sciences (02) or History and Archaeology (21). A two-digit FoR code consists of a collection of related four-digit FoR codes.

The four-digit FoR code is the second level of the ANZSRC hierarchy and relates to a specific discipline field of a two-digit FoR code. For example, Astronomical and Space Sciences (0201) or Archaeology (2101). Appendix 1 contains the full list of two-digit and four-digit UoEs that Macquarie has been assessed in over 2010–2018 for both ERA and EI.¹



Rating scales

ERA RATING SCALE

ERA uses a five-point rating scale for both two-digit and four-digit FoR codes. The rating scale is broadly consistent with the approach taken in research evaluation processes in other countries to allow for international comparison.

RATING	DESCRIPTOR
5	The Unit of Evaluation is characterised by evidence of outstanding performance well above world standard presented by the suite of indicators used for evaluation.
4	The Unit of Evaluation is characterised by evidence of outstanding performance above world standard presented by the suite of indicators used for evaluation.
3	The Unit of Evaluation is characterised by evidence of outstanding performance at world standard presented by the suite of indicators used for evaluation.
2	The Unit of Evaluation is characterised by evidence of performance below world standard presented by the suite of indicators used for the evaluation.
1	The Unit of Evaluation is characterised by evidence of performance well below world standard presented by the suite of indicators used for the evaluation.
n/a	Not assessed due to low volume. The number of research outputs does not meet the volume threshold standard for evaluation in ERA.

2018 ERA EXAMPLE RATINGS

2018 ERA OUTCOMES		
2-digit discipline	Education	4
4-digit disciplines	Education	5
	Education Systems	4
	Specialist Studies in Education	3

← 2018 ERA Ratings

EI RATING SCALE

EI uses a three-point rating scale for the engagement and impact ratings across a curated list of two-digit (or similar) FoR codes. Ratings are determined by discipline-based panels of experts that comprise distinguished researchers and highly experienced research end users.

ENGAGEMENT	
HIGH	The Unit of Assessment (UoA) is characterised by highly effective interactions between researchers and research end users outside of academia for the mutually beneficial transfer of knowledge, technologies, methods and resources. Research engagement is well integrated into the development and ongoing conduct of research within the UoA.
MEDIUM	The UoA is characterised by effective interactions between researchers and research end users outside of academia for the mutually beneficial transfer of knowledge, technologies, methods and resources. Evidence that research engagement is incorporated into relevant parts of the research process within the UoA and/or that research engagement is improving.
LOW	The UoA has little or no effective interactions between researchers and research end users outside of academia for the mutually beneficial transfer of knowledge, technologies, methods and resources. Little or no evidence that research engagement is incorporated into the research process or that research engagement activities are being developed.

IMPACT	
HIGH	The impact has made a highly significant contribution beyond academia. A clear link between the associated research and the impact was demonstrated.
MEDIUM	The impact has made a significant contribution beyond academia. A clear link between the associated research and the impact was demonstrated.
LOW	The impact has made little or no contribution beyond academia.

APPROACH TO IMPACT	
HIGH	Mechanisms to encourage the translation of research into impacts beyond academia are highly effective and well integrated within the UoA. Mechanisms for translating research facilitated the impact described.
MEDIUM	Mechanisms to encourage the translation of research into impacts beyond academia are effective and integrated within the UoA. Mechanisms for translating research facilitated the impact described.
LOW	Mechanisms to encourage the translation of research into impacts beyond academia are not effective and integrated. The mechanisms for translation did not facilitate the impact described.

2018 EI EXAMPLE RATINGS

2018 EI RATINGS		
EI rating categories	Engagement	Highly effective
	Impact	Significant contribution
	Approach to Impact	Highly effective

← 2018 EI Ratings

Medicine and health sciences

A major achievement was the 2013 establishment of Australia's largest research centre for understanding the causes of motor neurone disease and frontotemporal dementia.

In Oncology and Carcinogenesis, two major research themes have been developed in the past five years at Macquarie: melanoma, prostate and breast cancers, and the study of lymphoedema, a reasonably common consequence of cancer surgery that can have disabling impacts on patients. Important discoveries have been made in the precise molecular profiling of melanoma tumours, allowing the design of targeted therapies against specific melanomas, resulting in a dramatic improvement in survival rates in patients. This research has been supported through the award of back-to-back National Health and Medical Research Council (NHMRC) Program Grants in molecular cancer therapies for melanoma (2011–2015, 2016–2020), with the current \$15 million grant administered by the University. Another important area has been the evaluation of surgical interventions for oncology treatment.

Neurosciences cover major research programs across several topics, including neurophysiology and mapping of neural circuits that regulate blood pressure, heart rate and respiration, and investigation of the molecular pathogenesis of neurodegenerative diseases. A major achievement has been the 2013 establishment of Australia's largest research centre dedicated to understanding the causes of motor neurone disease (MND) and frontotemporal dementia. The Macquarie University Centre for Motor Neuron Disease Research co-locates Australia's largest MND clinic in MQ Health, Macquarie's academic health sciences precinct, with leading Australian researchers in this field. This research program leads one of only six NHMRC Dementia Research Team Grants, valued at nearly \$6.5 million.

Research activities in Cardiovascular Medicine and Haematology include studying the association between vascular changes and disease states, and surgical innovations that improve patient outcomes following cardiothoracic surgery.

Examples of research excellence include participation in major international

consortia responsible for major meta-analyses of statin therapies for work identifying risk factors associated with hypertension and cardiovascular disease. As part of MQ Health, Macquarie University Hospital provides advanced cardiothoracic surgery and interventional cardiology procedures, and there is associated clinical research in these areas.

2018 ERA OUTCOMES

Medical and Health Sciences	4
Clinical Sciences	5
Neurosciences	5
Oncology and Carcinogenesis	5
Cardiovascular Medicine and Haematology	4
Ophthalmology and Optometry	3
Public Health and Health Services	3

ABOVE RIGHT:

Research in Macquarie's extensive medical laboratories.
Photo by Chris Stacey.



ENGAGEMENT WITH THE MEDICAL INDUSTRY

The Surgical Skills Lab and Simulation Lab works closely with industry and clinicians to provide access to cutting-edge facilities and to create training packages in new surgical techniques (eg robotic surgery) and the use of new types of orthopaedic implants (eg patient-specific implants design). This facility, founded in 2010, is the largest training facility in Australia and one of the largest and most respected training facilities in the world. It has partnerships with more than 30 national and international medical companies, trains some 1500 surgeons per year and has aided major advances in clinical or surgical techniques such as synthetic tendon repair (Rotation Medical, United States) and patient-specific hip replacement (Optimized Ortho, Australia).

The Macquarie University Centre for the Health Economy (MUCHE) was established in 2013 in response to the health-related industry's need to understand the sector-wide economic impacts of intersecting research, technologies, systems, people and processes involved in healthcare. Led by workforce professionals who are bridging the gap between academia and industry, MUCHE is very much an end-user focused centre. For example, since 2016 it has been contracted by the Australian Government Department of Health to evaluate applications made by pharmaceutical companies seeking to list drugs on the Pharmaceutical Benefits Scheme.

PATIENT ENGAGEMENT: RESEARCH-INFORMED HEALTHCARE

The Australian Lymphoedema Education, Research and Treatment (ALERT) group routinely engages with members of the public by providing research-informed clinical care – in early detection, diagnosis and conservative and surgical management – to patients with lymphoedema. From 2014 to 2016, ALERT surgically treated 71 patients and had more than 250 patient visits for conservative therapy. Patients have also had access to international randomised controlled trials with ALERT contributing 450 patients to an international clinical trial in early detection of lymphoedema in partnership with Vanderbilt University and 18 to another trial with Stanford University. The team hosted regular information sessions, running two public forums involving more than 200 attendees from the community. ALERT also engages with industry in its research and partnered with five companies on collaborative projects during 2014–2016.

ENGAGEMENT WITH THE HEALTH INDUSTRY

The Australian Institute of Health Innovation (AIHI) engages with hospitals and health services to optimise the implementation of research outcomes. These engagements range from long-term formal collaborations on projects, often supported by competitive government grants, to fast-turnaround research that is directly relevant to industry, as well as commercialisation of research and technologies into products and services, and joint venture spin-off companies.

CareTrack Kids is a world-leading example of industry-focused collaborative research. This landmark national study investigated the standard of healthcare provided to children in Australia and involved funding partners with the Bupa Health Foundation, the Sydney Children's Hospitals Network, NSW Kids and Families, the South Australian Department of Health, Children's Health Queensland and the NSW Clinical Excellence Commission. The project examined 17 common childhood conditions and measured adherence to clinical practice guideline recommendations across health services and medical practitioners in three states. It also measured the frequency and nature of adverse events involving children in our healthcare system, offering a unique opportunity to address safety deficiencies.

The Repository of Antibiotic resistance Cassettes (RAC) is a free online application for microbiologists, doctors, practitioners and researchers that was developed by AIHI in collaboration with the Western Sydney Local Health District. RAC is an automatic annotation of bacterial DNA sequences with antibiotic resistance gene cassettes. Commercialised by Spokade, RAC had more than 160 users from 22 countries by the end of 2016.

The Townsville Hospital and Health Service funded several projects, including training and interventions, to establish the effectiveness of a new model of organisational resilience (TenCs Model) in facilitating safe workplace practices and to evaluate the implementation processes. Dissemination of the TenCs has already commenced in Queensland, with the Sunshine Coast Hospital and Health Service funding adoption and evaluation of the advanced surgical care planning for fragile patients at Nambour General Hospital. This process has also garnered interest from the Royal Australasian College of Surgeons. Queensland Health, representing 166 public acute hospitals in the state, has expressed interest in the training and is awaiting outcomes from the evaluation at the Townsville Hospital and Health Service.

Treating motor neurone disease

Macquarie Neurology and Macquarie's Motor Neuron Disease (MND) Service run the largest specialist clinic for patients with MND. The co-location of academic clinical services with Australia's largest concentration of MND researchers provides patients with bespoke, patient-focused care. This supports a translational research platform that has made important discoveries of genetic origins of familial MND, which has enabled MND pre-implantation in-vitro fertilisation (IVF) services to ensure babies are free of MND in Australia. Our genetic discoveries have also been incorporated into standard-practice diagnostic genetic tests that are used worldwide for MND patients.

GENETIC TESTING AND PATIENT IMPACT

The availability of genetic testing is particularly important for patients with inherited forms of MND. Professor Ian Blair and his team have collected DNA from more than 200 Australian families with a history of MND and have now mapped the causative gene mutation in about 60 per cent of these families. These research discoveries

benefit our patients through Macquarie's provision of the first and only genetic counsellor employed within an MND clinic in Australia. This service provides expert advice and genetic counselling for patients and their families.

A topic of common concern for patients is the risk that they may pass MND on to their children, as most causative mutations are dominantly inherited, so there is a 50 per cent chance of offspring developing MND. Until recently,

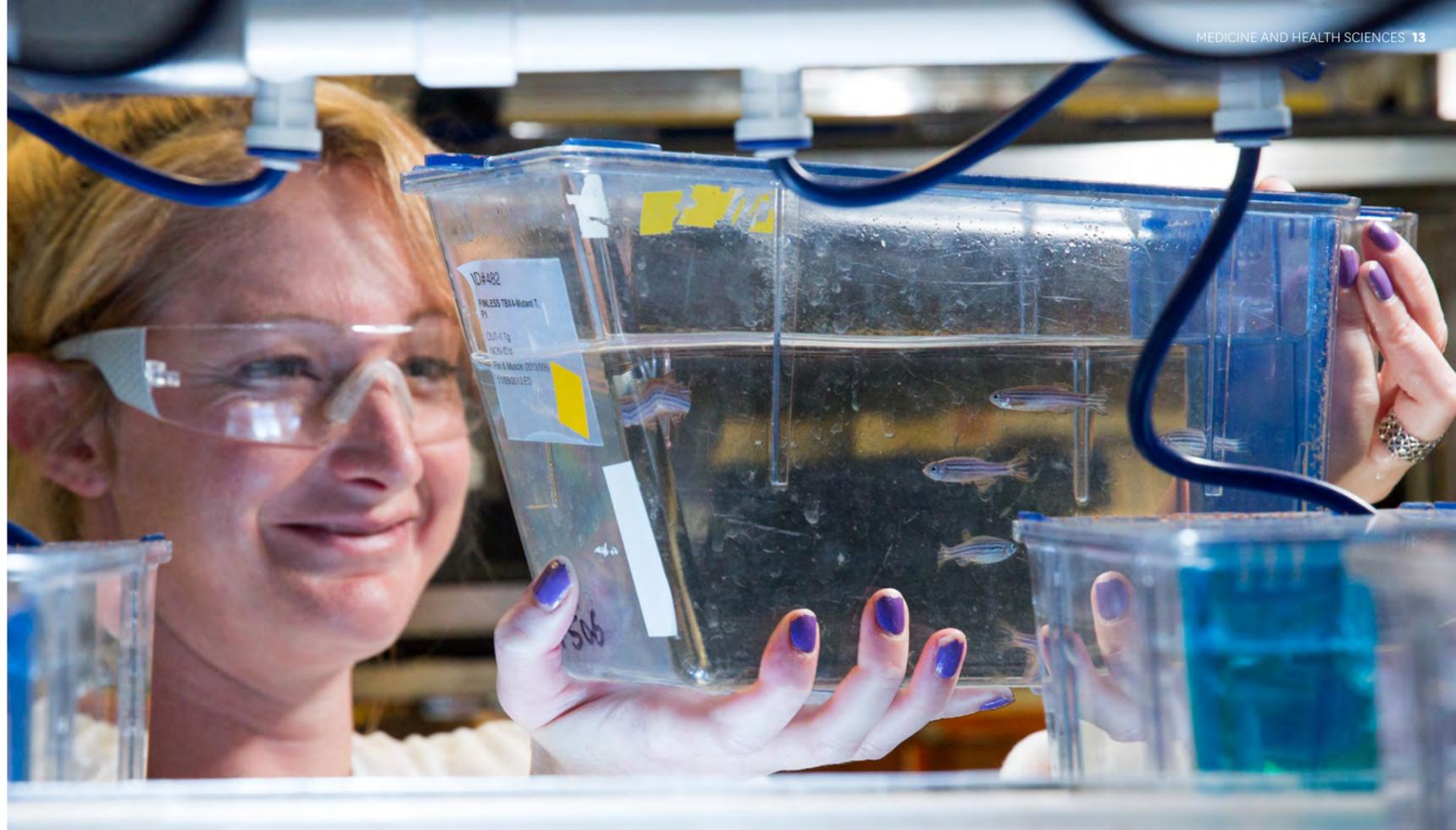
the options for parents were to either not have children or take the risk. To address this, the Macquarie MND clinic provides the first and only MND pre-implantation genetic IVF service in Australia, delivered through Genea. To date, we have delivered three babies born MND free. This service was made possible by Macquarie's genetic discoveries and the translation of those discoveries into tools for parents to ensure their children do not inherit MND-related gene mutations.

The Macquarie University Hospital is the only Australian hospital owned and operated by a university. The MND clinic was established at Macquarie in 2010 and is one of the largest specialist MND clinics in Australia. In 2013, Macquarie strategically brought together five MND research teams from across the country to create the largest concentration of MND researchers in Australia. Macquarie funded the infrastructure that underpins MND research, including laboratories and a biobank.

THE MACQUARIE MODEL FOR MND CLINICAL CARE

For more than 10 years, Professor Dominic Rowe has led the MND clinic based at the University. He offers multidisciplinary care for MND patients in an outpatient setting, where in a single session the patient has access to a group of MND-specific medical experts, including neurologist, clinical nurse consultant, speech pathologist, orthotist, respiratory consultant, social worker, physiotherapist, dietician and so on. This delivers integrated patient care that improves the quality of healthcare provided to MND patients. It is also delivered from a single location on the same day and prevents patients and their families having to coordinate these medical services from multiple providers at different sites, which can be complicated, stressful and expensive. Notably, the multidisciplinary MND clinic is offered at little cost to patients, with all costs outside of rebatable support covered by donations to the University.

As the disease progresses, MND patients might be hospitalised. At Macquarie there is full integration of clinical care for MND patients between the clinic and Macquarie University Hospital, with specialist MND nurses in the hospital who provide care directly guided by the consulting MND neurologist, who is able to regularly check on patients because of physical proximity.



2018 EI OUTCOMES

Biomedical and Clinical Sciences

Engagement	Highly effective
Impact	Highly significant contribution
Approach to Impact	Highly effective

Critically for MND is the analysis of the outcomes for MND patients across Australia has shown that this care model creates a statistically significant increase in the length of a patient's life. For a terminal illness with no current cure, this is a major impact on the patient and their families. In addition, the MND service at Macquarie University has an indigent fund that pays for the care of patients in Macquarie University Hospital who might not have private health insurance.

The professional and personalised care provided to MND patients through the clinic has translated into strong patient support for the Macquarie MND biobank that facilitates our research activities. Macquarie's MND biobank builds upon our longstanding experience in the collection of DNA samples over 20 years of genetic research, and over the past three years it has become the largest national biobank to collect longitudinal samples from patients each time they visit the clinic, generally every 3–6 months. The strong rapport of patients and their families with the clinical team facilitates most of them providing ongoing samples for the biobank. To date, more than 600 participants have contributed to the MND biobank. Approximately 400 patients and 200 controls.

Patients and their families can also tour the University's MND research facilities, located one floor below the clinic, to see how their generous contribution to the biobank enables research towards finding a treatment for MND. We also have researchers visit the multidisciplinary clinic as observers to embed a holistic integration of the MND research pipeline and the critical importance of patients within it. A strong indication of the impact this has on patients is through their willingness to continue providing samples to the biobank. In turn, this ensures we have a rich biobank of longitudinal samples collected across the disease time course, which is a key resource for MND research.

COMMUNITY IMPACT

MND has a devastating impact on the Australian community. The way in which the disease manifests and progresses is emotionally distressing for families and friends to observe. While it has publicly been considered a rare disease, the latest national data indicates that two Australians die from MND each day – it is not rare. A recent economic analysis undertaken by KPMG under the commission of MND Australia identified that the financial cost of care per patient per year is approximately \$1 million. Therefore, this is an extremely costly disease, socially and economically, to the Australian community.

ABOVE:

Transparent zebrafish models of MND are helping us unlock the disease mechanisms and work towards future therapies. Photo by Chris Stacey.

E-health and global patient safety

Macquarie consults globally on e-health risks to patient safety, and Macquarie's confidential reports inform policy changes in Australia, North America and the European Union. Macquarie works with the Institute of Medicine and the Emergency Care Research Institute (ECRI) in the United States, the National Health Service (NHS) in the United Kingdom and the Australian Digital Health Agency and the Australian Commission on Safety and Quality in Health Care.

Annually, Macquarie's e-health work benefits more than 250,000 patients in Australian hospitals and 500,000 in general practice. Additionally, the International Organization for Standardization (ISO) uses Macquarie's

schema for classifying e-health risks. Macquarie's work has therefore resulted in significant healthcare policy change and impacted patient safety around the world.

Macquarie's Associate Professor Farah Magrabi

and Professor Enrico Coiera conducted the first international identification and analysis of adverse healthcare events arising from information technology (IT) systems. This research has gone on to have global impact.

In late 2014, vital IT systems were not available in every hospital in Queensland and this disrupted care delivery to thousands of patients across the state for several hours. Macquarie's work ensures that e-health risks like these are minimised, resulting in significant gains to patient safety and care delivery.

2018 EI OUTCOMES

Public and Allied Health Sciences

Engagement	Effective
Impact	Significant contribution
Approach to Impact	Highly effective

Macquarie's e-health research has had far-reaching impact across the world. This has been achieved through sustained engagement with end users in government and non-government organisations. Macquarie's work ensures patient risks are minimised within the context of digitally enabled healthcare.

PATIENT BENEFICIARIES

Australian hospitals currently provide care to more than 235,000 patients every day, and Australian general practices see more than 367,000 patients daily. Large-scale IT events typically last for eight hours or more and organisations typically experience 25 hours of system downtime per year. Such downtime puts patients at unacceptable risk of harm in our hospitals and healthcare environments, which are now so critically dependent on IT systems for delivering correct patient care.

Macquarie's schema for classifying e-health risks enjoys global use, including by healthcare organisations such as the ISO, the NHS, the ECRI and the Pennsylvania Patient Safety Authority as well as the Australian Digital Health Agency and Australian Commission on Safety and Quality in Health Care. Patient risks are rapidly increasing in the e-health domain and the impact of Macquarie's research on policy reform has been essential to ensure the ongoing safety of patients in environments of digitally enabled healthcare.

AUSTRALIAN POLICY CHANGE

There are approximately 1300 hospitals in Australia and each of them is increasingly dependent on IT systems for routine clinical processes: 80 per cent of New South Wales patients are supported by electronic medical records, and in general practice, 97 per cent of doctors use electronic records. Whether it is for pathology, medications, radiology or record keeping, these systems are mission critical to hospitals.

Macquarie's schema has been critical during the rollout of more than \$1.6 billion of national and state e-health record systems over the past five years.



INTERNATIONAL IMPACT

Over 2014–2016 Macquarie's research on e-health incidents has been integrated into the reports and guidelines of international organisations such as the ISO, the US Joint Commission, the US Office of the National Coordinator for Health Information Technology (ONC) and the ECRI.

The ISO has used Macquarie's schema as the basis for a new technical specification to improve reporting about the safety of health software.

The Joint Commission used Macquarie's work to examine sentinel events resulting in patient death or serious injury. In 2015, the Joint Commission used Macquarie's work certifies nearly 21,000 healthcare organisations in the United States, and Macquarie's work was integrated into the Joint Commission's standards on e-health patient safety. This has improved the standard of healthcare provision in the United States as well as how the country monitors and manages e-health safety.

The ONC has integrated Macquarie's schema into their guides for Safety Assurance Factors for Electronic Health Record Resilience. The ONC enables the electronic sharing of health records in the United States, and its integration of Macquarie's schema has a significant positive impact on the US healthcare sector.

Macquarie's schema was also taken up by the ECRI, of which more than 5000 international healthcare providers are members. The institute consults on healthcare risks and ensures patient safety, and for the last six years it has identified IT risks as its highest priority risk, so it has adopted Macquarie's safety schema.

LOCAL IMPACT

Macquarie University Hospital has been used to pilot the application of e-health research at the University. Due to the unique governance arrangements at the hospital – the only privately owned not-for-profit hospital on a university campus in Australia – it has been possible to rapidly test e-health initiatives. This has resulted in gains to patient safety and e-health protocols at the hospital and in the North Ryde local community.

Macquarie University Hospital was the first paperless hospital in Australia. Associate Professor Farah Magrabi is on the patient safety committee at the hospital and has been able to directly translate Macquarie's e-health research into patient outcomes through this role.

ADVISORY COMMITTEES

Associate Professor Farah Magrabi is a co-chair of the Technology Assessment and Quality Development working group for the International Medical Informatics Association, the premier international body for e-health.

She is also a member of the Clinical Care Standards Advisory Committee at the Australian Commission on Safety and Quality in Health Care. The commission works in partnership with patients, consumers, clinicians, managers, policymakers and healthcare organisations around Australia. The standards of the commission are informed by Macquarie's e-health research on the delivery of healthcare throughout the country.

ABOVE:
Photo by Chris Stacey.

Economics

The University predominantly conducts research in applied economics and econometrics. Other strengths include macroeconomics, financial economics, cultural economics, and labour and development economics. Our research in experimental economics and health economics is likewise having an increasing impact. Macquarie has a strong research reputation in labour economics and in the economics of growth, development and income distribution for the emerging market economies of Southeast Asia.

Macquarie has a strong research reputation in labour economics and in the economics of growth, development and income distribution for the emerging market economies of Southeast Asia.

In macroeconomics, Macquarie's contributions are in theory-based simulation models and data-driven structural econometric models of the macroeconomy. In financial economics, the focus is on forecasting financial relationships, modelling systemic risk and evaluating financial products designed for retirement. Macquarie's econometricians have made outstanding contributions to the statistical identification of macroeconomic models and to the early detection of asset price bubbles in housing and equity markets.

In cultural economics, recent contributions evaluate the

heritage value of Indigenous art, the income prospects of artists and writers, the box office prospects of Australian films and the economic losses associated with illegal downloading. Macquarie's contribution to the formulation of cultural policy within Australia and internationally is actively sought by the the Australia Council for the Arts, the World Bank and the United Nations Educational, Scientific and Cultural Organization (UNESCO).

The increased capacity to combine applied theory with laboratory experiments provided by the experimental economics laboratory launched in 2015 has enabled the investigation of a range of economic behaviours, such as charitable giving, search and sequential decision making, market entry and exit decisions, and price formation.

Researchers have prepared reports on culture and heritage for the World Bank, reports on health services for NSW Health and reports for the Australian Self Medication Industry, the peak body of the consumer health industry.



2018 ERA OUTCOMES

Economics	3
Applied Economics	3

ENGAGEMENT

Macquarie has concentrated engagement activities in the Research in the Economics of the Arts, Culture and Heritage (REACH) network, the Macroeconomics and Financial Stability (MAFS) network and the Labour, Economic Advancement and Development (LEAD) network. Several staff are also members of the Faculty of Business and Economics' Australia-Asia Research Network. The research networks produce commissioned reports and papers for government as inputs into the formulation of public policy. Public discourse is supported by government-sponsored lectures and workshops conducted by the networks.

The Macquarie University Centre for the Health Economy (MUCHE) engages in paid consulting activities for both the private and public sectors in relation to the economics and public policy aspects of the healthcare sector.

RESEARCH SERVICES FOR GOVERNMENT AGENCIES

The REACH network undertook research on digital disruption in the Australian book industry, which was jointly funded by the ARC and the Australia Council. The REACH network's work on the role of culture in sustainable development influenced the formulation of the United Nations Sustainable Development Goals in 2015.

ABOVE:
Photo by iStock

LEAD network members have undertaken research projects for the Asian Development Bank and for AusAID.

MUCHE undertakes funded economic research across the healthcare sector and provides expert advice. It has undertaken research in mental health for the Black Dog Institute and for Beyond Blue. Several members have been appointed to expert panels, notably on aged care for the Australian Government Department of Social Services and on hospital performance and efficiency for the National Health Performance Authority.

MAFS network members undertook research projects for the Centre for International Finance and Regulation (CIFR) to address fundamental issues affecting the Australian finance industry. The MAFS network contributed research on the pricing of investment products, mainly in relation to superannuation, and on managing systemic risks in financial markets. This research was presented at CIFR workshops and symposia in 2015 and 2016.

MAFS network members, in conjunction with the faculty's Centre for Financial Risk, organise and participate in the faculty's Financial Risk Day, an annual event that brings together experts from industry and regulatory authorities to discuss issues of risk in banking, insurance and superannuation. Members of MAFS have also participated in the faculty's Academic 2 Business – Research Informing Business Symposium.

The economics of arts and culture

Macquarie's research on the economics of arts and culture has had a range of national and international impacts. Building on a long period of sustained engagement with the field by Distinguished Professor David Throsby AO, the research has had a significant impact on Australian national cultural policy analyses of the cultural industries, the development and conduct of artist surveys, and path-breaking empirical work on the economics of the Australian book industry. The research has additionally had an impact through the development and implementation of a national survey of remote Indigenous artists. At an international level, the work has affected policymaking in institutions such as the World Bank and UNESCO.



THE ECONOMICS OF CULTURAL POLICY

Macquarie's Distinguished Professor David Throsby has had a long career undertaking theoretical and applied research in the economics of art and culture. His two research monographs *Economics and Culture* (2001) and the *Economics of Cultural Policy* (2010), as well as his many published papers, have had a profound effect on research and policymaking in the field.

This research included the development of the concentric circles model of the cultural industries, which has been adopted as an appropriate framework for considering the economic structure of the cultural sector. In particular, the model had an impact on the policy recommendations arising from the Creative Australia panel at the 2020 Summit in 2008, and subsequently on the *National Cultural Policy* Creative Australia released in 2013. The ongoing need for a national cultural policy originated in an influential research monograph on this subject published by Throsby in 2006.

SURVEY OF AUSTRALIAN ARTISTS

Throsby has undertaken surveys of practicing professional artists in Australia every 5–7 years, with the most recent survey conducted in 2016. These surveys have been funded by the Australia Council and are directly incorporated into the council's strategy of support for Australian artists. Throsby's work – developing the methodology for these surveys, carrying out the data collection and analysis, and authoring the final reports – has had a direct impact on the mechanisms of financial support available to Australian artists through the council.

The survey results have been used by cultural industry organisations such as the Australian Society of Authors, the National Association for the Visual Arts, the Media, Entertainment and Arts Alliance, and many others, who use the data to inform their policy recommendations to the government.

ABOVE:
Distinguished Professor David Throsby.
Photo by Jesse Taylor.

Macquarie's impact in the economics of arts and culture is founded on researcher engagement through advisory committees, reference groups, high-level policy advice and public lectures. The Research in the Economics of Arts, Culture and Heritage (REACH) network concentrates emerging and mature research strengths and enhances the University's research in the economics of art and culture.

AUSTRALIAN INDIGENOUS IMPACT

As a component of an ARC Discovery Project in 2011–13, Throsby developed and implemented a survey of Indigenous artists in northeast Arnhem Land. This led to the formulation of a National Survey of Remote Indigenous Artists, the first module

of which covered remote Aboriginal artists in the Kimberley region of Western Australia. Throsby presented the findings of this survey at the annual Meeting of Cultural Ministers in 2015. The presentation resulted in agreements with federal, state and territory governments to carry forward the national survey, the first of its kind ever undertaken.

The results of the Kimberley survey directly influenced Western Australian arts policy with regard to the closure of remote communities being considered in 2016. The survey showed the importance of art and cultural production to the economic sustainability of remote communities in the region.

RESEARCH ON THE AUSTRALIAN BOOK INDUSTRY

Macquarie's work on digital disruption in the Australian book industry had a direct impact on the work of the Book Industry Collaborative Council 2012–13, which Throsby chaired. The council formulated a blueprint for industry reform and made recommendations to government for the creation of an Australian Book Council.

Surveys of authors, publishers and readers carried out as part of this research and funded by the ARC and Australia Council had a direct impact on book industry organisations and their policymaking procedures during 2015 and 2016, as well as informing the development of Australia Council for the Arts programs related to literature and reading.

INTERNATIONAL IMPACT

Throsby's research has influenced policymaking for art, culture and heritage at an international level. The World Bank has adopted the methodology developed by Throsby for evaluating the economic, social and cultural impacts of heritage-led investments in towns and cities in developing countries. Assessments in Jordan, Lebanon, Saudi Arabia, Macedonia and Georgia have all incorporated Throsby's methodology for valuing and assessing the impacts of heritage investments.

Throsby's work with UNESCO on definitional issues and sustainability provisions in drafting the 2005 Cultural Diversity Convention continues to have an impact through periodic implementation reviews of the convention's sustainability provisions in a range of developing countries. This impact was also evident through Throsby's extensive research on the role of culture in sustainable development leading up to the formulation of the United Nations Sustainable Development Goals in 2015. In the field of heritage, the development of the economic concept of cultural capital had a major impact on the practice of the economics of heritage, both within UNESCO and beyond.

The UNESCO Institute for Statistics in Montreal has drawn on concepts and methodologies developed by Throsby in its collection of data regarding global arts and culture. The concentric circles model has been incorporated into the methodological structure recommended by the institute for the compilation of national satellite accounts for culture, the Australian version of which was completed by the Australian Bureau of Statistics in 2015.

2018 EI RATINGS

Engagement	Effective
Impact	Significant contribution

Commerce, management, tourism and services

Macquarie's research is predominantly in accounting, auditing and accountability, banking, finance and investment, business and management, and marketing. We have built an extensive scholarly reputation in several areas spanning:

- accounting and financial regulation and reporting
- auditing and accountability
- corporate governance
- ethics and sustainability
- risk management
- insurance and actuarial studies
- asset pricing and derivatives
- commodity and energy markets
- employment relations
- the management of work and careers
- international business
- advertising
- marketing strategy
- service marketing.

Consistent strengths in organisations, employment and work environment recently resulted in high-quality outcomes in relation to performance regimes as well as different organisational forms and processes across sectors. We also achieve high-quality outcomes in the areas of organisational and management knowledge, organisational performance and climate, commitment, cultural change, careers, leadership, gender and cultural diversity, and higher education management. There has been a growing trend towards multistakeholder and multidisciplinary work, with increasing strength in research on environmental and organisational sustainability and business in China.

We have also experienced continuing consolidation of strength in management accounting, international accounting and behavioural research, with significant increase in high-quality financial capital markets accounting research. In the finance and investment field, there has been a major increase in research on corporate finance and energy markets with publications on Chinese capital markets appearing regularly in the most prestigious international corporate finance and banking journals.

Research in business and management has expanded in breadth and quality in recent years as demonstrated by publications on corporate social responsibility, supply chains and competitiveness in emerging markets. Our work on multinational and small-to-medium-size firms in the Asia-Pacific region, organisation studies and human resource management, as well as business ethics has also been published in the highest quality journals. Macquarie has produced a significant body of work in marketing strategy, product and service innovation, and services marketing.

Applied research has contributed to public policy and business strategy and outcomes through collaborations with the Australian Government Department of Industry, Innovation and Science, Cochlear, Beletich Associates, and Optus, as well as financial institutions. Research with external organisations such as the Catholic Schools NSW, Energy Australia, Smith & Nephew and the McKell Institute has been supported by matching University-Enterprise Collaboration funding.

Further achievements include a staff member receiving the 2016 Prime Minister's Prize for Innovation, and our research on superannuation, long service leave and workers compensation impacting New South Wales and Victorian parliamentary inquiries and government policies. Staff have also been appointed to the Auditing and Assurance Standards Board and the NSW Ministerial Roundtable on Cultural Diversity in the Workplace.

ACCOUNTING, AUDITING AND CORPORATE GOVERNANCE

In accounting, governance, standards and auditing, staff have collaborated with the CPA Australia to present at annual forums, which have included representatives from ASX, Macquarie Group, the NSW Treasury, the NSW Self Insurance Corporation, the Australian Health Service Alliance, the Taxi Services Commission, Ernst & Young and Citibank.

Macquarie holds an annual CFO event attended by representatives from the Whiddon Group, Cochlear, Deloitte and others. We have also drawn on our research in providing advice to the Auditing and Assurance Standards Board, the Association of Chartered Certified Accountants, the Australian Auditing and Assurance Standards Board, and the Chartered Institute of Management Accountants. Macquarie participated in the Australian Auditing and Assurance Standards Board Data Analytics Roundtable in 2016.

2018 ERA OUTCOMES

Commerce, Management, Tourism and Services	3
Banking, Finance and Investment	4
Business and Management	3
Marketing	3



FINANCIAL SERVICES AND RISK

Macquarie has engaged with leading national and international financial organisations, government bodies and professional and practitioner organisations. Macquarie's partner research on risk cultures since 2015 has resulted in advisory meetings with executives and the boards of numerous Australian banks, international banks, financial services firms, national regulators and international regulators.

Partner banks include:

- Bank of America
- Bank of Montreal
- Bank of Nova Scotia
- Hong Kong and Shanghai Bank
- JP Morgan, Lloyds
- Merrill Lynch
- National Bank of Canada
- Royal Bank of Canada
- Royal Bank of Scotland Deutsche Bank
- Toronto-Dominion Bank

In Australia, our regulatory partners include the Australian Securities and Investments Commission and the Australian Prudential Regulation Authority, while our insurance partners include AIG, Suncorp, Zurich, and HCF. Internationally, we work with the UK Prudential Regulation Authority, the UK Banking Standards Board, the US Federal Reserve Board, the US Securities and Exchange Commission, the US Office of the Comptroller of the Currency, the Monetary Authority of Singapore, the Financial Stability Board and the Chicago Mercantile Exchange.

Macquarie has provided expert advice to the Actuaries Institute Education Strategy Working Group Taskforce; Gilchrist Connell on insurance; and the Reserve Bank of Fiji – Actuary on trust funds, solvency and capital adequacy regulations. Macquarie has presented workshops in Saudi Arabia on liberalised electricity markets, including to the Electricity and Co-Generation Regulatory Authority.

ORGANISATION, WORKFORCE AND SUSTAINABILITY

Macquarie has engaged with government and non-government organisations (NGOs) in collaborative activities to improve work processes, management, organisational strategies and practices. Partnered research with National Disability Services and the McKell Institute contributed to industry and government inquiries. Macquarie's researchers have addressed practitioner conferences attended by Australian Institute of Superannuation Trustees members, Fund Executives Association members and work health and safety and workers compensation practitioners. Macquarie's work on sustainability has engaged with the Thailand Sustainable Development Foundation, the United Nations G77 meeting in Bangkok and numerous Thai community organisations.

Migrant employment and the management of cultural diversity

Macquarie's research on migrant employment, education and cultural diversity management has impacted on migrant support organisations and government in New South Wales as well as on practitioner understanding of Australian approaches in other countries. Building on a long period of sustained engagement with the field by Professor Lucy Taksa, the research has had a significant impact on migrant and refugee human and social capital development in employment and education in Greater Western Sydney. Through contributions to symposia with Hudson Recruitment and the Ethnic Communities' Council of NSW (ECC), NSW Government and NGO advisory committees, Taksa has brought about positive change for migrants and refugees.



RESEARCH REPUTATION

Macquarie's Centre for Workforce Futures and its Cultural Diversity Research Network collaborated with the private sector and NGOs to disseminate research findings from an ARC-funded project that investigated mobility and cultural diversity, and from the Affinities in Multicultural Australia research project, which began in 2012–13 with support from Macquarie.

Professor Taksa presented at symposia organised by Hudson Recruitment and the ECC between 2011 and 2014 where she addressed decision-makers and stakeholders from state and local government bodies, the private sector and NGOs. Additionally, Taksa presented at the Cultural Diversity Unplugged forum in 2012, hosted by the Diversity Council Australia for industry representatives, and to Australian federal and state MPs at the 2014 ECC Annual General Meeting (AGM). Taksa also featured in the Mount Druitt Ethnic Communities Agency AGM and the North Ryde Human Resources Forum's Diversity Strategies to Support Business workshop.

SPILLOVER BENEFITS

Professor Taksa presented to more than 40 NGOs from Western Sydney in 2012, an event organised by the Sydney Alliance, a coalition of community organisations, religious organisations and unions. This resulted in an invitation from the NGO Western Sydney Community Forum (WSCF) to help formulate the approach to its NSW Department of Family and Community Services-funded Culturally and Linguistically Diverse (CALD) Worker Mentoring Project. Taksa translated her research findings into practice by devising a collective group mentoring model for the project. As a member of the project's advisory committee, she helped develop the program's structure, guidelines and implementation. Taksa also helped to select participants for the program's five mentoring groups. Through Macquarie's Cultural Diversity Research Network, Taksa collaborated with WSCF to assess the project's outcomes, which included enhanced knowledge sharing, network and professional development for participants.

During her time as a member of the NSW Ministerial Roundtable on Cultural Diversity in the Workplace in 2012–13, Taksa contributed to the identification of gaps in the recognition of migrant employment skills and the need for new approaches to mentoring. The Roundtable's recommendations resulted in the development of the Skilled Migrant Employment Project (SkillME) in 2014, launched in 2015 with NSW Government funding of \$450,000 over three years. By the end of 2016, Metro Assist had delivered the program to 409 migrants.

2018 EI RATINGS

Engagement	Effective
Approach to Impact	Effective

Macquarie strategically concentrates research strength to enable consolidation and capacity building. In 2011, the Centre for Workforce Futures was established as a faculty-level cross-disciplinary concentration of academics focused on organisation, regulation and management, sustainability, and economic and social inclusion. The Cultural Diversity Research Network was then formed in the Department of Marketing and Management to provide greater focus on migrant employment, ethnic and religious diversity, and intersectionality.

SETTLEMENT SERVICES INTERNATIONAL

In 2015, Taksa was appointed as a non-executive board member of Settlement Services International. With nearly 500 staff, SSI is the largest NGO servicing refugees and migrants in New South Wales. The organisation is committed to launching refugee scholarships for school, VET and university students, and also focuses on skills and qualifications recognition. Taksa played a leading role in shaping the formulation of scholarship guidelines and assessment processes, and has been a member of its assessment committee. Over 2015 and 2016, 84 scholarships from \$500 to \$5000 were awarded to enhance refugee students' human capital development and employment opportunities. The contribution of Taksa's research to SSI governance, decision making and scholarships committee has had lasting impact on the lives of many migrants in Sydney who are now better placed to contribute economically, culturally and socially to Australian society.

Education

There is wide acceptance that education, from early childhood to adulthood, plays a fundamental role in improving lifelong academic success, social competence, emotional wellbeing and general quality of life. Macquarie's education researchers enhance the transformative power of education by conducting research that is at the cutting edge of scholarly developments, while engaging with practitioners and policymakers to maximise the relevance and applicability of our research findings.

Macquarie's educational research covers all sectors, from early childhood to higher education. Our early childhood researchers have longstanding relationships with stakeholders, resulting in productive research collaborations that directly inform practice and policy. As well as producing significant insights into education practices in the real world, our researchers respond in evidence-based ways to public inquiries, such as the Productivity Commission's 2015 report *Childcare and Early Childhood Learning* and the Inquiry into the Status of the Teaching Profession.

Our educational researchers conduct high-quality educational studies at all levels, addressing issues such as STEM (science, technology, engineering and mathematics), language and literacy learning, effective pedagogies, physical education and wellbeing, and educational diversity and inclusion. Much of the research is conducted in educational contexts, such as schools and early childhood centres, thus maximising the relevance and applicability of the findings. Ongoing community engagement ensures that our work influences practice and policy, advances theory and debate, and leads to methodological advances. There is a strong commitment to incorporating research findings into professional development for practitioners.

Maintaining international collaborations and study opportunities has been a cornerstone of Macquarie's research in education, keeping our research in the field impactful both nationally and internationally. To date, we have established partnerships with the universities of Tampere, Hamburg, Lapland and Edinburgh, as well as Linköping University

and Justus Liebig University. Queen Maud University College (Trondheim) is an example of a leading institution where there has been collaboration with multiple staff, involving visits, workshops, journal articles, book chapters and higher degree research (HDR) supervision of PhD and master's candidates.

Macquarie's educational research covers all sectors, from early childhood to higher education.

Prestigious international institutions such as UNESCO and Save the Children have commissioned reports and sought expert consultation from our researchers. The Macquarie cotutelle program, which involves the award of a scholarship for HDR students to complete their project with supervision from two universities, has become one of the key mechanisms by which we maintain our international collaborations.

Due to the strong track record of Macquarie's education researchers, the discipline is in a period of rapid expansion. The expansion has led to the development of new research infrastructure, the implementation of improved publishing and grant-writing practices, the promotion of thesis by publication for HDR students and the development of international collaboration arrangements for HDR candidates. As a result, we are seeing an increase in multidisciplinary research with high translation potential and industry research partnerships. To further consolidate the discipline's efforts to improve collaborative opportunities, capitalise on beneficial infrastructure and advance research administration, researchers were unified under a single department in 2016.



2018 ERA OUTCOMES

Education	4
Specialist Studies in Education	4
Education Systems	3
Curriculum and Pedagogy	3

RESEARCH PARTNERSHIPS AND SUPPORT

During 2014–16 our education researchers were involved in more than 36 consultancies, which were directly commissioned by end users to inform their practice. Such partnership opportunities have helped to inform our research priorities, providing insights into the current challenges that exist within practice and increasing the relevance and impact of research in real-world settings. These consultancies were commissioned by government stakeholders such as the NSW Department of Education, the State Library of New South Wales, and the Australian Sports Commission; NGOs such as the Australian Institute for Teaching and School Leadership, The Benevolent Society, and Children and Young People with Disability Australia; and international organisations, including the British Academy and UNESCO.

ABOVE:
Photo by Joanne Stephan.

CHARITABLE ENDORSEMENTS

Our research has also received a large amount of charitable endorsement. Most notably, a private philanthropist provided \$1.34 million to support our research with vulnerable families. This research was conducted in partnership with three NGOs, which otherwise would not have the financial means to engage with research. In another project, the philanthropic St George Foundation supported an early childhood STEM research initiative that was conducted in partnership with schools in disadvantaged areas.

DEMONSTRATION PROGRAMS ON THE FOREFRONT OF EDUCATION

Macquarie is unique in that it houses a school and an early childhood education centre, both of which provide evidence-based, best practice demonstration programs. The Mia Mia Child and Family Study Centre (Mia Mia) has a strong national and international reputation for excellence in early childhood education. It provides opportunities for observation, mentoring and applied research for staff and students.

In addition, Mia Mia receives hundreds of visitors each year from national and international early childhood education practitioners and government representatives interested in delivering quality early childhood programs. Mia Mia attracts considerable cross-disciplinary interest, with frequent visits from practitioners and community members, as well as researchers with an interest in the creative arts, architecture, landscaping, family support services, infant mental health and allied health services.

The Macquarie University Special Education Centre School (MUSEC School) is for primary school-aged children with special learning needs. The MUSEC School also has a key role in research engagement, hosting visits from national and international practitioners and government representatives, as well as scholars interested in evidence-based intervention and teaching practices for children with disability. Special education academics from the MUSEC School provide outreach support to community early childhood centres and primary schools that are seeking mentoring in the delivery of high-quality programs for children with diverse learning needs. The leadership staff of Mia Mia and the MUSEC School have academic appointments within our Department of Educational Studies and are leaders and collaborators in educational research.

Transforming mathematics education in preschool and primary school

Macquarie's research on teaching and assessing children's mathematics development has fundamentally changed how mathematics teaching and learning is approached in Australia, including in Indigenous communities. This has transformed mathematics learning and teaching worldwide, significantly impacting professional practice and family involvement in children's education. The translation of Macquarie's research into the classroom has resulted in significant mathematical learning gains for preschool and primary school children. Curriculum developers, teachers, educators, pre-service education teachers, students, families and children have all benefited from the mathematics teaching programs and assessment tools developed at Macquarie.

PRIMARY SCHOOL

Macquarie researchers conducted groundbreaking research on pattern and structure that had a direct impact on the content of the Australian Curriculum for mathematics. In *Elements of Numeracy*:

Internal grant schemes, including research centre funding, have supported the development of rigorous mathematics education research programs, including *Opening Real Science*, a project designed to improve science and mathematics education by engaging pre- and in-service teachers in real science. Support from the University has also provided research infrastructure and an engagement culture, which facilitates the development of research with real-world translation, further enabling collaboration with professional, policy and community organisations.

'Recognising and using patterns and relationships', students identify trends and use mathematical rules to solve problems in authentic contexts. To support the implementation of the curriculum, Macquarie researchers developed professional resources including the 'Top Drawer Teachers: Patterns, K-2' for the Australian Association of Mathematics Teachers.

Macquarie researchers developed and implemented a new Pattern and Structure Assessment, which was

validated in 2015 in collaboration with the Australian Council for Educational Research through a large study of 600 kindergarten and Grade 1 students. Implemented in more than 540 Australian classrooms – and in classrooms across Australasia, Asia, Europe and North America – this assessment interview provides teachers of four-to-eight-year-olds with a unique tool to

measure children's fundamental concepts of number, patterns and algebra, geometry and measurement, and graphical representation.

The aligned Pattern and Structure Mathematics Awareness Program provided primary school teachers with pedagogical strategies and a program of learning experiences that foster early mathematics learning. Research findings from our experts were incorporated into teachers' pedagogies – their teaching skills and practices – via a series of professional learning seminars delivered to professional organisations and pre-service programs Australia-wide.

A study following the academic outcomes of 319 kindergarten children evaluated the impact of the new program on practice, showing significant gains for children and changes in teacher knowledge and practices. In a subsequent project, which focused on patterns and structures in data modelling for Grades 1–3, the impact of the program was extended to statistical reasoning.



PRESCHOOL

Through the Patterns and Early Algebra Preschool project, our research has also influenced preschool education. The preschool research program, including the development of the Early Mathematical Patterning Assessment, transformed the way early childhood educators teach numeracy while also engaging parents and communities in children's learning.

In one study, preschool children's mathematical pattern knowledge was fostered through a 12-week intervention program developed by our researchers. The program, which was trialled in 14 preschools in rural New South Wales in 2011–14, resulted in improvements in the children's mathematical pattern knowledge, which extended into their first year of formal schooling.

A detailed report, released in 2015, explained that the program produced significant gains in preschool children's mathematical reasoning skills, with flow-on effects to the children's general confidence, communication and problem-solving skills. Following the release of the report, participating early childhood services created a community book and board game about mathematical thinking to use in their services. The report's findings were subsequently widely disseminated to peak early education and mathematics organisations, through professional learning programs, and contributed to a DVD on children's mathematical thinking, distributed to every early childhood centre and tertiary early childhood program provider in Australia.

As a result of the preschool research program, our researchers joined the writing consortium for the Early Years Learning Framework, Australia's national framework for prior-to-school settings, ensuring that specific patterning, numeracy and structure concepts were included in assessable curriculum outcomes in Australia.

INDIGENOUS COMMUNITIES

The success of the Patterns and Early Algebra Preschool project has been extended to rural and remote Indigenous communities in the Broken Hill region of New South Wales. In partnership with early childhood services, our researchers conducted intensive professional development with educators to enhance their competencies in the teaching and assessment of children's mathematical and scientific concepts.

Since 2014, our collaborations with Gowrie NSW and the Maari Ma Health Aboriginal Corporation increased community participation in, and ownership of, the program. To facilitate this, our researchers worked closely with community organisations to co-create and co-produce professional development workshops as well as resources for parents so they could better support their children's learning. As a result, community health service staff have begun incorporating their professional development into work with families by using mathematics games during young children's vision and hearing assessments.

2018 EI RATINGS

Engagement	Highly effective
Impact	Highly significant contribution
Approach to Impact	Effective

Studies in human society

Four core disciplines anchor the University's studies of Human Society: anthropology, human geography, political science and sociology.

Across the discipline of Human Society, Macquarie's social researchers investigate key challenges facing contemporary societies and have made significant contributions to scholarship on the state of democratic institutions and regional security threats.

Our areas of study include:

- violent extremism and the increased influence of China
- the social impact of changing economic and employment systems, most prominently ageing
- comparative social policy
- democratic cohesion, especially the effects of migration and multiculturalism
- development studies with a special focus on climate change, disaster, health, and precarity in Australia and Southeast Asia
- sustainability of cities, with a particular strength in urban politics and risk.

Four core disciplines anchor the University's studies of Human Society: anthropology, human geography, political science and sociology. Each of these subdisciplines within Human Society maintain a strong tradition of collaboration, both with other disciplines as well as external partners, including NGOs in Australia and overseas. Given the diversity of our intellectual contributions, one hallmark of Macquarie researchers in Human Society is the use of strong community links to maximise the impact of our research.

2018 ERA OUTCOMES

Studies in Human Society	3
Anthropology	4
Sociology	4
Human Geography	3
Political Science	3

Macquarie researchers within this discipline include two members of the Academy of the Social Sciences in Australia, one member of the Australian Academy of Technological Sciences and Engineering, three members of the Australian Institute of Aboriginal and Torres Strait Islander Studies, and two members of the ARC College of Experts. Researchers at Macquarie have consistently played important roles in maintaining the integrity, efficacy and capacity of the discipline through a range of service roles in ARC and international grant reviewing, editing and refereeing for outstanding publishing houses and journals. We have also contributed through discipline organisations and internal service in university ethics review, research training and research governance.

Staff and students received numerous accolades for their research, including internal recognition for community engagement and a Vice-Chancellor's Commendation for excellence in research supervision. Our research has also earned external awards, such as a 2011 Endeavour Award Scholarship, a Carson Fellowship, an Office for Learning and Teaching Fellowship for pedagogical research, and multiple book prizes, including from the Australian and New Zealand Society of Criminology.



INDIGENOUS RESEARCH COLLABORATION

Our projects with Australian Indigenous communities include the Bawaka Collective, a long-term research collaboration with the Burarrwanga family from Bawaka homeland. In addition to 24 articles, many co-authored with Indigenous collaborators, the Collective also produced the book *Welcome to My Country*. The book was nominated by the Children's Book Council of Australia, resulting in all libraries in Australia buying a copy (2014-16). *Welcome to My Country* sold 10,000 copies, generating more than \$10,000 in royalties for Indigenous collaborators. This book is used in many schools in New South Wales to support the teaching of mathematics and Human Society and its Environment, and content has been incorporated into the new Australian curriculum. The Collective ran a workshop at the Garma Festival in 2016. Macquarie has awarded an honorary doctorate to one of the Indigenous collaborators, Laklak Burarrwanga, in recognition of her knowledge and leadership. The Bawaka Collective has been singled out internationally as a leading example of de-colonising research practice and community engagement, particularly for jointly publishing with Bawaka Country as kin.

Other research-related engagement with Indigenous communities includes collaborating with Mudjee Local Aboriginal Land Council and convening the Indigenous Peoples' Knowledges and Rights Study Group.

SOCIAL POLICY ON AGED CARE

Macquarie researchers have substantial engagement with providers and policymakers in aged care, especially around issues of privatisation, quality assurance, and superannuation policy. Researchers were awarded an ARC Linkage Project grants with Baptist Care, the Whiddon Group, KinCare, and Community Options Australia, and convened the Paid Care Research Network, which included researchers from relevant trade unions.

Macquarie produced the Australian Community Care Outcomes Measurement tool, applied by four community aged care services in New South Wales during 2016. It was later adopted in Queensland. The long-term implications of privatisation of aged care and superannuation require international comparison and collaborative analysis, and our international engagement includes reports and presentations on elder care in the Nordic countries and on retirement incomes in New Zealand.

SECURITY AND COUNTER-TERRORISM

We have significant engagement with law enforcement and policymakers in Australia and internationally on a range of issues, including security among Australia's neighbours (such as the Solomon Islands), the changing role of China in the region, money laundering, cryptomarkets and the rise of and response to violent extremism.

Macquarie research has especially influenced policymakers in the area of countering violent extremism (CVE), such as through Australia's first CVE symposium in 2014, co-sponsored by the Australian Government Attorney-General's Department, NSW Counter Terrorism & Special Tactics Command, NSW Police, and Multicultural NSW, among others.

Projects funded by the NSW Government (2015) and ARC (on online radicalisation, 2016) led to the establishment of an \$8 million CVE program in New South Wales. In addition, other staff members have been involved in applied research on the financing of terrorism and founding the Cryptomarkets Research Hub, a multinational and interdisciplinary research network.

FURTHER ENGAGEMENT ACROSS STUDIES IN HUMAN SOCIETIES

Macquarie researchers have worked with endusers to produce reports and presentations on climate change, policing, housing, infectious disease, food production, public opinion about migration, disasters and resilience, welfare, and multiculturalism in 'super-diverse' societies, as well as producing major resources for professional training in social impact assessment and human research ethics.

Reducing infectious disease risk among marginalised groups in Southeast Asia

The impact of Macquarie's research on the health security of marginal populations in mainland Southeast Asia has been sustained across multiple projects over many

years. Macquarie's Professor Chris Lyttleton has been regularly employed by the ADB and have also contributed, through contracted research reports, to programs focused on reducing vulnerability to HIV and malaria in border zones and areas of infrastructure development in the Greater Mekong Subregion (GMS).

His research findings have been integrated into decision making, funding, development assistance and regional projects funded by the ADB and have also contributed, through contracted research reports, to Government Department of Foreign Affairs and Trade strategies for improving Australia's contribution to global health.



Macquarie's contributions to the activities of the ADB in the GMS, which include Lao PDR, Vietnam, Cambodia, Myanmar, Thailand, and Yunnan Province and Guangxi Zhuang Autonomous Region of the People's Republic of China, have been manifest across multiple projects through the contract services of Professor Lyttleton. These projects focus on reducing vulnerability to HIV and malaria infection in border zones and areas of infrastructure development.

HIV PREVENTION

Throughout 2011–16, Lyttleton worked closely with the ADB and the Australian Government. For the ADB, Lyttleton was contracted to two projects. The first, HIV Prevention and Infrastructure: Mitigating Risk in the Greater Mekong Subregion, was funded by \$6 million from the Australian Government and ran from 2009 to 2014. The project's activities supported HIV prevention in ADB-financed infrastructure projects in Cambodia, Lao PDR and Vietnam. Lyttleton's input drew on an earlier study for the ADB and on research funded under the Australian Development Research

Awards Scheme (ADRAS). The ADRAS work overlapped this contract, which allowed his findings to be directly integrated into the ADB project activities.

Lyttleton's research enabled him to provide recommendations to NGOs and national monitoring and evaluation specialists, implementing sub-projects working with vulnerable groups near economic corridors in border zones. These included appropriate community outreach and culturally sensitive information, education and communication campaigns. Together, these components made HIV mitigation more effective across the GMS. In 2013–14, Lyttleton was part of an ADB team that designed a \$10 million HIV project in Myanmar and, in 2012, secured a \$20 million combined loan and grant to build capacity for HIV projects in border areas of Laos and Vietnam.

Professor Lyttleton was tasked with data analysis of existing sector and national strategies to identify information gaps relating to understanding the risk dynamics of HIV in the context of greater connectivity and mobility in the GMS. Findings were tabled at annual forums hosted by the ADB and the Joint United Nations Initiative on Migration, Health and HIV in Asia (JUNIMA). In 2013, the ADB distributed media material containing case studies written by Lyttleton demonstrating effective mitigation approaches.

In 2011, health ministries of the six GMS countries signed a regional memorandum of understanding (MOU) for Joint Action to Reduce HIV Vulnerability Related to Population Movement in the GMS.

Macquarie actively supports the travel needs of its researchers to help ensure that research is grounded in empirical fieldwork and community engagement. Macquarie facilitated Professor Lyttleton's work in the GMS through periods of research leave, especially with flexibility around teaching, service, and engagement activities. Innovative teaching arrangements and support for research release provides our academics with time for research and consultancy.

Lyttleton was a key member of the ADB team facilitating its ratification, and he was co-convenor for a workshop held in Yangon in 2012 that developed an action plan attached to this MOU. Between 2011 and 2014, Lyttleton also assisted in convening annual GMS forums run by the ADB and JUNIMA that focused on HIV and infrastructure development and allowed

national governments to share advances made in the prevention of HIV transmission along economic corridors.

Further impact of Lyttleton's work in this area was as a research consultant to AusAID. In 2011, he prepared a situational analysis of HIV in Lao PDR, which was used, together with other country analyses, by the Australian Government to advise donors, governments and their partners on opportunities and priorities for financing, policy, programming and partnerships. In 2014, he was part of team that prepared a concept note and design blueprint for the next phase of HIV funding, anticipated in 2014 at \$10 million, to Indonesia. Both these consultancy reports entailed recommendations for improving Australia's contribution to global health.

MALARIA ERADICATION

Malaria and Communicable Diseases Control in the Greater Mekong Subregion was the second ADB project, which began in 2016, to which Lyttleton was contracted. In late 2014, he took part in multicountry consultation and planning for this project and an associated health security initiative that led to a \$4 million investment in anti-malaria projects in Cambodia, Lao PDR and Myanmar.

His role was as a migrant and mobile populations specialist for three subprojects seeking to control the spread of drug-resistant malaria. His expertise builds on research into malaria risk funded by Macquarie in 2014–15. As with prior work with the ADB, he was contracted to review the subprojects implemented by NGOs hired by the ADB and provide recommendations for project activities, as well as to assist and co-convene higher-level workshops and think tanks on migrants, malaria and health security.

The impact of Lyttleton's work has been far-reaching, contributing to the health security of vulnerable populations across the GMS. His recommendations and reviews draw on his fine-grained knowledge of local communities, gained through ethnographic research at community level, providing empirical data that supports the development of effective health programs. Lyttleton's work at Macquarie during this period has thus had impact on the allocation of approximately \$25 million in project funding across Southeast Asia and created concrete benefits in the lives of thousands of people living and working in the region.

2018 EI RATINGS

Engagement	Highly effective
Impact	Significant contribution

Psychology and cognitive sciences

The University's Department of Cognitive Science and the Department of Psychology are world leaders in the interdisciplinary study of the human mind and the brain.

The University's Department of Cognitive Science and the Department of Psychology are world leaders in the interdisciplinary study of the human mind and the brain. Our innovative and translational research is conducted through partnerships and collaborations across the University and throughout the community. Our success over the past six years is testament to our interdisciplinary approach, with Psychology and Cognitive Science researchers receiving three Laureate Fellowships, six Future Fellowships, nine ARC Queen Elizabeth II Fellowships/Australian Research Fellowships, eight ARC Discovery Early Career Researcher Awards, five National Health and Medical Research Council (NHMRC) Early Career Fellowships and one NHMRC-ARC Dementia Fellowship.

Our departments have assembled one of the largest collections of brain and behaviour research facilities in the country, since establishing the ARC Centre of Excellence in Cognition and its Disorders in 2011 and hosting it through to completion in 2018.

The world-class technology housed within the University – readily available to scientists – includes three bespoke magnetoencephalography (MEG) machines, functional near-infrared spectroscopy, transcranial magnetic stimulation, event-related potentials and electroencephalography, eye-tracking, and virtual reality technology.

The discoveries made through these technologies are translated directly into practice via an array of university clinics and clinical partners on campus. For example, the Macquarie University Reading Clinic, which supports the community via 2000 individually tailored treatment sessions per year, has benefited from discoveries through our eye-tracking technology.

Our MEG facility, established in 2012 with \$40 million awarded by the Department of Education and Training, has facilitated opportunities for Macquarie research centres and teams; government research organisations such as the National Acoustics Laboratories, leading Australian companies, for example Cochlear; and NGOs including the Sydney Cochlear Implant Centre, a service of the Royal Institute for Deaf and Blind Children.

In 2013, Macquarie also invested \$3 million in a new Simulation Hub, the only facility of its type in the world, which co-locates a range of simulation devices to enable applied research.

Macquarie has made sustained strategic investment in Psychology and Cognitive Science through national, university, and faculty research centres. At the national level, we have facilitated the development of the Department of Health-funded MindSpot Clinic, Australia's first free national online mental health clinic. At the University level, we host four of the University's largest clinics: the Centre for Emotional Health Clinic, the Macquarie University Reading Clinic, the eCentreClinic and the Macquarie Psychology Clinic. We also lead the Centre for Elite Performance, Expertise and Training and the new Macquarie University Centre for Reading. At the faculty level, Psychology and Cognitive Science host the Perception in Action Research Centre and the Centre for Atypical Neurodevelopment.



COMMUNITY CLINICS

Macquarie's Department of Cognitive Science and the Department of Psychology have five established community clinics, which have delivered assessment and treatment services to more than 75,000 community members. With more than 85 full-time professional staff delivering services for mental health, learning disorders and employment services, often for free or at a reduced fee, our clinics also have more than 43 research collaborations with community, government, and industry partners to translate research knowledge, methods and resources to better support consumers nationally and internationally.

Members of our clinics have delivered public talks and professional development programs to more than 2200 clinicians, teachers and consumers to aid translation of research findings. They also have a large following on digital media with in excess of 27,000 Facebook followers combined; the MindSpot Clinic and the eCentreClinic have more than 1.5 million website hits combined. This level of clinical engagement and service is rare in the university context, not only in Australia but around the world.

More about the five Macquarie University clinics:

1. The Centre for Emotional Health applies Macquarie research discoveries on the causes, treatment and prevention of anxiety and related mental health problems across the life span. In conjunction with users, the centre develops and trials Macquarie research-informed evidence-based assessment tools and interventions, which are delivered to the public both online and face-to-face via the distribution of clinic-developed therapy resources. To date, research from the centre has informed more than 11,000 therapist manuals and self-help books internationally. Furthermore, the centre has run professional development sessions onsite for 750 clinicians and offsite at 35 organisations nationally, as well as many more internationally. The centre has also actively engaged the community through a series of more than 700 public talks and trained more than 60 future clinicians.
2. The eCentreClinic is responsible for the development and evaluation of state-of-the-art online treatment courses for people with common mental health and chronic physical health conditions. As of 2016, it has conducted more than 15 large clinical trials to achieve this. The effective interventions that have been developed through the clinic

have now been translated to MindSpot, an online assessment and treatment tool for anxiety and depression that delivers these programs to Australians for free and continues to be enhanced through cycles of research development and translation.

3. The MindSpot Clinic – a free telephone and online service for Australians with stress, worry, anxiety, low mood or depression – received \$23 million during 2014–16 from the Australian Government Department of Health to deliver free internet-based mental health services for Australian adults. In this time, it received in excess of 1.4 million website hits for its online services, which include screening assessments and psychological treatments developed in the eCentreClinic that also integrate with local health services.
4. The Macquarie Psychology Clinic provides a wide range of evidence-based services to the community, including psychological therapy, psychometric and neuropsychological assessment, and career counselling. During 2014–16, the clinic provided more than 6200 consults for community members. The clinic has also trained 225 future clinical psychologists, neuropsychologists and organisational psychologists, and created a new generation of practitioners conversant with and interested in research with the prospect of becoming future research partners.
5. The newly developed Macquarie University Reading Clinic offers research-informed evidence-based assessments, either face-to-face or via live streaming, and interventions to clients. The clinic grew rapidly during 2014–16, with a fourfold increase seen in delivered interventions, as well as a fivefold increase in formal training programs for Macquarie-developed assessment and interventions for people with reading and spelling difficulties.

Children's emotional health and the Cool Kids suite

The Cool Kids suite of programs, developed by researchers at Macquarie, has improved the mental health of thousands of children in Australia and across the world. These programs arose from our researchers' vision to build an emotionally healthy community through science and practice. Translating scientific evidence into applied materials to change the way clinicians treat young people with anxiety disorders, Cool Kids has also pioneered treatment services for young people in remote areas and is now accessed across the world. The Cool Kids suite operates at the interface of research and practice, directly translating research into benefits for children, parents, clinicians, schools and teachers. Children that go through the programs show positive mental health outcomes and improved quality of life with reduced rates of anxiety and depression that are sustained.

Using an interdisciplinary approach, our researchers have developed a suite of structured, skills-based psychological therapy programs to teach children, adolescents and parents how to treat anxiety.

The Cool Kids programs include:

- self-help books for parents and families to treat their anxious child on their own
- online therapy programs, supported by calls from a therapist, that participants can complete
- therapy manuals for clinicians and teachers that detail, step by step, how to treat child and adolescent anxiety using best practice
- face-to-face and online programs to train clinicians and teachers how to use the resources and conduct evidence-based assessment of child anxiety.

The suite is available for children from preschool age through to adolescence, with adaptations for school-based delivery and specialist populations (eg autistic, depressed, and victimised young people), and is available in online, work-at-home and face-to-face formats. All the Cool Kids programs and adaptations are evidence-based, having been developed through efficacy and effectiveness clinical trials, and are continually being refined based on research and clinical outcomes.

2018 ERA OUTCOMES

Psychology and Cognitive Sciences	3
Psychology	3

2018 EI RATINGS

Engagement	Highly effective
Impact	Significant contribution
Approach to Impact	Highly effective



GLOBAL IMPACT

The Cool Kids suite was the first program in the world to deliver an anxiety program for children with a family-based approach involving parents as well as their children. This subsequently became widespread practice in public mental health services in Australia. The program was also the first in the world to deliver treatment by distance care to anxious young people. Originally, delivery by telephone serviced remote and rural Australians; in 2006, Cool Kids was delivered on CD-ROM. By 2016, the programs were available through internet browsers, becoming the world's first online, comprehensive clinical service for anxious young people. Public mental health services in the United Kingdom used the CD-ROM, and the online program is currently being trialled in the United Kingdom, the United States and the Netherlands.

Clinicians can also follow the structured program to ensure treatment effectiveness by accessing the Cool Kids therapy manuals. This structured approach to treatment has impacted the way in which treatment

is delivered and ensures evidence-based techniques are effectively delivered to children and families. By the end of 2016, the Cool Kids suite of books and therapy manuals had been translated into 15 languages and were used in 24 countries.

Importantly, the Cool Kids suite has had a significant impact on mental health assessment guidelines across Australia. The ways in which anxiety disorders are diagnosed in children and teenagers have been informed by research and outcomes. In fact, our researchers have published clinical guidelines based on the Cool Kids suite findings. These findings have informed international bodies such as the American Psychiatric Association, which used the findings to revise the *Diagnostic and Statistical Manual of Mental Disorders (DSM-5)* and NICE guidelines in the United States.

AUSTRALIAN IMPACT

Tens of thousands of children have received mental health care through the Cool Kids programs, including through private clinics, public services and schools that use Cool Kids resources and therapy manuals. During 2011–16, Macquarie clinicians treated more than 1250 Australian children. During the same period, we have sold more than 5000 manuals and 20,000 workbooks to Australian professionals to deliver treatment in public mental health services such as Headspace, which provides child and young people mental health services in primary and high schools, and psychological practice settings across Australia.

To increase impact, our clinic programs are subsidised through Medicare. We also offer Rotary Australia grants-in-aid to disadvantaged families, and we have supplied our services using postgraduate clinical psychology interns.

Macquarie has provided targeted financial and in-kind support for the ongoing development and impact of Cool Kids mental health programs. Support includes funding the creation of electronic care resources such as CD-ROMs and online programs as well as backing on-campus clinics in their delivery and refinement of the Cool Kids suite.

In consultation with the NSW Education Standards Authority, the developers of the Cool Kids suite have provided evidence-based information to inform the development of new disability provisions, implemented in 2018, for anxious and depressed students requesting special examination provisions for the Higher School Certificate. More widely, public mental health services have changed their practices to implement internet therapy, group-based therapy and stepped-care therapy for child anxiety using the Cool Kids suite.

TRAINING CLINICIANS AND STUDENTS

The Cool Kids programs have also become a core part of clinical training for mental health practitioners specialising in assessing and treating child and adolescent anxiety. From 2011 to 2016, 112 postgraduate clinical psychology interns completed formal training on the Cool Kids suite through Macquarie. Cool Kids has formed part of the training of intern psychologists from the universities of Wollongong, Newcastle, Western Sydney and, more recently, Tasmania and Canberra, and from the Australian College of Applied Psychology. In addition, around 1500 clinicians and school teachers have completed training in the Cool Kids suite nationally, and hundreds more internationally. Since 2016, professional training has been offered online to ensure outreach to distant and rural practitioners.

LEFT:

Image courtesy of the Centre for Emotional Health. Photo by Chris Stacey

Law and legal studies

Research in Law and Legal Studies at Macquarie has a long tradition of fostering interdisciplinary approaches to the law, promoting social justice in the broadest sense and extending the boundaries of the discipline of law. Macquarie conducts multicontextual, cross-disciplinary, trans-jurisdictional

and collaborative approaches to the law and its social, environmental and regulatory dimensions both in Australia and internationally. These approaches are focused on the theoretical and practical foundations of legal and governance structures, including human rights regimes and other mechanisms of global regulation. This research informs and critiques legal and public policy debates, with emphasis on disadvantage and historical injustice. Many of Macquarie's research outputs reflect a longstanding commitment to legal scholarship that emphasises law in context. A significant proportion of this scholarship is inherently international and comparative in nature and is published in esteemed international journals.

In the broad discipline of international law, Macquarie has recognised research strengths in:

- international economic and trade law
- international and comparative intellectual property law
- international human rights law
- non-discrimination law
- international dispute settlement
- refugee law
- marine security
- gender
- law of the sea.

Our historical strength in social justice issues has also found recent research expression in issues of technology law, data protection, privacy, healthcare and aged care.

In these areas, we have secured competitive external funding, including ARC funding. There is an associated area of research concentration in environmental law, some of which is focused internationally, while the remainder has a more domestic application in the context of local government and environmental planning. This research is supported by the Faculty of Arts Centre for Environmental Law located within the Macquarie Law School, which has established particularly strong research links with Bangladesh and Indonesia. Our historical strength in social justice issues has also found recent research expression in issues of technology law, data protection, privacy, healthcare and aged care.

Three members of the Law School have been recognised for their research excellence through invitations to become fellows of the Australian Academy of Law, and one professor is a current fellow. One Macquarie professor was also a member of the ARC College of Experts, 2016–2018. Other scholars serve as experts on international law bodies.

Our researchers have been appointed the advisory committees of the Australian Law Reform Commission (ALRC) to help guide the research and test the reform recommendations on the following inquiries: Freedoms Inquiry, Age Barriers to Work, and Family Violence and Commonwealth Laws. Law researchers have also contributed to public inquiries undertaken by the NSW Law Reform Commission, the Productivity Commission, the Senate Standing Committees on Legal and Constitutional Affairs, and the NSW Legislative Council Select Committee, and to reviews conducted by the Australian Government Attorney-General's Department. One researcher is the co-founder of the Australian Research Network on Law and Ageing, which has made significant contributions to national and state law reform inquiries on elder abuse, housing and guardianship.

2018 ERA OUTCOMES

Law and Legal Studies	3
Law	3



LAW REFORM

The involvement of legal scholars at Macquarie with the ALRC has influenced the national reform agenda. A history of staff movement between the two institutions has facilitated the transfer of knowledge for mutual benefit. Two past researchers and one current researcher in the Macquarie Law School were previously employed at the ALRC, and Emeritus Professor Rosalind Croucher AM, who holds an honorary appointment in the Law School, was the president of the ALRC from 2009 to 2017. She brought her research expertise in family law and health law to ALRC inquiries, including inquiries into elder abuse, family violence, and equality, capacity and disability. Macquarie has provided advice in the area of rights, with an appointment to the advisory committee for the ALRC's Traditional Rights and Freedoms—Encroachments by Commonwealth Law in 2015. Macquarie provided substantial advice on draft chapters of the final report of the inquiry.

ENVIRONMENTAL LAW AND LAW OF THE SEA

Research in environmental law and international law of the sea, including oceans governance, have been cornerstones of law at Macquarie. Macquarie was actively involved in the work of the Deep Ocean Stewardship Initiative, which is a network of scientists and law and policy experts who advise on strategies to maintain the integrity of deep-ocean ecosystems. In this capacity, Macquarie provided advice to the International Seabed Authority (ISA) and national governments, chiefly Australian and German. Macquarie significantly contributed to a submission to the ISA regarding the content of the ISA's future mining regulations, co-authored with an international team of marine biologists, ecologists and legal experts. A Macquarie legal scholar participated in the ISA's annual meeting of States Parties in 2016. Macquarie also has a longstanding history of engagement regarding law of the sea matters with bodies such as the Department of Foreign Affairs and Trade (in 2016), the Attorney-General's Department (in 2015), the Korean Consulate General (in 2015), and the Korean Ministry of Foreign Affairs (in 2014).

Environmental law researchers at Macquarie have also contributed to development and capacity building in Southeast Asia. The Centre for Environmental Law (CEL) hosted capacity-building projects for the Bangladesh Government in 2014, 2015 and 2016. Macquarie law researchers participated in the delivery of these programs, which focused on the implementation of international treaty obligations, sustainable development and good governance. These programs were informed by research undertaken by members of CEL in the areas of sustainable development, free trade and international environmental law. Another Macquarie researcher contributed to four UN climate change reports in 2016, providing technical reviews of the second biennial reports of Finland, Latvia, Slovakia and the European Union.

HUMAN RIGHTS AND SOCIAL JUSTICE

Other Macquarie law researchers have used their research in human rights and social justice to benefit end users in areas such as elder abuse, child sexual abuse and gender equality. For instance, in 2014 and 2016, two researchers made substantial contributions to four inquiries on the topic of elder abuse, housing and guardianship. Two of these submissions were made individually and two were made jointly with members of the Australian Research Network on Law and Ageing. The network itself was co-founded by one of the two Macquarie researchers. One researcher was awarded a contract for research (\$47,448) by the Royal Commission into Institutional Responses to Child Sexual Abuse. This research resulted in a 2016 report published by the Royal Commission.

ABOVE:

Macquarie's research has focused on law of the sea. Photo by Rob Harcourt.

Economically empowering Pacific women

LAW REFORM AND POLICY DEVELOPMENT TO INCREASE WOMEN'S PARTICIPATION IN THE PRIVATE SECTOR

Macquarie's research activities have improved the ability of Pacific women to engage in business activities through supporting law reform in the Solomon Islands and Papua New Guinea (PNG). Its research has been used by both the Department of Foreign Affairs and Trade (DFAT) and the South Pacific Stock Exchange in Fiji to develop legal, regulatory and workplace practices that remove barriers and provide support to women in business. Macquarie has partnered with institutions in Tonga and Fiji to increase the representation of women in senior positions and corporate boards. It has published reports that have changed discourse among civil society organisations such as the International Women's Development Agency (IWDA) and the NSW Council of Social Service.

The research of Macquarie's Professor Vijaya Nagarajan has improved Pacific women's ability to engage in business activities and influenced the way the Australian and Pacific governments respond to the legal, social and institutional constraints faced by Pacific women.

Macquarie's impact has resulted from close working relationships with Pacific governments. These relationships developed from a network of engagement involving consultations with community and practice groups, coupled with end-user research contracts and research consultancy. As Professor Nagarajan's research translation matured, Macquarie assisted by facilitating her co-appointment with the Asian Development Bank.

The beneficiaries of the research have been Pacific governments, particularly of the Solomon Islands and PNG, as well as DFAT, other civil society institutions, women entrepreneurs and consumers, the Pacific business community and other researchers.

The economic impact of the research has been to provide greater opportunities for women to engage in business

through working with institutions to create a women-friendly regulatory environment. The social impact of Macquarie's research, through contributions to seven institutional reports and 10 invitations to present at international meetings of civil society and multilateral donor bodies, demonstrates considerable levels of awareness and engagement with the research.

Macquarie has assisted many Pacific governments to reform discriminatory laws and develop inclusive policies. Working with the Pacific Private Sector Development

Initiative of the Asian Development Bank, Macquarie proposed several reforms to discriminatory laws that limited women's entrepreneurship. One such reform, adopted in 2014, was an amendment to the *Business Names Act* in the Solomon Islands that removed the need for women to supply the names of husbands or fathers when registering a business. The impact of the reform saw a 63 per cent increase in the number of female-owned businesses in 2016, compared to an increase of 40 per cent in male-owned businesses.

Another significant reform was the introduction of the electronic online business registration system in Tonga, which allowed women to start a company online. There has been a steady increase in the number of women shareholders, reaching 29 per cent in 2016, which can be attributed to these reforms.

In PNG, Macquarie worked with a group of competition law experts on a review of the consumer and competition framework. The focus was on improving women's access to markets for goods and services and their ability to access complaints mechanisms. This impacts on the continuing review of consumer and competition policy by the PNG Department of Treasury.

Macquarie has advised DFAT and the South Pacific Stock Exchange of Fiji on ways to improve women's participation in the formal and informal economies of the private sector.



2018 EI RATINGS

Engagement	Effective
Impact	Significant contribution
Approach to Impact	Effective

Macquarie was invited to prepare a paper on the regulatory options for increasing the presence of women on corporate boards, which was considered and endorsed by the South Pacific Stock Exchange Board in December 2016. The beneficiaries of this reform will be businesswomen, the stock exchange and the wider business community. Macquarie was invited to draft a paper on the role of women in the informal economy in the Pacific, which was presented at the Pacific Women's Parliamentary Partnerships Forum, Apia, Samoa, on 4 April 2016. The presentation was reported in Samoan newspapers, increasing its impact.

Macquarie has worked with Pacific institutions to implement leadership programs to advance women economically. In 2014, Macquarie worked with the Solomon Islands Chamber of Commerce and Industry to develop a corporate governance training program specifically for women. It was undertaken by more than 30 women and resulted in changing institutional practice. One participant, who was the deputy registrar of Company Haus, has incorporated aspects of this training into her institution's practice, which will benefit women seeking to start a business.

In Tonga and Fiji, Macquarie introduced a program to increase the representation of women in senior management roles on corporate boards (Tonga, 2015; Fiji, 2016).

This included using a range of regulatory strategies, such as increasing women's knowledge of corporate governance and risk management, using senior men as male champions of gender equality and using mentoring as a way of improving women's networks. The program was reported widely and led to invitations to replicate the program in other countries, which is underway.

Macquarie has been a contributor to six institutional reports on how challenges faced by Pacific women seeking to engage in business activities may be addressed. These reports have been cited by other institutions including IWDA, Radio Australia, Fiji Sun, the Asian Development Bank, the Coral Triangle Knowledge Network and the International Finance Corporation.

Macquarie has published the research undertaken in the form of three refereed articles and a book chapter, which have informed scholars involved in Pacific work. These publications have led to invitations from multilateral banks and civil society and academic institutions to share best practice and findings, which continues to impact on the development of scholarship and institutional practice.

ABOVE:
Professor Vijaya Nagarajan.
Photo by Joanne Stephan.

Studies in creative arts and writing

Research in Creative Arts and Writing at Macquarie is concentrated in film, television and digital media, and performing arts and creative writing. In addition to researchers in media, music, performance and English, researchers in cultural studies, communication, and philosophy are active contributors, reflecting the strong interdisciplinary focus of creative arts research. The strength of research in these fields at Macquarie is evident in ARC funding awarded to key

researchers, prestigious fellowships, awards and nominations, the selection of works for significant national and international festivals, and venues and partnerships with external arts and cultural organisations.

Film, television and digital media is characterised by strengths in documentary and non-fiction media, screen media, mediated performance and the impact of new technologies on creative practice. Research in performing arts and creative writing is distinguished by research on intercultural contexts, new technologies in music, and writing about place.

A distinctive feature is the close set of relationships between traditional scholarly outputs and creative outputs, reflecting a commitment to both contextualising and

theorising creative arts practices and a drive to explore multiple research methodologies and modes of knowledge production. Creative arts research is often highly applied, and researchers aim to develop strong relationships with external partners.

Macquarie's researchers were awarded the Ned Kelly Lifetime Achievement Award for Crime Writing, an ARIA Award, the Best Feature Documentary at the Antennae Documentary Film Festival and the Best Short Fiction at the Australian Teachers of Media (ATOM) Awards. We also received nominations for the Australian Writers' Guild Awards and the NSW Premier's Literary Awards. Researchers have served on editorial or advisory boards of leading journals, edited book series, and reference works from respected publishers. Numerous researchers have also served as assessors for arts funding agencies and awards including Screen Australia, Screen NSW, the Australia Council for the Arts, Create NSW, and the Man Asian Literary Prize.

2018 ERA OUTCOMES

Studies in Creative Arts and Writing	3
Film, Television and Digital Media	3
Performing Arts and Creative Writing	3



ENGAGEMENT

Macquarie research outputs reached a range of audiences via live performances, broadcasts, screenings, publications, downloads, and public talks and lectures, thus making a significant contribution to Australia's intellectual and cultural life.

An exemplar project is *Pulp Confidential*, a curated exhibition of works from the 1940s and '50s that the Sydney publishing industry delivered in partnership with the State Library of New South Wales. The exhibition received 46,208 visitors and included extensive media coverage across print, radio, television and online, with more than 182 individual media mentions. Combined coverage reached an audience of 1.8 million people nationwide. Twitter engagement reached an audience of 980,000 people and the State Library of New South Wales. Facebook activity reached 170,919 people and created 241,910 impressions.

A suite of films – including *Shock Room*, *In My Father's Country*, *Woman with an Editing Bench*, *Mortars*, and *The Boot Cake* – reached audiences via event screenings at venues including the Antennae Documentary Festival, the Australian Centre for the Moving Image (ACMI), the Powerhouse Museum, the Riverside Theatres, the Jakarta International Documentary and Experimental Film Festival, and the Cineteca di Bologna as well as being broadcast on National Indigenous Television. Their contribution to innovation in the screen industries was acknowledged in awards and nominations from ATOM, the Australian Writers' Guild, the Australian Screen Editors' Guild and the Antennae Documentary Festival.

Performance project *Robot Opera* used eight purpose-built automatons to explore our interactions with technology in the fields of art and entertainment. A research partnership between Macquarie and Performance Space, *Robot Opera* was presented at Carriageworks as part of the Liveworks Festival of Experimental Art and subsequently toured to Taiwan.

ABOVE:
Photo by Chris Stacey.

Researchers in this field have ongoing commercial contracts for the production and dissemination of research outputs with screen distribution companies, non-academic commercial book and journal publishers, music and audio publishers and media streaming sites. These include Kanopy, CAT&Docs, Fandor, Beamafilm, Goodship, Alexander Street Press, Apple Music, Spotify, and Soundcloud while publishers include Picador, Granta and Griffith Review. A significant proportion of the research produced is accessible to audiences without paywalls via online streaming services and local libraries as part of Macquarie's commitment to community and intellectual access.

A number of scholars worked with partners to benefit creator communities. For example, Macquarie researchers led an ARC Linkage Project (from 2015) investigating how communities in Melanesia mobilise through the integration of digital media, mobile phones and music. In collaboration with community organisations, the research tested innovative models of building communities through music and stimulating income for musicians. Other projects involved partnerships with organisations within the Macquarie Park Innovation District such as the City of Ryde and the Salvation Army, drawing on creative arts researchers' work to build local communities.

Macquarie researchers were members of funding selection, arts advisory and award panels including the Australia Council for the Arts, Create NSW, the NSW Writer's Fellowship and the United Nations Association of Australia Media Awards.

Scholars held positions on the boards of the arts organisations Music NSW, ReadyMade Works and Music Australia. We also provided expert evidence to the 2016 Independent Liquor Law Review on the impact of lockout laws on live music venues in New South Wales. Researchers provided advice to arts organisations and community-based groups in Australia and the Pacific including the City of Sydney, the Biennale of Sydney, the Indigenous Collaboration Film Advisory Resource Project, Riverside Theatres, the Blacktown Arts Centre and the National Circus School in Montreal.

Shock Room

Shock Room (2015) is a feature documentary film re-examining psychologist Stanley Milgram's influential Obedience to Authority experiments. One of the most difficult dilemmas we can face is having to respond to directions that go against our conscience. In the early 1960s, Milgram ran a series of experiments that seemed to show that most of us would comply with such directions. This cross-disciplinary project restaged and re-examined Milgram's experiments. *Shock Room* – which has been shown worldwide via public screenings and discussions at museums, cinemas, universities, academic conferences and online streaming – has had a far-reaching impact on our understanding of Milgram's obedience paradigm and the circumstances that lead people to resist harmful orders.



The result of a long-term collaboration between Creative Arts and Psychology, *Shock Room* was the major output of a project led by Professor Kathryn Millard with partner investigator Professor Stephen Reicher (Psychology, St Andrews) and with input from Professor Alex Haslam (Psychology, Queensland).

Stanley Milgram's Obedience to Authority experiments have been influential in many fields including psychology, sociology, legal studies, history, philosophy, ethics, the creative arts and management studies. While there is considerable ongoing interest in Milgram's studies, for ethical reasons it is not possible to restage them with randomly selected participants. This makes it difficult to challenge his original findings. By showing versions of Milgram's experiments that had not been filmed before, *Shock Room* contributes to ongoing international debates about them. This research demonstrates that firstly, many of the experiments contained as much evidence of resistance as obedience; secondly, that the relationship between participants might better be described as a partnership based on shared goals; and thirdly, that the experiments were as much art as science.

ABOVE:
Milgram's Shock Machine

Macquarie creates pathways for engagement with industry and end users through flexible intellectual property arrangements coupled with substantial investment in industry-standard creative production facilities and the employment of technical personnel who support research staff and higher degree research students.

The film was invited to leading venues for screenings and panel discussions, and organisers consistently commented on the audiences' robust engagement. Specific markers of impact included public screenings held by POLIN (Museum of the History of Polish Jews, Warsaw), the London School of Economics Public Lecture Programme, ACMI, the Antennae Documentary Film Festival and the Powerhouse Museum's Science Festival.

Renowned historian and broadcaster Professor Richard Overy, a panellist for the POLIN Museum screening, wrote that "Shock Room is essential viewing for everyone concerned with how humans behave when they are asked to obey a difficult order. It has a powerful message skilfully communicated – above all, that we all have a choice whether to obey or not and should recognise that hopeful reality."

Shock Room won the prestigious Best Australian Documentary Award at the 2015 Antennae Documentary Film Festival. The international jury wrote: "A riveting 70 minutes that explores the dark side of human nature ... Millard's excellent direction of dramatic re-enactments drew us into the many uncomfortable situations that put us in a position to ponder – when would we just stand up and say 'No!'"

The defence 'I was only following orders' has been used to absolve people of responsibility for their actions in a range of situations including the My Lai massacre, the Rwandan genocide, the Enron Corporation collapse, the Abu Ghraib prisoner abuse, the Deepwater Horizon oil spill and News of the World phone hacking. Macquarie's research challenges this defence and thereby assists people to deal with situations in which we are ordered to take actions that may harm others: in the military, workplace and institutional settings and the community. According to Distinguished Professor Eric Muller of the North Carolina Law School, the film has been used in programs in both the United States and Germany that teach lawyers about moral responsibilities.

Shock Room was subject to a range of peer-review processes across academia, and the screen industries and input from these processes contributed to its impact. In 2009, highly competitive script development funds were awarded by Screen NSW. In 2012, Millard's appointment as a visiting fellow in Film Studies, Yale University, was based on the project proposal and her body of work as a practice-led researcher.

After a peer-review process *Shock Room* was the first film signed by highly regarded social impact film distributor Goodship, which distributed it in Australia in partnership with Ronin Films. In 2016, *Shock Room* was accepted for international representation by one of the world's leading documentary distributors CAT&Docs based in Paris. At their request, a 52-minute version was edited for broadcast. ATOM prepared a study guide for this version of the film for educational use in psychology, media studies and ethics.

Following a preview of the film at the Canadian Institute for Advanced Research, Professor George Akerlof wrote "Shock Room is 72 minutes edge of the seat. As psychology, [it] changed my fundamental view of human nature: permanently." In a feature article for Metro, Hannah Schenkel wrote that *Shock Room* set new benchmarks in ethical documentary.

A co-authored article based on the Milgram archives research resulted in more than 100 news articles internationally. The project and its innovative methodology contributed to shifting public perceptions of Milgram's influential experiment. Audiences for public screenings included high school students, with psychology teachers commenting that the project brought contemporary ethical standards to a discussion of Milgram's paradigm while its immersive performance method brought the experiment to life, encouraging future research.

Shock Room has changed the way Milgram's obedience model is understood around the world, while also contributing to a more nuanced understanding of harmful decision making within administrative power distributions.

2018 EI RATINGS

Engagement	Effective
Impact	Significant contribution
Approach to Impact	Highly effective

Language, communications and culture

Communication and Media Studies is characterised by strengths in digital and social media studies, media history, politics and policy, and radio studies. Cultural Studies research is distinguished by critical analyses of biopolitics, social justice, equity and ethics, and race and gender. Research in Language Studies focuses on the nexus between language and culture, historical and linguistic description of languages, intercultural interactions, and cultural productions in and across languages. Linguistics includes strong concentrations of researchers on applied, functional, and experimental linguistics, with strengths in speech science, and child language acquisition. Literary Studies combines cognitive

and global approaches with strengths in medieval literature, medievalism, early modern literature, modernist literature, and children's literature, with cross-disciplinary strengths in creative writing.

Macquarie's excellence is evidenced by the central contribution of Linguistics researchers in establishing the Australian Hearing Hub (AHH) and the ARC Centre of Excellence in Cognition and its Disorders during the census period.

The AHH includes the Kanazawa Institute of

Technology – Macquarie Brain research laboratory, established to investigate language processing. This facility houses three magnetoencephalography systems, two of which are world-first systems for examining brain activity in preschool children and cochlear implant patients. Additional evidence of outstanding performance comes from ongoing recognition of the Macquarie-funded Centre for Language Sciences, an interdisciplinary group involving researchers in linguistics and computing science. Australian Government funding for the Adult Migrant English Program – Longitudinal Study ensured Macquarie's leading role in research into migration and multilingualism.

The Centre for Media History (CMH), funded by the Faculty of Arts, is the only Asia-Pacific research centre in this field and is a focus for interdisciplinary research. Its website is the central portal for all researchers in Australian media history, hosting the Australian Media History Database since 2011 and the Media Archives Project. The CMH participated in the successful bid to NeCTAR (National eResearch Collaboraton Tools and Resources) for Humanities Networked Infrastructure (HuNI): Unlocking and Uniting Australia's Cultural Data. Research-based creative practice collaborations with external partners in media studies and social media studies have been enhanced by a purpose-built Digital Newsroom, which has industry standard facilities for broadcasting, audio-visual editing and developing social media content.

The quality and the international impact of Macquarie's research is evidenced by national and international awards, including an honorary fellowship of the Library Council of NSW, the John Dunmore Medal for the advancement of French Culture, a Talkley Award, the Anne Devereaux Jordan Award for contributions to children's literature, a fellowship of the Academy of the Social Sciences in Australia, and a fellowship of the Royal Society of NSW. Macquarie outputs have also been nominated or shortlisted for the Socio-Legal Studies Association Hart Book Prize, the US Herbert Jacob Law and Society Book Prize, the British Association for Applied Linguistics Book Prize and the Walter McRae Russell Award for the Study of Australian Literature.

2018 ERA OUTCOMES

Language, Communication and Culture	4
Communication and Media Studies	4
Linguistics	4
Literary Studies	4
Cultural Studies	3
Language Studies	3



COLLABORATIVE ENGAGEMENT AND SUPPORT

Macquarie's collaborations with non-academic partners have attracted significant funding and in-kind support. The ARC Linkage Project When Science Meets Art: an Environmental Portrait of the Shoalhaven River Valley was supported by the Bundanon Trust and the Australia Council for the Arts. Projects conducted in the Hearing Cooperative Research Centre have been supported by partners including Cochlear, Australian Hearing, including its National Acoustic Laboratories, and the Royal Institute for Deaf and Blind Children. Funding for smaller projects has come from the Commonwealth Broadcasting Association, Screen Australia, the State Library of NSW, Optus, the Australian Government Attorney General's Office, and the Australian Performing Rights Association. Partners providing in-kind support include the British Library, the National Film and Sound Archive, the Copyright Agency Cultural Fund, SBS, Sky News, and the ABC (for an ARC project on the history of Radio National).

CONSULTANCIES TO CULTURAL AND PROFESSIONAL ORGANISATIONS

Macquarie researchers advise the National Rugby League on its gender education programs, sit on the Council of the National Museum of Australia, the Education and Scholarship Board of the State Library of New South Wales, and the Board of the History Council of New South Wales. Project-based consultancies were conducted in 2014–16 with several Aboriginal cultural organisations in New South Wales and Victoria and with the Australian War Memorial. Research expertise has led to invitations to judge prizes, including for the Australian Media Hall of Fame, Arts NSW, and the annual United Nations Association of Media Awards. Linguistics researchers apply their expertise to reviewing professional standards for organisations such as the National Accreditation Authority for Translators and Interpreters, and the Health Education and Training Institute.

SUBMISSIONS AND SERVICES TO GOVERNMENT

Macquarie's culturally transformative research contributed to two submissions to parliamentary reviews: one to the Senate Inquiry into Harm Being Done to Australian Children Through Access to Pornography on the Internet (March 2016), and one (emerging from ARC-funded research) to the Parliament of Queensland's Inquiry on Strategies to Prevent and Reduce Criminal Activity in Queensland (2016). The latter research, on the social reintegration of prisoners, has also featured on the Australian Policy Online database and on the website of the Sentencing Advisory Council of Victoria since 2014. Researchers in Linguistics were contracted in 2014–16 by the Australian Government Attorney-General's Department to develop the multilingual online tool LawTermFinder to explain terms in family law to non-experts. Their involvement in the Adult Migrant English Program assisted the Department of Education and Training's delivery of language and settlement skills to migrants.

MEDIA ENGAGEMENT

Engagement in cross-media research dissemination is an area of strength at Macquarie, communicating socially inclusive research to a broader public. A highly successful instance of digitally disseminated research is the sociolinguistics website Language on the Move, which showcases Macquarie's work on intercultural communication. Voted the #7 Top Language Professional blog in 2016, its posts across 2014–16 attracted 186,797 views and 14,400 Twitter followers. Professor Joseph Pugliese in 2015 co-founded the scholar-activist website Researchers Against Pacific Black Sites, an online repository of research, resources, and asylum seeker testimony, which has been archived by the National Library of Australia to ensure ongoing accessibility. Professor Catharine Lumby wrote a regular column across 2014–16 for *The Guardian*, commenting on current gender-related controversies. The monthly readership of *The Guardian* is 1.3 million.

Australian best practice for communicating goes global

In our modern, interconnected world, developments and changes in the English language happen quickly. It is very important that authorities keep on top of current trends to ensure that the language used in national and international relations, policy and law, consumer education, health and literacy is current and valid. Our researchers provide crucial evidence-based advice to authorities, both nationally and internationally, promoting valuable and harmonious communication in an array of areas. We have provided evidence-based advice to Australian authorities, including the Australian Government through the *Style Manual for Authors, Editors and Printers* of Australian Government Publications, and the language advisory body of the ABC. Our researchers have also promoted informed discussion of variations and innovations in Australian English among language professionals through style councils and national editors conferences, and with the public through the online newsletter *Australian Style*.

KEEPING AUSTRALIANS UPDATED ON LANGUAGE TRENDS

Keeping up with the organic changes in language may not seem like a big task, but they can be fast and pervasive: think of the introduction of 'selfie' in 2002 and how quickly the use of this word took hold. Australian authorities require a reliable, up-to-date, whole-of-government reference on Australian language trends and style, in order to save federal and state governments time and money in the preparation of documents and development of content for their websites.

Macquarie has had significant impact on Australian writing and publishing practices through contributions to the Australian Government Style Manual. Our research into language trends in written style, and attitudes to usage as they vary with age and education, has ensured that the Style Manual's advice is aligned with current norms. *The Cambridge Guide to Australian English Usage* (2007), also evidence-based and developed by a Macquarie researcher, serves as a companion reference on matters of expression.

Editors, journalists, English teachers and other language-focused professionals are supported through regular style councils, designed to engage with and impact on language usage in their various sectors. At the international Style Council (2011), Macquarie hosted 100 language and writing professionals from Australia and New Zealand to develop best practice for public communication on both sides of the Tasman. Our University generates discussion on current style and usage at the IPEd (Institute for Professional Editors) every two years. The University's free *Australian Style* newsletter, published online since 2008, engages with around 1200 subscribers, including English teachers and WEA (adult education) groups, by reporting new research findings on Australian usage and eliciting public feedback.

Our research also has national impact on spoken language in Australia. Our researchers have aided the ABC's Standing Committee on Spoken English, renamed ABC Language in 2015, by bringing evidence-based advice to contentious issues of usage in broadcasting. We have acted as consultants on the ABC's project to develop a single comprehensive style manual for all its media.

2018 EI RATINGS

Engagement	Highly effective
Impact	Significant contribution
Approach to Impact	Effective



IMPROVING HEALTH AND LAW LITERACY

Freely available on the internet, Macquarie's TermFinder™ termbanks are dictionary-like, multimedia, multilingual websites, offering easily understood information on technical terms for access by the general public. The termbanks are designed for those with lower reading skills, using plain language definitions, and enriched with sound recordings and graphics to provide alternative paths to understanding.

Macquarie provides advisory, financial and infrastructure support for researchers to engage with end users and maximise impact through the translation of their research. The University ensures end users can access Macquarie-authored non-traditional research outputs – encyclopedias, dictionaries and reference materials – with ease, and these outputs are publicised nationally and internationally through Macquarie's online channels.

LawTermFinder, our first termbank clarifying terms used in family law, offers plain language definitions to help people without a legal background understand technical concepts affecting their relationships, as well as citizens who have to represent themselves in court. It has been translated into a number of community languages, including Chinese, Arabic, Vietnamese, Spanish,

Korean and Turkish, to help immigrants who struggle to read English. Constructed under a series of contracts with the Attorney-General's Department, the department publicises LawTermFinder through its Family Relationships Online and Legal Aid offices and negotiated with the Australian courts to have links to the resource on their websites, too.

HealthTermFinder, our second termbank clarifying terms used in cancer medicine, provides open-access health information for patients, carers and second-language health professionals. With a focus on common types of cancer (breast, bowel, lung, liver), the platform provides accessible explanations of the core terms to enhance health literacy in the Australian community. Since its establishment in 2014, HealthTermFinder's reach has extended internationally under a 2016 agreement with medical English staff at Fudan University (Shanghai) to translate each of the current termbanks. The Chinese translations support up to 1800 medical trainees at Fudan per year and strengthens Chinese medical education, while meeting the needs of Chinese-heritage citizens and health workers in Australia.

IMPACTS ON WORLD ENGLISH

Second-language learners worldwide now have access to *The Cambridge Guide to English Usage* (2004), developed through research at Macquarie. The guide has gained global readerships in the major English-speaking countries, and through republication in Italy and India (2006) and translation into Chinese (2011). Our researchers, as part of the Varieties of English in the Indo-Pacific project endorsed by the Union Académique Internationale, have studied the use of English by multilingual speakers in transitional nations such as South Africa, Uganda, India, Sri Lanka, Singapore, the Philippines, Fiji and the Cook Islands. This research demonstrates how English takes on new cultural characteristics and social functions in post-colonial habitats, and has developed through regular meetings with our international partners in Germany, the Czech Republic and Belgium at the World Humanities Conference.

ABOVE:

Emeritus Professor Pam Peters.
Photo by Effy Alexakis Photowrite.

History and archaeology

The scope of research in History and Archaeology at Macquarie is unique in Australia. Temporally, the research spans from the Big Bang and prehistory, through ancient and premodern civilisations to the medieval, early modern, modern and postmodern world. Spatially, our interests cover the globe with a special focus on Europe, Eurasia, Australia, the South Pacific and North America. Our methodological practices are diverse, using a wide range of archival and archaeological materials, with varying analytical approaches.

Macquarie has an international reputation in the application of transdisciplinary approaches to the past. The Macquarie Ancient Cultures Research Centre is a concentration of excellence that addresses issues of cultural development and interaction across the ancient Mediterranean and Eurasia. Further, the Centre for Media History and the Centre for Applied History draw scholars from several disciplines to their research focal points, while the world-leading Big History Institute fosters a highly original approach to world history.

Thematically, the discipline has established strengths in the broad fields of economic, labour, social, cultural, political and diplomatic history. Subsets within these areas include gender and sexuality, biography and life history, popular culture and sport, media, war and conflict, religion and society, communication networks, social complexity, historical sociolinguistics, and environmental history.

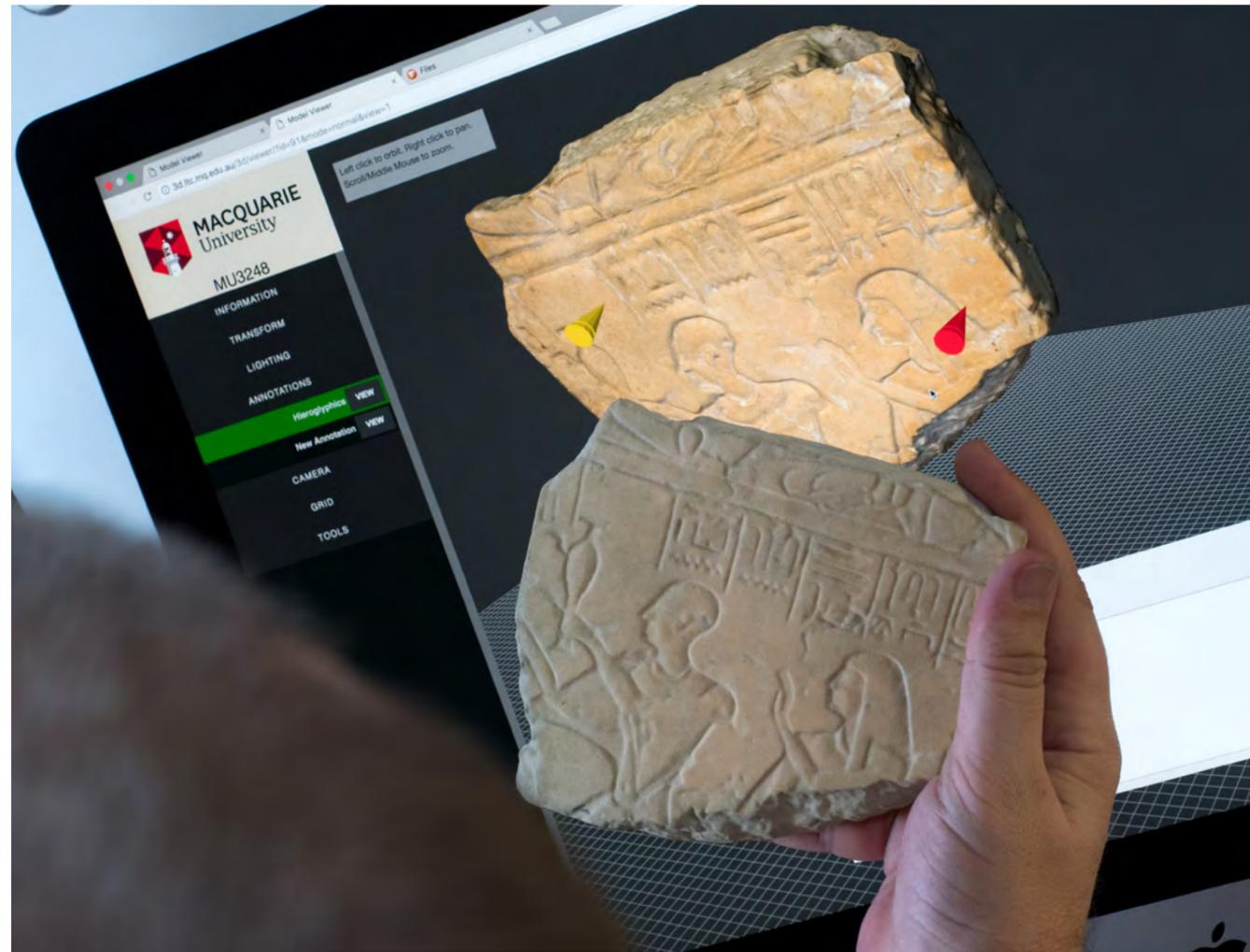
2018 ERA OUTCOMES

History and Archaeology	3
Archaeology	3
Historical Studies	3

Macquarie's archaeology fieldwork extends from new and ongoing research in the Mediterranean, to the Balkans, Eurasia and Australia. Archaeology also reflects our transdisciplinary strengths. Cross-disciplinary international collaborations have placed our work at the forefront of humanistic and scientific approaches to archaeology, producing innovative applications of cutting-edge science and technology to field research. The Macquarie University Archaeological Fieldwork Laboratory advances these developments, and we are home to the international Field Acquired Information Management Systems project, a world-leading information infrastructure project funded by NeCTAR, the program, the NSW Research Attraction and Acceleration Program and the ARC Linkage Infrastructure, Equipment and Facilities scheme.

Collaboration has been nurtured through the articulation of funded research clusters. The discipline has national collaborations with public and private institutions and has seen the development of enduring research relationships with leading universities and organisations.

The University's work into History and Archaeology continues to be recognised through a range of national and international achievements, including seven fellows of the Australian Academy of the Humanities; the ARC Discovery Outstanding Research Award; Fulbright Scholar, Malle Fellow (Harvard); two Watson Fellows (National Archives); British Academy Fellow; Istituto Nazionale di Studi sul Rinascimento Junior Scholar; Alexander von Humboldt Postdoctoral Fellows; Leverhulme Fellow; Fellow, State Library of New South Wales. NSW Premier's History Awards shortlists (2013 and 2016) and 2014 Multimedia and 2016 Community and Regional History winners.



Macquarie has an international reputation in the application of transdisciplinary approaches to the past.

PUBLIC AND CULTURAL INSTITUTIONS

Macquarie is highly regarded for its research-led outreach with the general community, schools and teachers, and peak bodies. We publish *Ancient History: Resources for Teachers*, which shares the latest research findings in the field, and we have enjoyed a long association with the NSW Education Standards Authority in shaping syllabuses and their assessment. Twenty-five colleagues visited schools and participated in teacher professional development activities. We host four annual conferences: two for the general public on Egyptology and Early Christianity, and two for students and teachers on HSC Ancient History and HSC History Extension. Over 2014–16, 110 NSW schools sent teachers and students to our HSC History Extension Day hosted with the History Teachers' Association of NSW. At the event, students embarking on their own primary research had the opportunity to discuss research with our leading historians.

Macquarie's public museums, the Museum of Ancient Cultures – which incorporates the Australian Centre for Ancient Numismatic Studies – and the Australian History Museum showcase our research to a wide audience. Thousands of people from the general public, community groups and schools visit the museums each year.

CONSULTING AND RESEARCH COLLABORATIONS/PARTNERSHIPS

Twenty historians and archaeologists worked with more than 40 institutions at home and overseas. These relationships included research collaborations, curations, public lectures, and paid and voluntary consulting. Research end users included the World Economic Forum, the Metropolitan Museum of Art (New York), the State Hermitage Museum (St Petersburg), the Asian Civilisations Museum (Singapore), the Athens Numismatic Museum, the National Museum of Australia, the National Hellenic Museum (Chicago), the Yambol Historical Museum (Bulgaria), the Australian War Memorial, the National Library of Australia, the NSW Police, the National Geographic Society, The Benevolent Society, the European Science Foundation, Mission Australia, and Ancestry.com.

The Tundzha Regional Archaeology Project (TRAP) is a good example of this work. This project, led by Macquarie, is among the most durable and productive international archaeological collaborations in Bulgaria. Working with local museums and government departments, TRAP submitted more than 1000 sites to the Bulgarian national heritage register, and this served as evidence to support a successful Bulgarian petition for a memorandum of understanding with the US Department of State to interdict illicit antiquities. A display of the project's work is permanently featured in the central square of the UNESCO-listed Bulgarian town of Kazanlak. Macquarie archaeologists thus contributed to cultural heritage policy and process in Bulgaria, and supported conservation and tourism.

THE MEDIA

Twenty-one historians and archaeologists have appeared in the media through expert commentary and work as consultants or talent on documentaries and other major media productions. The UK Channel 5 and 360 Productions documentary *Rome: The World's First Superpower* provided a new and exciting way for Macquarie to publicise its research. The producers were keen to engage with research topics that had not previously been presented to the general public. Working closely with the production company, Macquarie was able to share groundbreaking research on the material conditions of the urban poor, as well as elite property ownership on the Bay of Naples, including evidence for the development of oyster beds and fish farming. Filmed on site in Rome, the program enriched public understanding of the Roman past by making new research accessible.

Big History

TOWARDS A UNIFIED HISTORY OF HUMANITY,
EARTH AND THE UNIVERSE

Macquarie has played a foundational role in developing and disseminating the transdisciplinary field of Big History since 1989, when Professor David Christian and other Macquarie academics taught the first modern course in the field. With funding and support from Bill Gates' company bgC3, Macquarie led the design of the Big History Project, a free online course for high school students aged 15–16 years. Macquarie's Big History Institute then designed and developed Big History School, the first comprehensive K–12 resource for schools globally. Big History School has three courses: Junior (ages 8–12), Core (ages 12–16) and Senior (ages 16–17). The institute has trained and mentored Big History teachers in Australia and other countries, including India and Korea, and given many talks on Big History for educators, teachers and schools. Members of the institute led the production of a Big History massive open online course (MOOC) on the Coursera platform and participated in a 10-part History Channel series on Big History.

Macquarie has championed Big History for 30 years, as a way of helping students understand the many links between disciplines in the humanities and sciences, the underlying coherence of modern knowledge, and the critical significance of the global changes taking place today in the Anthropocene Epoch, the era in which our species dominates change on planet Earth. People from more than 150 countries have accessed Big History courses offered through the Big History Institute. Macquarie's impact on the teaching of history is global, because Big History not only reframes the human and non-human past as a global story but also creates a framework for students to engage with the great global challenges of our time.

2018 EI RATINGS

Engagement	Effective
Impact	Significant contribution
Approach to Impact	Highly effective

The Big History Institute was established with the innovative brief to drive growth and develop Big History as an integrated and priority activity across the University. Macquarie saw that Big History could achieve global impact but that this needed resources to promote and sustain external partnerships and collaborative engagements.

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GLOBAL IMPACT

By the end of 2018, Big History had been taught in more than 2000 schools around the world. Macquarie's Tracy Sullivan, Professor Christian and Andrew McKenna have played a major role in mentoring teachers in Australia, India, Hong Kong, Korea and elsewhere. As many teachers have reported, the course transforms students' thinking by helping them see connections between multiple historical disciplines. It has introduced the concept of the Anthropocene Epoch into schools and contributes to a holistic widening of their understanding of the history discipline.

Big History has been embraced as an important global framework by the World Economic Forum (WEF). WEF presentations have included Interdisciplinary Approaches to Solving 21st Century Challenges (Davos 2012); Big History for Big Picture Thinking; and Big History, Big Decisions (Tianjin 2014). In 2015, the WEF Annual Meeting in Davos had four sessions devoted to Big History including three interdisciplinary Big History, Big Future panels on cooperation, innovation, and global growth and stability.

The embrace of Big History by the WEF is matched by a tremendous popular resonance. Christian's TED talk has been viewed more than eight million times and is listed as one of the 11 classic TED talks.

CURRICULA CHANGE

There is increasing interest in and deployment of Big History curricula from many countries, including Korea, Japan, China, Indonesia, India, Russia, as well as in Europe and South America. The 2015 Coursera MOOC Big History: Connecting Knowledge was developed and presented by members of the institute in collaboration with scholars from all faculties at Macquarie. By the end of 2016, it had attracted about 30,000 enrolled learners from more than 100 different countries. Through this course, Macquarie became one of only 150 universities worldwide offering courses on the Coursera platform. In 2017, Macquarie launched a Coursera specialisation (a suite of four MOOCs) using Big History as a framework to solve complex problems.

BIG HISTORY AND EDUCATION

In 2014, the History Channel presented a 10-part documentary on Big History with Christian as a participant. Members of the institute have given numerous talks to schools, at Macquarie events and to its alumni, and organised two major conferences on the topics of Big History and Education, and the idea of the Anthropocene Epoch. During 2011–16, Christian gave 26 keynote lectures or presentations at corporate conferences including four at the WEF, a keynote at the Credit Lyonnais Securities Asia Investors' Forum in Hong Kong, a talk at Vivid Sydney, and a workshop organised by Al Gore at Harvard University. There have been 33 media interviews or articles about Big History and the work of institute members, including interviews with Stephen Colbert and Richard Fidler, and several articles in China.

One of the key impacts of Big History on education has been on international schools, as it meets their demand for non-national formats to teach history. As Big History is currently an English-only resource, its global uptake is largely due to the international schooling system. Big History offers a non-nationalistic and deeply interconnected interpretation of historical events coupled with a framework for inspiring interest in science, technology, engineering and maths.

EDUCATION RESOURCES

Members of Macquarie's Big History Institute provided the framing ideas and some of the material including a preface for the book *Big History* (Dorling Kindersley, 2016). Other publications by institute members have had significant sales and are widely cited, including *This Fleeting World: A Short History of Humanity* (Berkshire Publishing Group, 2018).

Macquarie's support for the teaching and dissemination of Big History has encouraged academics from across the University to translate their research into resources that the global community accesses on a daily basis. The take-up of Big History is still in its infancy, and yet it has already begun to transform the framework within which the stories of cosmological and human history are told and retold.

Philosophy

Applied ethics has strong research streams in bioethics including surgical and clinical ethics, animal ethics, neuroethics, and feminist bioethics.

Philosophy and Applied Ethics at Macquarie comprises an energetic and active group of researchers committed to a pluralistic approach to philosophical research. Our researchers explore key philosophical and social questions such as:

- What is the relationship between mind and brain?
- How do emotions shape our moral views?
- Can cinema do philosophy?
- How do evolution and culture interact?
- What are the ethics of experimental surgery?
- What is the nature of work in the modern world?

Our current research areas are diverse, with many sub-specialisations. Philosophy of mind and cognition, for example, includes specialisations such as embodied and extended cognition, pain, philosophy of neuroscience, niche construction and evolution, and consciousness. Under ethics and moral psychology, specialisations include Kantian ethics, moral responsibility, agency and autonomy, addiction, free will, cinematic ethics, and feminist ethics, while European philosophy encompasses the philosophy of work and critical theory. We also cover philosophy of biology and of medicine, ethics and applied ethics.

There are emerging research strengths in pragmatism and the philosophy of race. Applied ethics has strong research streams in bioethics including surgical and clinical ethics, animal ethics, neuroethics, and feminist bioethics. Philosophy research at Macquarie spans many of the traditional areas of the discipline. It also involves innovative, interdisciplinary and applied research in collaboration with local, national and international partners from diverse disciplines, especially cognitive science and psychology, biology, law and sociology. Applied ethics researchers work closely with practicing clinicians, health services researchers, legal scholars and policymakers. During the submission period, research capacity for mind and cognition has grown substantially, leading to a growth in publications and an enhanced standing in that field.

The Macquarie University Research Centre for Agency, Values and Ethics (CAVE) provides a lively and supportive environment for researchers. CAVE is organised into five research clusters: Human Agency and Selfhood; Applied Ethics, Bioethics and Clinical Ethics; Moral Cognition, Neuroethics and Neurolaw; Mind, Brain, Evolution and Culture; and Human Rights and Social Justice.

2018 ERA OUTCOMES

Philosophy and Religious Studies	4
Philosophy	5
Applied Ethics	4

CAVE provides funding and mentorship for researchers across its clusters, with regular workshops, visiting speakers and reading groups. From 2014 to 2016, CAVE held more than 50 events spanning workshops and conferences. CAVE hosts an annual public lecture and a series featuring distinguished visitors, providing excellent opportunities for higher degree research students and early-career researchers to interact with internationally renowned philosophers. CAVE funding has supported workshops on multiple topics including the philosophy of race, addiction, work, cinematic ethics, moral responsibility, social cognition, the self, sex selection, surgical innovation, and animal ethics.

The high standing of Macquarie researchers is demonstrated by numerous invitations to give keynotes at international conferences, as well as the endowment of prestigious awards and honours including three fellows of the Australian Academy of the Humanities, four ARC Future Fellowships, a Templeton World Charity Fellowship and two presidents of the Australasian Association of Philosophy. Appointments to prestigious national committees include the Australian Health Ethics Committee; chair of the National Health and Medical Research Council (NHMRC) committee leading the revision of the National Statement on Ethical Conduct in Human Research; ARC College of Experts and the Australian Laureate Fellowships Selection Advisory Committee. Our publication *What the Body Commands* (OUP, 2015) won the 2016 David Harold Tribe Philosophy Prize.



PANELS AND COMMITTEES

CAVE philosophy researchers have ongoing engagements with health and government bodies and make significant contributions to advisory boards and committee panels. Macquarie's researchers contributed to the NHMRC's Australian Health Ethics Committee (2012–15) and chaired the working group on the rolling revision of the National Statement on Ethical Conduct in Human Research.

Macquarie has also contributed to the clinical ethics working group that produced a manual for healthcare providers, *Clinical Ethics Capacity Building Resource Manual* (NHMRC, 2012–15); chaired the NSW Ministry of Health Clinical Ethics Advisory Panel providing advice to the NSW chief medical officer; and contributed to the South East Sydney Local Health District Clinical Ethics Committee, an advisory committee for practitioners and executives.

POLICY ADVICE

Macquarie has produced policy submissions for government, one on draft ethical guidelines on the use of assisted reproductive technology in clinical practice and research and another by Doctors Against Forced Organ Harvesting to the Department of Health.

Internationally, Macquarie contributed to the International Advisory Board of Deutsches Referenzzentrum für Ethik in den Biowissenschaften, the German Reference Centre for Ethics in the Biological Sciences. These advisory roles demonstrate how CAVE researchers use their expertise to link practitioners, government and the public.

NEUROLAW DATABASE

CAVE hosts the Australian Neurolaw Database, which is supported by Macquarie funding. Launched in 2015 by Justice Monika Schmidt of the NSW Supreme Court, this resource is a world-first, open-access database of criminal and civil cases involving brain evidence and is the only publicly accessible database of Australian neurolaw cases. It has in excess of 750 subscribers, more than 200 of which are international public servants. It has established a high profile among medical and legal practitioners: declared users from the non-academic sector include 13 from government departments, 27 legal practitioners, six journalists and 13 mental health practitioners. It supports significant industry engagement and impact through direct use by industry, conferences and workshops based on cases from the database that have attracted national and international interest. An example is the Dementia in the Courtroom event in 2016, which focused on criminal cases drawn from the Australian Neurolaw Database.

ABOVE:

Metal statue of a woman thinking, entitled *la Pensadora*
Photo by José Luis Fernández in Oviedo, Asturias, Spain, ca. 1968/1976.

Supporting safer surgical research and innovation

Surgical innovation is an essential part of modern healthcare. New techniques such as robotic and laparoscopic surgery, and new devices such as joint replacements and blood vessel grafts, have improved the health of millions. But surgical research and innovation can be risky for patients, some of whom have been harmed by their surgeons ‘trying something new’.

Macquarie’s research in this area has had local, national and international impact on support for safer surgical research and innovation. Macquarie’s research has been included in professional guidance by the Royal College of Surgeons of England which led to changes in international guidance on evaluating surgical innovations, informed revisions to Australian research ethics guidelines and influenced local health district practice.

Macquarie’s Professor Wendy Rogers has led a multidisciplinary team from within and outside academia to develop safer ways

of introducing surgical innovations into practice. Supporting surgical innovation is challenging because innovations are difficult to define and identify. But if innovations are not identified and then appropriately supported, patients are exposed to risks of harm, including death. Macquarie research has included developing a conceptually rigorous definition of surgical innovation and created a

freely available tool, the Macquarie Surgical Innovation Identification Tool (MSIIT), to help healthcare professionals identify surgical innovation prospectively and trigger appropriate supports.

This research changes the processes that hospitals and surgeons use to identify surgical innovation so that any identified risks can be managed safely. The tool for achieving this, the MSIIT, is freely distributed by the authors. The beneficiaries of this research are surgeons and their associations, hospitals and directors of clinical governance, medical indemnity providers,

the research community and, ultimately, patients. A public health specialist with the North of England Specialised Commissioning Team of the UK’s National Health Service wrote that Macquarie’s work will assist in carrying forward the implementation of a program to evaluate the introduction of innovations in the United Kingdom.

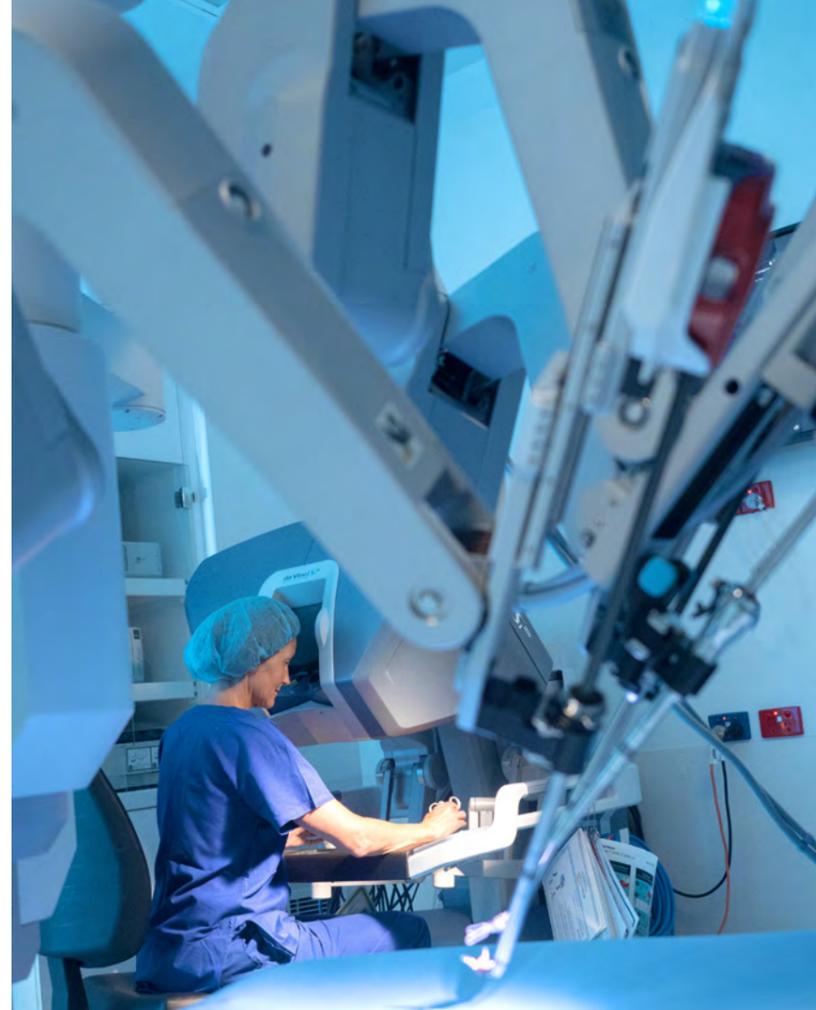
The research has provided insightful ways of thinking about ‘new’ in the context of surgical intervention and provided practitioners with a practical conceptual framework within which they can review their innovations and the associated risks.

Macquarie’s definition of surgical innovation is cited in the Royal College of Surgeons of England 2013 guidance on monitoring quality of care, thus influencing practicing surgeons in the United Kingdom as well as those charged with clinical governance of surgical innovation, such as the directors of clinical governance.

2018 EI RATINGS

Engagement	Highly effective
Impact	Highly significant contribution
Approach to Impact	Highly effective

The University has supported the development of the Macquarie University Hospital and the Macquarie Health Precinct. The unique governance arrangements of the hospital have facilitated the pilot study of Professor Rogers’ Macquarie Surgical Innovation Identification Tool (MSIIT). Macquarie’s support for the Australian Institute for Health Innovation ensures a close nexus between theoretical developments and translational research.



In Australia, hospitals and directors of clinical governance use the MSIIT to develop safer ways to introduce innovation, improve patient safety and reduce risk. Rogers and her team have presented their research to clinicians in local hospitals Westmead, St George and Macquarie University Hospital. A pilot trial of the MSIIT commenced at Macquarie University Hospital and Westmead Hospital in 2016, and the research has had impact on safety and quality among local healthcare providers.

Major insurance company GIO, which provides insurance for all public hospitals in New South Wales, invited Rogers and Hutchison to its 2014 Clinical Risk seminar to present on identifying surgical innovation. Directors of clinical governance from all New South Wales’ public hospitals attended this event.

Macquarie’s research has influenced the Australian research community in two main ways. The first is via partnerships with organisations allied to health research. Bellberry, a national, private not-for-profit organisation providing scientific and ethical review of human research projects, and Houston Thomson, a consulting company on the institutional governance of research, were partner organisations in the research. As part of the partnership, Rogers and her team have provided training to members of Bellberry’s ethics committees, and Houston Thomson used the results in its own consultancy work.

Secondly, Rogers is chair of the NHMRC’s Section 39 committee for the rolling review of the National Statement, Australia’s national research ethics guidelines. Her expertise in surgical innovation has contributed to the current revision of Section 3 of the National Statement, ‘Ethical considerations in the design, development, review and conduct of research’.

Macquarie’s work has been taken up by the IDEAL Collaboration in the latest revision of their influential framework. The IDEAL Collaboration is a group of leading international surgeons and research methodologists whose framework guides the gathering, reporting and use of evidence about new surgical procedures. The Macquarie research has been presented by Professor Rogers, invited keynote speaker, at the IDEAL Conference 2016, which was attended by practicing and academic surgeons. Rogers and her department colleague Dr Katrina Hutchison were participants at the invitation-only 2016 IDEAL workshop. This workshop led to the latest published iteration of the IDEAL Framework, which now includes the Macquarie ethical guidance.

Macquarie has influenced practice and policy on surgical innovation through national and international conferences attended by practicing surgeons and policymakers. Macquarie researchers have twice given invited presentations on innovation to the Annual Scientific Congress of the Royal Australasian College of Surgeons. This meeting is the college’s major educational activity and is the largest multidisciplinary surgical meeting in Australasia.

ABOVE:
Macquarie Hospital’s Da Vinci surgical robot.
Photo by Chris Stacey.

Mathematical sciences

Research in mathematical sciences at Macquarie is in the areas of analysis, category theory, dynamical systems, fluid dynamics, optimisation, waves, financial mathematics and stochastic modelling, biostatistics, computational statistics, and stochastic analysis.

Many of Macquarie's publications in pure mathematics are in prestigious journals such as *Advances in Mathematics*, the various journals of the American Mathematical Society and the London Mathematical Society, and the *Journal of Algebra*. Applied mathematics publications also appear in well-respected journals such as the *Journal of Fluid Mechanics* and the *SIAM Journal of Control and Optimization*.

Macquarie has made high-calibre appointments in each of the areas of pure mathematics, applied mathematics and statistics. These appointments enhance existing areas of strength in analysis and category theory, as well as significantly broaden capacity in our applied mathematics expertise in fluid dynamics and optimal control.

Macquarie researchers in Mathematical Sciences have been awarded a fellowship of the Australian Academy of Science, the IEEE Marie Skłodowska-Curie Award, the George Szekeres Medal of the Australian Mathematical Society, the Chaire de la Vallée Poussin in Belgium, and the 2017 Medal of the Australian Mathematical Society.

Macquarie researchers serve on the editorial boards of leading journals, national research assessment panels, major funding body grant panels, and committee chairs for high-calibre international conferences.

2018 ERA RATINGS

Mathematical sciences	4
Pure mathematics	5
Applied mathematics	3

Macquarie has made high-calibre appointments in each of the areas of pure mathematics, applied mathematics and statistics.



ABOVE:
Photo by Chris Stacey.

MEDICAL AND PHARMACEUTICAL WORK

Macquarie helps develop statistical methodologies for pharmaceutical companies, such as Johnson & Johnson and Janssen-Cilag, to present cost-effectiveness analyses based on data from diverse overseas studies for submissions to the Pharmaceutical Benefits Advisory Committee. Macquarie works with Cochlear on developing longitudinal models for changes in the perceived hearing of child and adult patients receiving implants. In 2011, Macquarie began working on the development of longitudinal models for predicting cognitive change with the Australian Imaging Biomarkers Lifestyle Flagship Study of Ageing, a collaborative project with hospitals and research centres around Australia.

Macquarie works with the Westmead Private Hospital and the Clinical Research Institute, part of Westmead Physiotherapy, to provide evidence of factors predicting a return to continence following radical prostatectomy, the results of which will help clinicians to advise potential prostatectomy patients.

Macquarie has collaborated with international end users at the Viseisei Sai Health Centre, a community health clinic in Fiji, and collaborated on an EU-funded project, Collective Community Ownership of Health and Social Issues. Local health workers visited rural villages conducting health education sessions and sustainable interventions targeting lifestyle risk factors that improve public health. As part of this work, they collected

survey and clinical data on the participants. Macquarie assisted the team with questionnaire design, data cleaning and integrity, and data analysis.

EXPERT ADVICE AND ADVISORY COMMITTEES

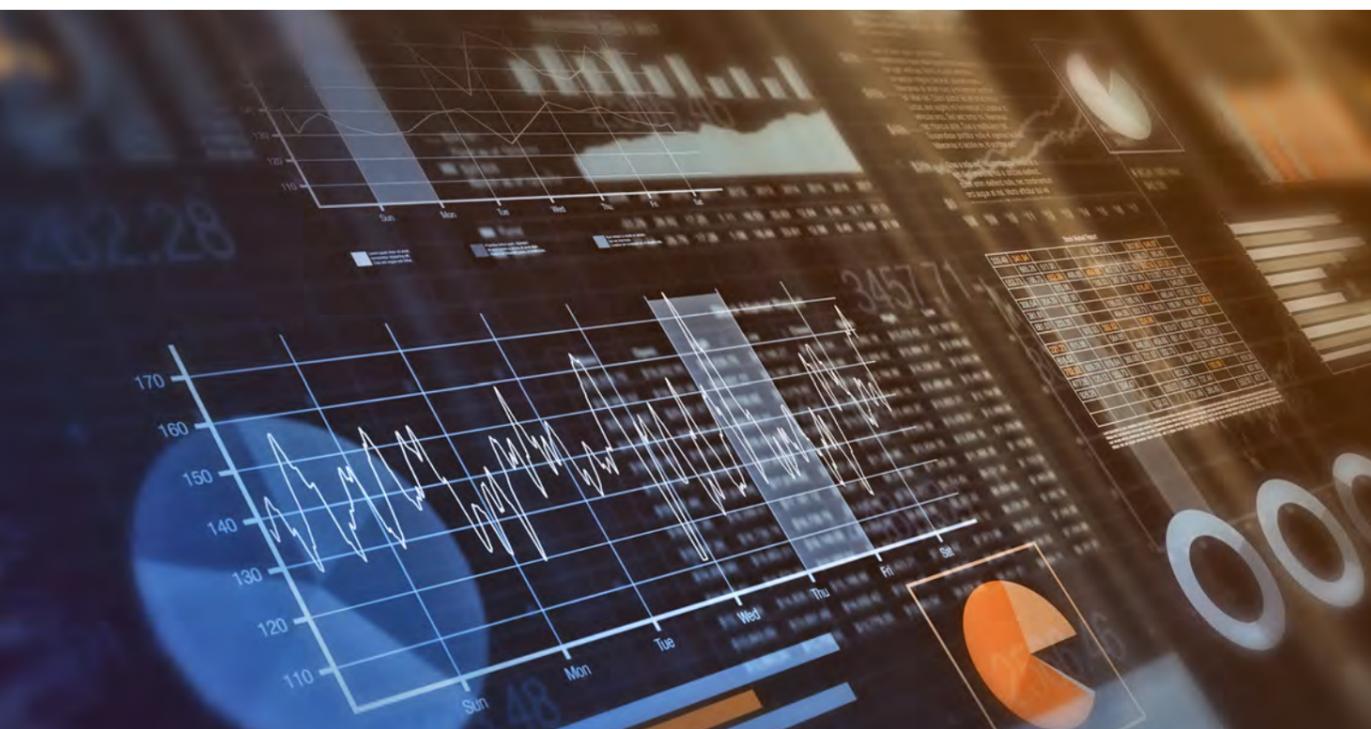
The National Committee for Space and Radio Science provides policy advice to the Australian Government and other organisations, and liaises with international groups such as the International Union of Radio Science. Macquarie has advised the Australian Government Department of the Environment and Energy on future activities in Antarctica; internationally consulted on the leap second and regulation of civil and astronomical time; provided input to the development of space activities in Australia, contributing to the recently announced Australian Space Agency; and conducted a mid-term review of 2010–19 Decadal Plan for Australian Space Science, which includes radio science.

Category theory is a highly specialised area of pure mathematics that can also be used to model business structures and information flows, and to minimise some cyber security risks. During 2014–16, this mostly involved accountants and finance professionals, sometimes in sessions organised by Chartered Accountants Australia & New Zealand. Typical end users would be CFOs and those who take a direct interest in their organisation's information and communication technologies.

Making better models for the real world

Statistics tells us a lot about the world, but real-world processes do not always fit neatly into statistical models. Generalized Additive Models for Location, Scale and Shape (GAMLSS) underpins a step change in data interpretation. Macquarie's Professor Gillian Heller has helped make GAMLSS applicable to scenarios that traditionally posed challenges for statistical models.

Her contributions to modelling actuarial data have had global impacts across the insurance industry, and she led the development of software downloaded more than 87,000 times. Today, GAMLSS is used in areas including environmental research, energy, economics, finance, and medicine. The International Monetary Fund, the World Health Organization (WHO), the European Central Bank and the Bank of England are among its users.



ABOVE:
Photo by iStock.

GAMLSS is a broad framework for statistical modelling in which the behaviour of a variable of interest is explained by other explanatory variables. This methodology underpins a diverse range of sectors. Macquarie's contributions to the continued development of this methodology have enabled enhanced analysis in a range of fields including actuarial science, economics, and climactic modelling.

Professor Heller has been a key figure in the GAMLSS team since 2005, following the public presentation of the GAMLSS fundamentals. Heller led the development of GAMLSS models for zero-adjusted distributions and the associated development of a software package that is freely available around the world.

Between 2012 and 2016, the R package GAMLSS software was downloaded 87,670 times, demonstrating its wide-reaching impact on the work of analysts globally.

THE GAMLSS METHODOLOGY

The GAMLSS methodology has globally impacted on data science. In the age of big data, the impact of this methodology has been vastly amplified. GAMLSS is used to interpret data daily, and these interpretations inform policy, business decisions and healthcare delivery.

GAMLSS is powerful because it can provide more than 100 continuous, discrete and mixed distributions for modelling the variable of interest. Previous regression modelling was restricted to a small number of such distributions, most notably the normal (bell-shaped) distribution. GAMLSS enables modelling in which the variable can come from a very broad range of distributions. The relationship between the variable of interest and the predictor variables has also been significantly extended in GAMLSS to include flexible, non-linear effects. The GAMLSS methodology has been made available in software (an R package), which is freely available and accessible to researchers worldwide.

CALCULATING RISK: ACTUARIAL AND ECONOMICS

Real-world scenarios where the outcome is either zero or a positive number (such as insurance claims) can cause difficulty for statistical comparisons. Heller's work, published in 2006 and 2007, made it possible for GAMLSS to be applied to the evaluation of insurance risk. Today, the GAMLSS methodology is widely used in the actuarial field for the statistical modelling of insurance claim frequency and size. This modelling is central to actuaries' accurate pricing of premiums and to the estimation of operational losses.

Heller's contributions were also instrumental in applying GAMLSS to investigate potential costs of a shock to the financial sector. In 2015, the International Monetary Fund used GAMLSS for stress testing the USA's financial system. GAMLSS was used for the European Parliament's *Making the European Banking Union Macro-Economically Resilient: Cost of Non-Europe Report* led by Gaël Giraud, Chief Economist of the French Development Agency.

CLIMATE CHANGE AND METEOROLOGICAL MODELLING

Heller's zero-adjustment work has been instrumental in allowing the GAMLSS methodology to be integrated into streamflow and meteorological modelling. GAMLSS has provided a new approach to discerning relationships within data. This has resulted in better streamflow modelling around the world and impacted on climate models, climate prediction, as well as government and intergovernmental understanding of climate change.

MORE EFFECTIVE INTERVENTIONS FOR PARKINSON'S FALLS

Heller played a key role in developing accurate models to evaluate the effectiveness of interventions for the prevention of falls in patients with Parkinson's disease. The work, which involved collaboration with the George Institute for Global Health and the Sydney Medical School, recommended interventions to manage freezing and reduce balance impairment in order to reduce fall frequency.

CHILDHOOD GROWTH CURVE MODELLING

The GAMLSS methodology was adopted by the WHO for the estimation of childhood growth curves and is now the international standard method for assessing childhood growth. Not only has GAMLSS had international impact through the creation and introduction of this assessment process, it has impacted upon the lives of millions of mothers and their children. The WHO growth charts are used in more than 140 countries.

2018 EI RATINGS

Engagement	Effective
Impact	Significant contribution

Physical sciences

Physical sciences research at Macquarie builds on an historical base in optical, plasma and condensed matter experimental physics. Research has now expanded into astronomy, biophotonics, nanooptics, and theory and experimentation in quantum optics.

Macquarie has a 35-year record of excellence in optics and laser physics, most recently hosting two major nodes of ARC Centres of Excellence (CoE): for Ultrahigh Bandwidth

Devices the Centre for Optical Systems (2002–10 and 2011–17) and the Centre for Nanoscale BioPhotonics (2014–20).

Macquarie has a strong track record in theoretical quantum research. The University hosted a node of the ARC CoE in Quantum Computer Technology (2002–10) and now hosts a major node of the ARC CoE for Engineered Quantum Systems (2011–18, 2018–24).

Astronomy research at Macquarie includes optical and radio astronomy, theoretical studies and instrumentation research. This active and expanding concentration of research was

formalised as the Macquarie University Research Centre for Astronomy, Astrophysics and Astrophotonics, Macquarie AAAstro, one of Australia's largest groups in astronomical sciences.

A major expansion of activity in astronomy and astrophysics at Macquarie from 2003 onwards has been underpinned by a collaboration established in 2014 with CSIRO Astronomy and Space Science. The group has been awarded more than 400 nights, valued at more than \$10 million, on major, international telescopes including the 8m Gemini in the optical, Very Large Array in the radio, and space telescopes such as Spitzer, Herschel, Chandra, and Hubble.

The professional standing of staff is indicated by several prestigious awards and representation as fellows of the Optical Society. Staff members have also served significant national and international leadership roles in recent years, including presidents of Science and Technology Australia and the Australian Optical Society, and committee memberships within the International Astronomical Union and the International Union of Pure and Applied Physics.

2018 ERA RATINGS

Physical Sciences	5
Astronomical and Space Sciences	5
Optical Physics	5
Quantum Physics	4

Physical sciences research at Macquarie builds on an historical base in optical, plasma and condensed matter experimental physics.



RAMAN LASERS

Macquarie's activities in Raman laser research provide an example of working directly with industry to transfer research outcomes and intellectual property to the commercial sector. Our goal is to tailor Raman laser technology to convert and enhance the output of lasers for new applications in quantum technology and terahertz sensing. Macquarie has worked with end users to develop new laser sources based on existing products.

Diamond Raman lasers have applications in defence, and Macquarie has collaborated with the US Army and Air Force on scaling Raman lasers to higher power, as well as working with diamond fabricator Element Six on measuring and improving material properties for laser applications. Macquarie participated in the CSIRO ON Prime training course in 2016, during which we engaged with end users on potential applications. Macquarie's applied Raman physics also encompasses yellow lasers. The University holds several patents in this area, one of which has been licenced to Optos Australia for retinal surgery.

AUSTRALIAN ASTRONOMICAL OBSERVATORY

Formally opened in 1974, the Australian Astronomical Observatory (AAO) was originally a binational facility of Australia and the United Kingdom. From 2010 to 2018, it was fully funded by the Australian Government. It has recently transitioned from Australia's national optical observatory into two separate entities with the Instrumentation, Astronomy Research, Astronomy Data Management entity, now the AAO, at Macquarie.

The AAO instrumentation capability brings to Macquarie a worldwide reputation in telescope instrumentation. Over its 45-year history as an observatory, it has developed instruments for use with the Anglo-Australian Telescope at Siding Spring, Coonabarabran, and for telescopes around the world. The early use of optical fibres set the organisation apart in the early 1980s when multi-fibre spectroscopy was transformed from an interesting novelty into a highly productive technique. Once the potential of this technique was demonstrated, the AAO built the Two-degree Field, a fibre positioner allowing the capture of 400 spectra at once. In the late 1990s, this was an unprecedented development and the scientific surveys that followed provided the worldwide astronomical community with some of its richest data.

Macquarie brings to the AAO its well-demonstrated track record in working with and hosting industry partners on its campus. Macquarie's AAO team of experts builds on the University's existing strengths in astronomy, photonics, laser technology, microfabrication, applied optics, sensing, and communications.

Small scale, big impact

HOW OPTOFAB'S LASERS ARE ADVANCING MANUFACTURING FOR OPTICS, DEFENCE, AND PHARMACEUTICALS

Macquarie has supported OptoFab financially over many years, providing equipment grants and custom-built laboratories in the Australian Hearing Hub. Commercialisation support has been provided by the commercialisation and innovation team, enabling OptoFab to experiment with new processes.

Macquarie's OptoFab has led the world in advanced manufacturing using lasers to remove or add very thin layers of material (ablation), enabling the development and commercialisation of products across the pharmaceutical, defence and optical sectors. It has pioneered additive and subtractive micromachining at a standard that surpasses many US and European competitors.

Cochlear sources its micromachining research and development needs from OptoFab. OptoFab also consults on technical specifications

for government and corporate optical fabrication facilities and runs equipment training placements. OptoFab's advanced manufacturing has contributed to the discovery of gravity waves and improving optical fibres. It has increased the profitability of many companies that contract its services.

OptoFab has been at the forefront of global laser microfabrication for more than two decades and has accelerated enterprise research and development across defence, medical devices and advanced manufacturing.

OptoFab has impacted on supply chain sourcing for major companies in Australia and around the world. OptoFab's leadership in additive and subtractive micromachining has led to the spin-off company Modular Photonics, created in 2015.

OptoFab is an essential enabler for advanced industrial processes tailored to create highly specialised products.

INDUSTRY STANDARDS

OptoFab has set the bar for quality in laser micromachining for decades. An essential enabler of this has been OptoFab's repeatable processes; the exact formula is still only known by OptoFab. This allows the facility to use laser machining to create holes a few microns wide, with an incredibly low margin of error.

The first major piece of equipment that OptoFab used for fabrication was designed and built in-house. It wasn't until 2010 that a supplier existed that could manufacture equipment to specification. Even then, it required deep collaboration between OptoFab and the supplier to construct the laser machining equipment to specification. This uniquely specified equipment, coupled with OptoFab's confidential processes, sets the industry standard in Australia for optical fabrication.

WORLD STANDARD

Cochlear has historically contracted its optical fabrication work in the United States; they now source fabrication from OptoFab. There is not a supplier in the United States that can surpass OptoFab's quality standards.

This has impacted Cochlear's research and development work. They are now able to source their laser fabrication services from a facility less than 100 metres away from their global headquarters. This rapid turnaround in production has helped fast-track their research and development, improving production procedures for Cochlear implants worldwide.

GLASS EXPANSION

Glass Expansion is a US company that has been manufacturing sample introduction components for inductively coupled plasma emission and mass spectrometers since the 1980s. In 2015, they began working with OptoFab, sourcing fabrication services to inform their research and development needs.

Once their research and development had moved beyond prototyping, they contacted OptoFab to assist with the creation of an optical fabrication facility at their Melbourne base. OptoFab consulted on the equipment specifications and provided in-house training for Glass Expansion personnel on using the equipment.

Glass Expansion now runs an optical fabrication facility modelled on OptoFab. It is an essential enabler of their current product suite, and the company's ongoing competitiveness is derived from their historical commercial relationship with OptoFab.

SPIN-OFF COMPANY: MODULAR PHOTONICS

OptoFab's research-informed commercial services led to the spin-off company Modular Photonics in 2015. Modular Photonics dramatically increases the capacity of legacy multimode fibre networks without the need for recabling or major service interruptions. The company's services provide a low-cost method for increasing network capacity using techniques developed at OptoFab. The company went through the first CSIRO ON accelerator program open to non-CSIRO organisations.

SETTING THE STANDARD FOR COMMERCIAL LASER MACHINING

OptoFab has consistently improved optical fabrication techniques, and a comparable commercial service is not available in Australia. OptoFab continues to set the standard for commercial laser machining worldwide.

OptoFab's indirect impact has been to model manufacturing standards for the global sector. The quality of products and the extremely low level of error rates have not only assisted a diverse array of industries with their research and development but also led the way for the improvement of industrial laser machining techniques. Though the OptoFab processing techniques remain trade secrets, the global laser machining sector has accelerated over the past decade to match the scale and skill of OptoFab's outputs.

TRAINING AND CONSULTATION

In limited circumstances, OptoFab provides training and consulting services. These services have been provided to customers in the defence, medical and advanced manufacturing sectors. The impact of these services has been to ensure that OptoFab's best practice model of optical fabrication is copied across, with customer appropriate modifications.

While OptoFab's equipment suite is characterised by a highly adaptive set of systems that suit a range of products, equipment consultations provide commercial advice on how to tailor equipment specifications to a single product requirement. This has had an impact across a range of sectors where laser machining processes have been introduced at OptoFab levels of quality.

SECTOR-WIDE IMPACT

OptoFab has had indirect and direct global impacts across the advanced manufacturing of optical fabrication. By setting standards, showcasing what is possible, consulting with organisations and providing research and development services, OptoFab has shaped government and corporate supply chains in Australia and internationally.

2018 EI RATINGS

Engagement	Effective
Impact	Significant contribution
Approach to Impact	Effective

ABOVE:
Photo by Paul Wright.



Chemical sciences

Macquarie's established research strengths are found in the areas of analytical chemistry and medicinal and biomolecular chemistry. An upcoming area with high citations is macromolecular and materials chemistry, supported by the appointment of several new academics.

Analytical chemistry is an essential part of research into areas such as genomics, proteomics, glycomics, biotechnology and chemical biology. A strong focus and basis for application and development of analytical chemistry is provided by the Australian Proteome Analysis Facility (APAF).

APAF is an internationally renowned entity driving major advances in basic and industrial research, especially in mass spectrometry and spectroscopy. APAF resources have supported Macquarie projects including the ARC Centre of Excellence in Nanoscale BioPhotonics, the ARC Training Centre for Molecular Technology in the Food Industry, the ARC SuperScience Project and a Cancer Institute NSW Translational Cancer Research Centre.

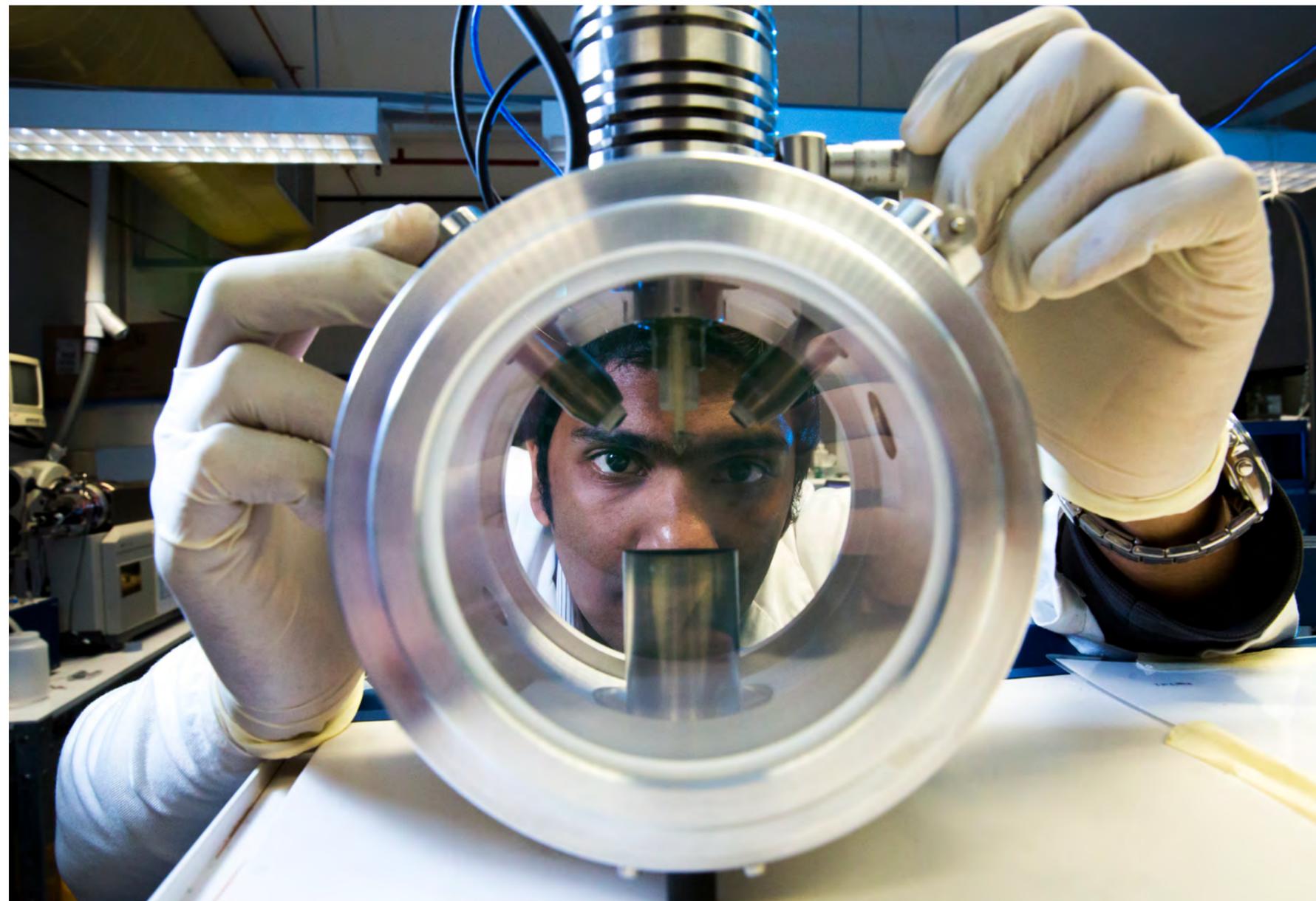
Further analytical support for chemical research is provided by the Macquarie University Centre for Analytical Biotechnology (MUCAB). MUCAB contains general-purpose analytical instrumentation that provides a unique and active focus for interdisciplinary research.

Medicinal and biomolecular chemistry connects proteomics, genomics, bioinformatics, organic chemistry, biochemistry, and analytical chemistry to

address complex medical and biological questions. Macquarie focuses on the rational design and discovery of biologically active small molecules and proteins. The Macquarie Biomolecular Discovery and Design Research Centre researches structural biochemistry, natural product research, drug discovery and drug applications. Macquarie continues to work in partnership with Indigenous communities on traditional medicinal plant knowledge (bush medicine) for cultural preservation and drug discovery.

2018 ERA RATINGS

Chemical Sciences	4
Analytical Chemistry	5
Macromolecular and Materials Chemistry	5
Medicinal and Biomolecular Chemistry	4



ENGAGEMENT WITH INDUSTRY AND GOVERNMENT

Macquarie hosts the Biomolecular Frontiers Research Centre (BMFRC) and the ARC Industry Transformation Training Centre (ITTC) on Molecular Technology in the Food Industry. Both the BMFRC and the ITTC have had a significant role in training higher degree research students co-supervised with external partners and provide opportunities for industry partnerships and placements. Industry collaborations have led to co-authored papers, patents, products and instrument development.

Macquarie works closely with Horticulture Innovation Australia on industry challenges in biosecurity. The project has collaborators from the NSW Department of Primary Industries, the QLD Department of Agriculture and Fisheries, and Eastern Mennonite University with the US Department of Agriculture.

ABOVE:
Photo by Chris Stacey.

The Synthetic Biology Consortium at Macquarie is deeply involved in the National Synthetic Biology Initiative supported by Professor Mary O'Kane, former NSW Chief Scientist and Engineer and Chair of the Planning Assessment Commission. The ultimate end users of this emerging technology are the public, health sector and industry.

Macquarie's researchers serve on more than 30 external committees, panels, professional bodies and advisory boards nationally and internationally, including as vice-president of the Synthetic Biology Australasia (since 2015), on the BioMed North Board for hospital research commercialisation, and as vice-president of the Asia Oceania Agricultural Proteomics Organization.

Australian Proteome Analysis Facility

From clues on Alzheimer's and cancer to optimising farming, the Australian Proteome Analysis Facility (APAF) is Australia's premier provider for proteomics analysis, detailed information on the proteins produced by cells. Co-funded by, and located at, Macquarie and supported by the National Collaborative Research Infrastructure Strategy and Bioplatforms, the facility was launched in 1995. It provides state-of-the-art, high-throughput proteomics analysis to research and development supply chains of many Australian and overseas companies, universities and organisations, analysing a total of more than 100,000 samples for about 120 organisations each year.

Macquarie set up APAF in 1999 and has financially sustained it since. Due to the cost of purchasing and maintaining equipment, labour and space, it is not possible to run a commercial proteome analysis facility at a profit, or even break-even, without making the cost of the service prohibitively high. Macquarie has therefore subsidised every aspect of the commercial service and ensures the benefits of the service can accrue to users who could not otherwise afford access. Macquarie has provided scholarships for students to conduct doctoral research on improving APAF's services.

The term 'proteomics' was invented and coined at Macquarie in 1993. Over the last 20 years, advanced bio-industries have drawn from Macquarie's research and APAF is a model of how research can be commercialised into a competitive and accessible service.

The high-quality and rapid proteomics services offered by APAF are near-unique and are not commercially offered anywhere else in Australia. This has resulted in APAF's techniques being requested by a host of industries and sectors across government, commercial and educational users. These three users often work in collaboration to access and interpret APAF's services to find new biomarkers of disease and novel targets for therapeutics. The commercial users bring the problems and the related samples and APAF provides the tools, facilities, expertise and analysis.

2018 EI RATINGS

Engagement	Effective
Impact	Significant contribution



ENABLING TODAY'S AND TOMORROW'S BIO-INDUSTRIES

Award-winning robotic instruments that automate protein analysis were developed with APAF expertise and commercialised as products (Xcise and ChiP) by the Japanese company Shimadzu in 2004. These products enable Macquarie's contributions to biomarker identification in collaboration with biotech companies and medical research institutes. The products further the identification of novel proteins for the diagnosis of diseases and discovery of new therapeutic targets. Macquarie developed the application notes for the commercial instruments that underpin this research around the world, which is indicative of Macquarie's expertise and influence in this area.

BIOMARKERS FOR DISEASE AND DRUG DEVELOPMENT

APAF has worked with numerous organisations on identifying biomarkers for diseases, including Alzheimer's disease and many types of cancer. APAF works on diseases that are difficult to diagnose or require highly invasive screening methods. For example, diagnosis of Alzheimer's disease has traditionally required samples of spinal fluid. APAF has identified 122 biomarkers associated with Alzheimer's in the retinas of deceased donors, providing possible diagnostics of Alzheimer's in the easily accessible eye organ.

AGRICULTURE

APAF's work has had ongoing impacts on the livestock industry in Australia and around the world by providing novel services that allow the optimisation of feedstocks. For example, APAF has been assisting the optimisation of poultry farming by analysing the post-enteral amino acids in chicken production. Other examples of agricultural contracts completed by APAF include comparing concentrations of A1 and A2 beta-casins in cow's milk and infant formula, and producing a detailed proteome characterisation of Yellow Canopy Syndrome in sugar cane to help understand the outbreak of this costly disease.

Fundamental to any breeding program is disease resistance. APAF has been working with the NSW Department of Planning and Industry (DPI) to help oyster farmers select the best lines of oysters resistant to QX disease, leading the massive transition of the industry to a pair-mated breeding program to meet the high demand for seed, approximately 30 million per annum. The work done at APAF has underpinned the selection of lines and has gone a long way in empowering the transition, which the DPI is now beginning.

ANTI-DOPING DETECTION

APAF gel technologies and advanced mass spectrometry techniques enabled the identification of additional blood-based biomarkers to detect the illegal taking of human growth hormone by athletes. Previous methods relied on ratio differences between artificial and naturally produced forms of human growth protein, or the increased levels of two molecules that arise after taking the hormone. APAF was able to create a novel method for tracking protein levels in the blood related to the use of the hormone, increasing the effectiveness and sensitivity of testing conducted by anti-doping authorities such as the Australian Sports Anti-Doping Authority.

TRAINING THE NEXT GENERATION

Higher degree research candidates undertake their work at APAF, with about 40 students per year gaining experience in proteomics. This not only advances the processes and techniques of APAF but also provides a high level of technical training to the student on proteomics analysis equipment to enable the investigation of a diverse range of research questions. Once graduated, these people are quickly recruited. For example, some of the first students associated with APAF are now professors of proteomics at Macquarie University, UNSW and the University of Sydney, as well as CEOs of Australian biotechnology companies such as Trajan, Regeneus, Ondek, and Sangui Bio.

Earth sciences

Macquarie's interdisciplinary approach to studying solid Earth science integrates geochemistry, petrology, geophysics and geodynamics and has made the University a world leader in research on the evolution of the lithosphere, the timing of Earth events and the nature of the deep Earth and its geodynamics. This delivers a new framework for mineral exploration, linking ore deposits to tectonics, mantle structure and the transport of material and energy.

Macquarie is a world leader in research on the evolution of the lithosphere, the timing of Earth events and the nature of the deep Earth and its geodynamics.

Macquarie's research on the Earth's surface and atmosphere encompasses collaboration across three departments and concentrates on past, present and future environmental crises, linking short-term environmental changes to long-term (100–1000-year) processes. The research employs field- and laboratory-based experiments, geochemical analyses and climate modelling, spanning across climate science, organic and inorganic contaminant geochemistry, fluvial systems, coastal dynamics, and palaeo-environmental reconstructions, some enabled by studies of marine sediments from the International Ocean Discovery Program and other shipboard expeditions. Similar methodologies in organic geochemistry are being applied to recognise biomarkers in ancient rocks from the first half of Earth history, tracking the development of life.

World-class infrastructure is critical to research productivity, outcomes and international profile. Macquarie Geoanalytical (MQGA) houses frontline instrumentation for determining the chemical and isotopic composition of Earth materials.

It pioneers world-first applications and methods, attracts more than 20 national and international users annually and has been one of three geochemical nodes in the National Collaborative Research Infrastructure Strategy AuScope Capability since 2007.

2018 ERA RATINGS

Earth Sciences	4
Atmospheric Sciences	5
Geochemistry	4
Geology	4
Geophysics	4
Physical Geography and Environmental Geoscience	4



Equipment is now being built up in the fields of geophysics, experimental petrology and mineral physics, supported by new academic staff in these areas. New geophysical capabilities are in seismology – including ambient noise seismology that uses low-level background noise in combination with information from earthquakes – and magnetotellurics, which studies the electromagnetic structure of the crust and mantle. World-leading whole-Earth numerical models of geodynamics integrate the geophysical and geochemical information, forming a complete picture of how the Earth works. Laboratory experiments can now simulate all pressure-temperature conditions from core to crust, using a combination of ambient pressure furnaces, high-tonnage solid-media apparatuses for depths to 600 kilometres and diamond-anvil cell systems that can achieve pressures of the lower mantle and core.

Macquarie has strategic alliances with major manufacturers of analytical equipment. MQGA has long been a test site for Agilent inductively coupled plasma mass spectrometry (ICPMS) instruments, and Agilent supports the use of MQGA's GLITTER software. This software, for online reduction of ICPMS data, is the industry standard and is used in more than 220 laboratories worldwide. New initiatives in the last three years include a Thermo Fisher Hub for developments in isotope geochemistry and collaborations to develop new equipment with Cameca (electron microprobes for in-situ geochemical analysis in minerals and other solids artefacts) and FEI (microbeam instrument 'NanoMin' for nanoscale imaging and quantitative modal analysis of minerals in fine-grained rocks). The broadening of analytical capabilities is enabling a wider range of scientific research. While improving the analytical base for solid Earth research, the new MQGA equipment is also supporting new research avenues in biomineralisation and surface and environmental process as well as cross-disciplinary initiatives such as archaeology.

The NanoMin technology is being combined with the advanced organic geochemical analytical capabilities at Macquarie, enabling work with national and international energy companies to provide the foundation to identify prospective parts of Australia's vast oil-bearing basins. A new femtosecond laser micropyrolysis-GCMS will enable the selective analysis of small (1–20 μm) organic matter components, with applications in the origin of life, fossil fuels, palaeontology, biomineralisation, and carbon sequestration. Macquarie seeks to determine if coal seam and shale gas impact greenhouse gas emissions relative to present sources and what steps could be made to mitigate fugitive gas contributions, once again linking geochemical analysis with environmental issues.

The University's collaborations with end users of research, including geological surveys and the mineral exploration industry (Australian and global, juniors and majors), have led to more than 30 ARC Linkage projects being funded in the assessment period. The Macquarie-developed novel TerraneChron® methodology provides a significant interface with the exploration industry. The Global Lithosphere Architecture Mapping approach provides global targeting strategies for resource exploration, including nickel, gold, platinum minerals, and diamonds.

TerraneChron delivers a powerful tool to help mineral exploration

BHP Billiton, Rio Tinto, Vale and many other companies use TerraneChron® to help them discover new mineral deposits. The technique, invented and commercialised by Macquarie, analyses grains of zircon collected from streams and riverbeds as a reconnaissance tool to rapidly identify rock systems of potential economic interest, without the time and expense of traditional mapping.

TerraneChron has contributed to the discovery of mineral deposits worth many billions of dollars in Australia and around the world. It has been adopted by government survey organisations in Australia, Norway, Brazil, Argentina and other countries and is a key tool for UNCOVER Australia, a national collaboration launched in 2013. It has also transformed basic geological research.

Macquarie has provided long-term financial and in-kind support to the development and commercialisation of the TerraneChron product suite and its underpinning research. Macquarie's ongoing collaboration with industry has ensured the success of TerraneChron and has fundamentally changed zircon geochronology research around the world.

Traditional mineral exploration relies on geological mapping, supported by geophysical surveys and remote sensing. Determining the age and origin of mapped rocks, which is key information in mineral exploration, is an expensive. TerraneChron has fundamentally changed this.

TerraneChron is based on zircon, a common mineral in many igneous rocks, and so resistant that it survives well in river placer deposits. Using laser-based analysis of an individual zircon grain, we can measure its age, its trace-element pattern and the Hf-isotope signature, revealing a great deal about the type of rock it came from. The analysis of about 100 grains from a stream sample (approximately four days' work) provides an overview of the ages and origins of rocks in the drainage basin. This information allows prospectors to evaluate the geological history of a drainage basin (from 1 to 1000 kilometres across) and focus their search on areas with the most promising geology. The technique has also proven useful in petroleum exploration because it helps evaluate the age and provenance of a sediment package.

GEOCHEMICAL REMOTE SENSING

Macquarie's Centre for Geochemical Evolution and Metallogeny of Continents (GEMOC, now part of the ARC Centre of Excellence for Core to Crust Fluid Systems), provides TerraneChron's geochemical remote sensing services to exploration companies on a commercial or commercial/collaborative basis. The companies send samples to GEMOC, where they are analysed. Over time, GEMOC has developed both broad expertise in interpreting the results and a large database with which new samples can be compared. Once the data has been interpreted, a report is provided to the company describing the tectonic and rock-type history of the sampled area. Usually the companies will provide locations so that GEMOC can integrate the new data into the database.

2018 EI RATINGS

Engagement	Effective
Impact	Highly significant contribution
Approach to Impact	Highly effective



GEOLOGICAL SURVEYS

The TerraneChron or similar techniques are now used by national and state geological surveys around the world. All the geological surveys in Australia use the techniques, as do the Norwegian, Brazilian and Argentinian surveys; other national surveys use techniques

derived from Macquarie's research and innovations related to TerraneChron. This has impacted on how governments understand and manage their geological endowment.

UNCOVER AUSTRALIA

UNCOVER Australia is a national and state-based government collaboration drawing on universities, companies and geological surveys. Launched in 2013, it will explore the 70 per cent of Australia's bedrock that lies beneath younger cover and probably hosts many economic deposits. A major initiative in this effort will be the isotopic mapping of the entire continent using the TerraneChron approach. This illustrates the impact that TerraneChron has had on geological thinking nationally.

INDUSTRY STEP CHANGE

TerraneChron has fundamentally altered the strategies of the resources industry around the world. By working closely with industry and governments on the development and commercialisation of TerraneChron, Macquarie has developed a virtuous cycle. Samples are sent by industry for analysis, and those analyses are then used to inform a database that is bringing together a deeper understanding of the evolution of the planet. Companies then use that database and the concepts arising from it to make probabilistic evaluations about where best to explore for new deposits. The training that Macquarie postgraduates receive in both the technology and the conceptual approaches are highly prized by industry, and Rio Tinto heavily recruits from the Macquarie campus.

IMPACT ON TIME SAVED

The technical developments that led to TerraneChron, in particular the in situ analysis of Hf isotopes in zircon, have made possible a volume of analyses and a level of interpretation that were not previously imaginable. In three months, GEMOC can analyse more samples than was previously possible in a lifetime.

For the exploration industry, the ability to rapidly assess the geology of a given area means less time is wasted exploring in areas unlikely to be prospective for deposits. Less time and less money spent on finding the next deposit increases its net present value.

MINERAL EXPLORATION

TerraneChron has proved particularly useful in exploration for gold, copper and nickel deposits, and has been used to target many other resource types. One helicopter can now quickly sample the length of a river, and large areas of alluvial deposits can be surveyed in a few months. As an example, one company scanned the entire western side of the Andes for Cu-porphyry deposits, in one field season.

INTERNATIONALLY ACCESSIBLE SOFTWARE

To improve and speed up data processing for laser-ablation analysis, GEMOC developed a sophisticated software package, commercialised as GLITTER. More than 300 copies of GLITTER have been sold internationally, including those bundled with instrument sales by Agilent, and this has helped both to standardise data protocols and to increase productivity in labs worldwide. GEMOC continues to update GLITTER and to provide service to users.

ABOVE:

Zircons, used by the TerraneChron® Method

Environmental sciences

Macquarie has research strengths in global change and its social and environmental impacts, marine and invasive species ecology and contaminated lands and their management.

Macquarie's Climate Futures Research Centre conducts global change research through strategic alliances with biologists, social scientists and economists. Climate Futures focuses on the natural impacts and the economic and financial risks associated with global change and bridging the divide between climate and adaptation research, policy and practice needs. The Climate Futures Research Centre serves as a hub for interactions between leading researchers, decision-makers, NGOs, businesses and vulnerable communities. Climate Futures has recently evolved into the Centre for Smart Green Cities.

Macquarie's researchers have made contributions to international activities in global change and biodiversity.

Macquarie is a major partner in the National Climate Change Adaptation Research Facility (NCCARF). Since 2015, the Macquarie University Energy and Environmental Contaminants Research Centre has reflected and supported the growing body of researchers in these important areas.

The area of environmental science relies heavily on collaboration both within and beyond the University. Most publications at Macquarie during 2011–16 involved collaboration with external institutions, a reflection of this group's strong engagement in research networks, Cooperative Research Centres, and nationally coordinated programs. Collaborators include the Sydney Institute of Marine Science, the Integrated Marine Observing System, the Australian Research Institute for Environment and Sustainability, the Australian National Low Emissions Coal Research and Development program and the NCCARF.

Collaboration at an international level has expanded and

been facilitated by recent appointments, particularly in Earth system and marine science, resulting in strong and lasting partnerships with the major European and US programs.

Macquarie researchers have made contributions to international activities in global change and biodiversity through involvement with the Intergovernmental Panel on Climate Change (IPCC) and the International Union for Conservation of Nature (IUCN), and in the management of toxic chemicals and environmental contaminants through the United Nations Environment Programme (UNEP) and the International Energy Agency.

2018 ERA RATINGS

Environmental Sciences	5
Ecological Applications	5
Environmental Science and Management	5



GLOBAL END USERS

Macquarie has a memorandum of understanding with the NSW Office of Environment and Heritage that supports its Adaptation Research Hub. Macquarie leads the Biodiversity Node, a \$2.3 million co-investment that brings researchers and end users together to deliver community solutions. The University's spin-out company Risk Frontiers is heavily engaged with the insurance industry.

Community organisations and NGOs that engage with Macquarie include Take 3 for the Sea, the Tangaroa Blue Foundation, Reef Check Australia, Conservation Volunteers Australia, Clean Seas Whitsunday, the Wildlife Conservation Trust, the Columbia Habitat and Monitoring Program, Pure Earth and Blacksmith Institute in the United States, the Wildlife Conservation Society in Fiji, The Nature Conservancy in Tanzania, and the European Water Framework Directive – Restore Rivers.

Macquarie collaborated with the World Wide Fund for Nature (WWF) to develop a framework for prioritising marine areas for France/Reunion, Madagascar, Mauritius and Seychelles.

Macquarie is distinguished by strong engagement with landowners in undertaking and disseminating Environmental Science research, including with traditional owners, such as the Ngukarr and Mirrar people, Yugul Mangi, Yirralka and Numbirindi Rangers, and the Gundjeihmi Aboriginal Council, rural landowners of coastal and inland catchments in New South Wales and local communities including Port Pirie, Mount Isa, Broken Hill, Townsville, Pioneer (Tasmania), Macdonald Valley and Blue Mountains.

EXPERT ADVICE AND PROFESSIONAL DEVELOPMENT

Macquarie Environmental Science experts engage internationally and have sat on close to 50 high-profile committees. They have served on high-profile national and international bodies including the IPCC, the United Nations Millennium Ecosystem Assessment, the United Nations Convention on Biological Diversity, the IUCN World Commission on Protected Areas, the IUCN Commission on Education and Communication, UNEP, the International Energy Agency Expert Group on Mercury Emissions from Coal, the UNEP Expert Group advising on Minamata Convention on Mercury, the International Atomic Energy Agency and Conservation International.

Domestically, Macquarie chaired the NSW Threatened Species Scientific Committee and the NSW Fisheries Scientific Committee, which are responsible for assessing threatening processes on ecological communities and the risk of species extinction. Macquarie engages deeply with legislation reviews and contributed to the drafting of the new Biodiversity Conservation Act (NSW). Our researchers sit on boards of NGOs including WWF and Bush Heritage Australia.

Researchers provided expertise to industry through advisory panels at the Australian Renewable Energy Agency, the Planning Institute of Australia, and the UNEP – Nairobi Convention Coral Reef Task Force. Macquarie researchers regularly contribute their knowledge as expert witnesses, for example, on whaling in the Australian Whale Sanctuary, coal mine expansion for the Environmental Defenders Office and, through the NSW Land and Environment Court, lead contamination.

Transforming river management on five continents

THE RIVER STYLES FRAMEWORK

Rivers in Australia, Europe, North America, South America and Asia are being managed more effectively using the River Styles Framework, a set of procedures and tools developed at Macquarie to interpret river character, behaviour, condition and recovery potential.

More than 225,000km of stream length in New South Wales and some 28,000km overseas has been assessed using the framework. Highlights include adoption by the European Union, integration into management planning for America's iconic Columbia River, and use in India's Ganga Basin, home to more than 45 million people. Use of the framework has generated significant improvements in river health throughout New South Wales and overseas, making catchment management more sustainable and benefiting millions.

Macquarie gave vital early funding support to the research on which the River Styles Framework is based and consistently helped the framework attract grant funding. The University incubated the framework so that by 2016 the program was able to fund itself almost entirely through external revenue, primarily through professional training courses and accreditation programs delivered in Australia and overseas.

The River Styles Framework has changed the way river management decisions are made and the level of intervention and resources required to reach environmental health targets. This has been achieved through catchment-scale and regional-level templates derived from the framework. These templates are integrated with other biophysical science tools and datasets to enhance planning, monitoring and forecasting of freshwater resources.

The framework is based on foundational research on the form and function of streams and their interaction with the landscape through which they flow (fluvial geomorphology). This research has been peer-reviewed, internationally recognised, and awarded.

The framework has a pioneering structure and coherence due to its open-ended and generic approach to river analysis and interpretation.

Going well beyond off-the-shelf imported manuals for river management,

it has been adopted because of its sophisticated, innovative approach to geomorphic analysis of rivers. The framework is tailored for the landscape and institutional context of any given place, to produce scaffolded, coherent and consistent datasets for place-based decision making. Through on-ground communication of place-based results, the application of the framework spans local, state, national and international networks and initiatives.

2018 EI RATINGS

Engagement	Highly effective
Impact	Significant contribution
Approach to Impact	Effective



IMPACT IN AUSTRALIA

In 2007 and 2010, Land and Water Australia (LWA) commissioned cost-benefit analyses of use of the River Styles Framework. The net present value was \$35 million (2007) and \$40 million (2010) with a benefit:cost ratio to LWA of 29 to 1, ranked second out of 33 case studies. This ratio has likely increased significantly since 2010 with rollout across New South Wales and internationally. LWA noted improved priority setting and expenditure on river rehabilitation, the development of comprehensive and transparent datasets, professional development of practitioners, improved citizen knowledge and reduced community conflict as the primary economic and social benefits of using the framework.

Since 2002, several NSW policy instruments have used the framework and this level of impact has intensified over the last six years. The NSW Department of Primary Industries (DPI) Water has continuously used the framework since 2000.

By 2016, the framework was integrated into the workings of DPI Water. This has been achieved through DPI Water generated Water Sharing Plans, licencing and compliance activities, monitoring and evaluation using the River Condition Index, risk and threat analysis, and re-prioritisation of on-ground rehabilitation using the recovery enhancement approach. Since 2002, each NSW Catchment Action Plan and River Health Strategy has implemented the

framework. Since 2016, Fisheries NSW has used the framework to assess and monitor threatened species distributions and habitat mapping. The NSW Environmental Protection Authority's State of the Environment reports in 2012 and 2015 used the framework. Other state government agencies and local councils in Queensland, South Australia and Tasmania have also used the framework.

The framework is embedded in the National Water Initiative through the national Water Act 2007. This has brought national impact through the Australian National Aquatic Ecosystems Classification Framework, the High Ecological Value Aquatic Ecosystems evaluation and Regional Biodiversity Management Assessments conducted through the Department of the Environment and Energy, as it is now known.

Policy decisions made by government agencies have flowed on to rural and urban industries and communities. Town hall meetings with Landcare and Rivercare groups, workshops with industry partners, formal expert advice, training and accreditation of practitioners, tenders for River Styles work, and job creation for consultants and graduates have been some of the spin-off impacts and beneficiaries. The long-term health of Australia's rivers significantly impact the Australian economy, and the framework has ensured Australia's freshwater is more sustainably managed in many parts of the country.

INTERNATIONAL IMPACT

Significant international adoption began in 2012 as part of the European Framework Directive program, REstoring rivers FOR effective catchment Management (REFORM). REFORM manages freshwater resources by river basin – the natural geographical and hydrological unit – not political boundaries. The framework has impacted on the assessment and management of water resources throughout the European Union and on the cross-border implementation of water policy within the Union.

The multi-million-dollar US Columbia River Habitat Monitoring Program integrated the framework into decision support tools for habitat assessment and restoration.

Baseline datasets were generated using the framework during the reporting period for the Ganga River Basin Management Plan funded by the Ministry of Environment and Forests, India; the Macae Catchment Management Authority, Brazil; and the Three Brothers (Plus) Agreement, China.

In recognition of this achievement and impact, Professor Kirstie Fryirs was awarded the internationally prestigious Gordon Warwick medal from the British Society for Geomorphology in 2015 and a NSW Young Tall Poppy award. Professor Gary Brierley was appointed a Distinguished Visiting Professor of the Chinese Academy of Sciences for his River Styles work in China. Team awards include a Macquarie University Innovation Award, the Thiess International Riverprize and the Hunter Coal Industry Environment Award.

Biological sciences

Within Biological Sciences at Macquarie, groupings of research strength can be distinguished in ecology and evolution, and in biomolecular sciences. Macquarie is host to two ARC Industrial Transformation Training Centres and contributes nodes to three National Collaborative Research Infrastructure Strategy (NCRIS) projects. Macquarie is a major partner in the Centre of Excellence (CoE) for Nanoscale BioPhotonics and the ARC Cooperative Research Centres Project (CRC-P) for Future Oysters, and was a major partner in the National Climate Change Adaptation Research Facility. A major new initiative in synthetic biology further integrates across disciplines via the international Synthetic Yeast Genome Project.

Macquarie's strengths in genomics, proteomics, glycomics, biochemistry, bioinformatics, microbiology, and biotechnology are cemented together by the Biomolecular Frontiers Research Centre.

Biomolecular research is underpinned by world-class analytical equipment and specialist support provided by the Australian Proteome Analysis Facility (APAF), which provides cutting-edge protein analysis technologies to both researchers and industry. Further infrastructure

capacity across the -omics has been built through funding from the ARC Linkage Infrastructure, Equipment and Facilities scheme, Cancer Institute NSW, Ramaciotti Foundation and industrial partners. Macquarie has heavily invested in a world-class seawater facility and provided a major upgrade to the University's plant growth facility.

The high-calibre research being conducted by Macquarie's academics has been recognised through fellowships and extensive collaborations. Some collaborating bodies include the Sydney Institute of Marine Science, the National Climate Change Adaptation Research Facility, the CoE for

Nanoscale BioPhotonics, the ARC CRC-P for Future Oysters, the three NCRIS facilities, two nodes of the NSW Adaptation Hub (Biodiversity and Coastal Processes), the Australian Museum, Taronga Zoo, the Synthetic Yeast Genome Project, and several collaborative projects with Horticulture Innovation, including Q-Fly Sterile Insect Technique consortium and Green Cities 'Which Plant Where'.

2018 ERA RATINGS

Biological Sciences	5
Ecology	5
Evolutionary Biology	5
Genetics	5
Plant Biology	5
Zoology	5
Microbiology	4
Biochemistry and Cell Biology	3

Macquarie's research centres include Biomolecular Frontiers, Climate Futures, Genes to Geoscience, Marine Science and Biosecurity Futures.



MARINE RESEARCH

Macquarie's research on the biology of marine mammals, fish and sharks contributes to fisheries management and shapes policy nationally and internationally. Macquarie staff have played key leadership roles in chairing and contributing to advisory committees for the Australian state and federal governments, including the Fisheries NSW Scientific Committee.

Reports prepared for the Marine Policy Division of the Australian Government Department of the Environment and Energy and the International Whaling Commission included topics such as the genetic structure of marine mammal populations and their migratory behaviours, impacts of the whale- and dolphin-watching industries, and best practices for monitoring responses to coastal development. Marine biology research generated by 21 Macquarie higher degree research students – in collaboration with staff from the NSW Office of Environment and Heritage (OEH), the NSW Department of Primary Industries (DPI), Taronga Zoo, the South Australian (SA) Research and Development Institute, the SA Department of Environment, Water and Natural Resources, the whale-watching industry and the Tongan Government – was used to develop management strategies for a variety of marine mammals. Research on biological effects of ocean acidification has changed the way that yellowfin tuna populations are modelled by the Inter-American Tropical Tuna Commission and by the Pacific Community, the principal scientific and technical organisation in the Pacific region.

Shark research is a highly engaged area at Macquarie. Researchers work in collaboration with Fisheries NSW and Taronga Zoo to use acoustic technologies and population genetics for tracking shark movements, migration and social behaviour. Research with Fisheries NSW on the life history and genetic structure of sandbar, dusky and spinner

sharks contributed to recommendations for changes in the *Environment Protection and Biodiversity Conservation Act*, the Australian Government's central piece of environmental legislation. Macquarie researchers contributed to the development of the current NSW Shark Management Strategy developed by the DPI. Research on cognition and welfare in fish and sharks is changing public perception and, in collaboration with the RSPCA, shaping animal welfare legislation. Macquarie researchers played a lead role in advising NSW DPI and in contributing to public debates on bather and surfer protection from sharks.

TERRESTRIAL PLANT SCIENCE

Macquarie researchers vigorously investigate many aspects of terrestrial plant science. Research on heat tolerance in wild rice species has led to a commercial arrangement with Bayer Crop Science, developing 'climate change-ready' varieties of several cereal crops. Our plant ecology research focuses on a deep understanding of the Australian flora, in particular with relation to the geography and climate of the Australian continent. This includes collaborative research with New South Wales and Queensland Herbaria on the evolution and biogeography of particular plant clades, NSW DPI on forestry management, NSW Local Land Services on riparian vegetation management and restoration, NSW OEH on woodland management restoration, and several projects focusing on species and ecosystem risk assessment and management. End users include the Australian Government Department of the Environment and Energy, NSW DPI, NSW OEH, the equivalent agencies in South Australia, Tasmania, Victoria and Western Australia, and the Australian Network for Plant Conservation.

ABOVE:
Photo by Chris Stacey.

Inbreeding, outbreeding, managing wild populations

HOW MACQUARIE'S WORK IS HELPING SHAPE BEST PRACTICE FOR SPECIES CONSERVATION AROUND THE WORLD

From improving the survival of Tasmanian devils and lemurs, to writing guides used in international training programs, to helping shape captive breeding best practice with zoos and museums, Professor Dick Frankham's work on minimising the genetic risks of inbreeding and outbreeding has had wide-reaching impact on the conservation of endangered species.

Frankham is the lead author of three professional reference books that have reshaped the conservation genetics field. These books have the express purpose of translating research into practice and positively influenced species conservation programs globally.

The global management of threatened and endangered species has been significantly impacted by Macquarie's

Macquarie has achieved global impact on conservation practice through creating professional reference resources now used by practitioners around the world. These have been informed by research collaborations with world-leading practitioners in zoos and museums. By researching real-world problems and creating real-world resources to assist people at the front lines, Macquarie has global impact.

work in conservation genetics. Prior to Emeritus Professor Dick Frankham's practitioner-oriented books, educated guesses were used to set the lower limit on the population size required to maintain genetic diversity. Frankham's research, meta-analyses and computer modelling of genetic diversity have been translated into best practice for captive breeding

and species reintroduction programs worldwide and the management of those species in wild habitats – especially those with fragmented distributions.

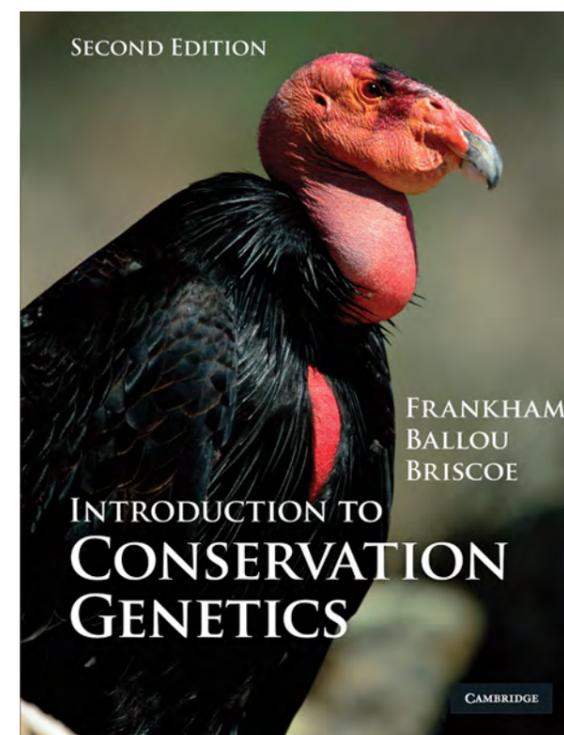
HELPING SET THE STANDARD FOR CAPTIVE BREEDING AND REINTRODUCTION

Frankham's collaborations with end users of research in the field, zoos and museums has set the global standard for applying and translating research in conservation. His collaborations with practitioners both in Australia, such as the Australian Museum, and overseas – including the Smithsonian's National Zoo, the Chicago Zoological Society and the San Diego Zoo – have influenced best practice for captive breeding and species reintroductions worldwide.

The period over which species reintroductions occur has been influenced by his work. Releasing animals into the wild is a critical step in the conservation of threatened species and requires close collaboration and cooperation between different captive breeding programs.

In 2008, Frankham was invited by the Tasmanian Government to participate in the Tasmanian Devil Population and Habitat Viability Analysis project. The devil facial tumour disease that devastated wild populations also put the species at risk of inbreeding, depression, and extinction. Through computer modelling, using key parameter estimates based on his research, the fate of the species was predicted under a range of possible scenarios. From 2010 to 2013, Frankham sat on two government committees providing advice on best practice for preserving and sustaining this iconic Australian species.

In a variety of projects, Frankham has assisted overseas practitioners in developing species management plans based on population genetic principles. In 2012, there were two competing taxonomic systems being used for lemurs, causing issues for their conservation. Different classification systems made it impossible to identify prospective mates when aiming to preserve population diversity. Frankham and his collaborators from zoos and the Australian Museum identified which classification system was applicable to the real-world problems of lemur conservation. This work set guidelines for appropriate classification systems for use in conservation – not only for lemurs but also for at-risk animal species in general.



INTERNATIONAL TEXTBOOK RESOURCE

Three professional reference books on conservation genetics, published in 2002, 2004 and 2010, are now used around the world. They were collaboratively written by Frankham and Professor David Briscoe of Macquarie, with Dr Jonathan Ballou from the Smithsonian's National Zoo in Washington DC. These reference books have been translated into Japanese, Chinese, Italian, Portuguese and Korean, and are the international benchmark for conservation genetic practice, with 11,000 book sales in 2011–16 alone. One resource was used as course material in staff training courses offered by the United States Geological Survey for more than a decade.

The key to these books' success in translating knowledge has been the layout, style and accessible language. In the mid-2000s, Cambridge University Press regularly used Frankham's book as an example of how to write and lay out a successful resource.

CONTRIBUTING TO FUTURE GENERATIONS OF CONSERVATION GENETICISTS

Between them, Frankham and Briscoe trained a generation of conservation geneticists and evolutionary biologists at Macquarie. Many of their postgraduate students have gone on to become influential researchers and/or practitioners in this field. For example, Jonathan Wilcken (MSc 2001) is now director of Auckland Zoo and a highly influential figure in the international zoo community. Associate Professor Adam Stow (PhD 2003) was lead editor for the 2015 book *Austral Ark*, which summarises the state of conservation biology in Australia and the greatest challenges and possible solutions, for a wide range of taxa and regions. Many current or past Macquarie students and staff contributed chapters to this book.

HELPING ANIMALS COPE WITH A CHANGING WORLD

As environmental change accelerates, translocations are becoming increasingly important for conservation of species. By teasing out the benefits of moving animal populations across landscapes to maintain genetic diversity and minimise inbreeding (genetic rescues), Macquarie has contributed to ensuring that endangered species do not suffer from genetic problems that could cause population-level collapse.

COLLABORATION WITH ZOOS AND MUSEUMS

Macquarie works closely with leading zoos and museums around the world, including the Smithsonian's National Zoo, the Saint Louis Zoo, the San Diego Zoo, Zoo Atlanta, the Chicago Zoological Society, and the Australian Museum. Additionally, Macquarie has collaborated closely with state government conservation programs in Australia and contributed to numerous advisory bodies in Australia and around the world.

Frankham has been a member of two species survival committees of the International Union for Conservation of Nature. Macquarie's work has permeated the practices of conservation around the world by working closely with leading practitioners at zoos and museums.

2018 EI RATINGS

Engagement	Effective
Impact	Significant contribution

ABOVE:

The cover of *Introduction to Conservation Genetics Second Edition*, courtesy of Emeritus Professor Richard Frankham

Agricultural sciences

In fisheries science, research strengths include work related to shellfish, particularly oysters, and to endangered species such as sharks.

Macquarie has strengths in crop and pasture production, fisheries sciences and horticultural production.

In fisheries science, research strengths include work related to shellfish, particularly oysters, and to endangered species such as sharks. Highlights include use of proteomic discovery to study biomarkers of heavy metal contamination in Sydney rock oysters, screening for probiotics in Greenshell mussels, responses of commercially important species to ocean acidification and disease and cellular responses to immunological challenges in sea urchins.

The largest activity relating to this discipline is centred in horticultural production, particularly in horticultural crop protection, oenology and viticulture. Some highlights include genetic studies of industrial strains of wine yeasts; yeast/flavour/aroma interactions in white wines; and lifespan, reproduction and diet consumption in the Queensland fruit fly, one of the most significant pests in Australia.

The research is characterised by rigorous fundamental biochemical and microbiological studies, which have extensive practical and industrial application. One measure of this is the funding profile for this discipline. Funding sources include the Grain Foods Cooperative Research Centre, Bayer Crop Science, the Grape and Wine Research and Development Corporation, the NSW Department of Industry and Investment, Dairy Australia, the Horticulture Innovation Research and Development Scheme and the US Department of Agriculture.

In food science, the Macquarie-led ARC Training Centre for Molecular Technology in the Food Industry brings state-of-the-art molecular analytical technologies into the mainstream of the food supply chain. In horticulture, Macquarie has joined the multi-million-dollar industry and government SITplus consortium, established to address the Queensland fruit fly pest problem.

In keeping with the applied nature of the SITplus research group, members have consulted widely on aspects of this research area such as in wine production and in pest control. Group members serve on editorial boards of key journals in the area. In horticulture, the SITplus group facilitates extensive collaboration with agricultural pest researchers, while in oenology and viticulture there are national links with the industry-funded Australian Wine Research Institute and a burgeoning international network of laboratories working on the synthesis of yeast.

2018 ERA RATINGS

Agricultural and Veterinary Sciences	5
Horticultural Production	5



WINE RESEARCH AND THE YEAST 2.0 PROJECT

Since 2014, Macquarie has worked with the NSW Department of Primary Industries (DPI) and the Australia Wine Research Institute (AWRI) in South Australia. A deep collaboration exists on the international Yeast 2.0 project, with Macquarie, the DPI and AWRI all contributing resources and expertise to the synthesis of two chromosomes in the yeast *Saccharomyces cerevisiae*.

The DPI has fully funded a research fellow at Macquarie to work on this project and committed \$500,000 to sponsorship of the project. By working with the DPI and AWRI, Macquarie can quickly translate basic and pure research into industry applications and better outcomes for the Australian wine industry.

The project is already producing secondary applications for other agricultural sectors. Findings from the collaboration are being applied to the optimisation of fruit ripeness and readiness for consumption as well as verification techniques for finding undesirable chemical residues in agricultural products. By working closely with government and industry, Macquarie ensures that biosensor technologies developed in yeast can be translated and applied to real-world problems.

Macquarie has completed a proof-of-concept project with AWRI on raspberry ketone and demonstrated the world's first synthetic industrial yeast in chardonnay. By collaboration with industry, Macquarie has demonstrated the use of a new knowledge domain to the Australian and global wine industries. Semi-synthetic yeast cell factories will enable the targeted blending of flavours to bring out novel taste profiles in the wines of tomorrow.

BAYER CROP SCIENCE

Macquarie's work with Bayer translated fundamental science on plant biochemistry through a prolonged and deep engagement with company headquarters in Belgium.

Macquarie academics have spent time in residence at Bayer in Belgium – more than six months in total across 2014–16 – as part of a commercial agreement signed in 2015 and then renegotiated in 2016. Bayer funded a postdoctoral position at Macquarie throughout 2014; the postdoctoral fellow on this project was then supported by Bayer Crop Science to continue research in its Ghent laboratories on a Marie Skłodowska-Curie Fellowship.

Macquarie's engagement with Bayer has ensured a two-way flow of resources and expertise and has been critical to the translation of pure research into applied outcomes.

Building a disease-resilient, more diverse oyster industry

In the early 2000s, the Sydney rock oyster industry was at risk of being wiped out by disease. Today, the industry has not only survived but grown and diversified. Macquarie, working with oyster farmers and the NSW DPI, has played a significant role in discovering how QX (Queensland Unknown) disease causes mass collapse and in improving selective breeding for disease resistance. Macquarie has also provided research-informed advice on the diversification of the NSW industry to include cultivation of Pacific oysters in New South Wales estuaries.

Through targeted support and financial contributions, Macquarie has provided its researchers access to the Sydney Institute of Marine Science. Macquarie financially contributed to the creation of a highly successful ARC Industrial Transformation Training Centre and a Biosecurity Research Centre. The University also maintains an on-campus aquarium.

During 2011–16, the total revenue derived from oyster sales had risen from \$38 million to \$44 million. This incorporates an increasing segment of Pacific oysters, almost \$5 million, demonstrating the impact of Macquarie's diversification advice.

QX disease kills the iconic Sydney rock oyster, the oldest and largest aquaculture industry in New South Wales. The disease is caused by a single-celled parasite, initially identified in Southern Queensland and Northern New South Wales. In 1994, the first outbreak of QX disease was recorded in the Georges River, eventually forcing the closure of the rock oyster industry in that estuary for several years. The Hawkesbury River was hit by QX disease in 2004 and, by 2006, it reduced oyster production to virtually nil.

Macquarie has collaborated closely with the industry and the DPI to identify the factors that trigger QX disease outbreaks and to evaluate strategies to reinstate oyster production in disease-afflicted estuaries. This has led to the diversification of the NSW oyster industry and changes to production methodology that have not only reinstated but also increased NSW oyster productivity.

2018 EI RATINGS

Engagement	Highly effective
Impact	Highly significant contribution
Approach to Impact	Highly effective



QX DISEASE

An initial conundrum with QX disease was understanding why mass mortality of oysters occurred in only a small subset of NSW estuaries in which the parasite is present.

Macquarie's research showed that low salinity, associated with heavy rainfall, causes stress in Sydney rock oysters, making them vulnerable to the parasite. Subsequent research with the NSW DPI identified additional environmental stressors, such as high temperatures and chemical contamination, as having the same detrimental effect on oysters. Macquarie demonstrated that the stressors cause a hormonal response resulting in the death of key blood cells responsible for controlling the QX-disease-causing parasite.

Understanding the mechanisms by which oyster immune systems are compromised by environmental stressors enabled Macquarie to work with the DPI to increase the effectiveness of selective breeding for QX resistance. In collaboration with the DPI and oyster farmers, Macquarie discovered about 30 genes that contribute to disease resistance. These genes are now being put to work in an overhauled selective breeding program.

As a result of the improved selective breeding program, the NSW oyster industry has transitioned from one based on wild capture to selective breeding. Sydney rock oyster sales have since risen from \$31.5 million in 2011 to \$36.9 million in 2016.

The second impact Macquarie had on the NSW oyster industry was in researching and advising on the diversification of the industry to include widespread aquaculture of the non-native Pacific oyster. The Pacific oyster is the most cultivated oyster species in the world and is not affected by QX disease. Though the Pacific oyster has been present in New South Wales waters since at least the mid-1980s, it was considered a noxious pest, with cultivation prohibited in all but one NSW estuary in Port Stephens.

After the QX outbreaks began, Macquarie began researching what would happen if Pacific oyster aquaculture was expanded into other NSW estuaries. Macquarie showed that the non-native oyster would not proliferate in the wild to displace natural populations of the native Sydney rock oyster. At high elevations on the shore, the non-native oyster did not display the same tolerance as the native oyster to periodic drying at low tide. The thin shell of Pacific oysters makes them more susceptible to predators.

Triploid Pacific oysters (with three chromosomes for sterility) have now been introduced under trial permits into estuaries across New South Wales. Macquarie's advice to the DPI has had a large impact on Pacific oyster revenue growth. In 2011, sales were \$4.2 million. In 2016, sales were \$5.8 million, contributing more than 10 per cent of industry sales in 2016 and more than a twofold increase on 2002.

Macquarie researchers Professor David Raftos and Associate Professor Melanie Bishop were key to the industry collaboration. Raftos was recognised for his contributions to the NSW oyster industry with the 2015 Eureka Prize for Rural Innovation. Bishop received the 2010 NSW Scientist of the Year award in the Environment, Water and Climate Change Sciences category, and was one of three national finalists for the Eureka Prize for Emerging Research Leader in 2013.

Macquarie has conducted follow-up investigations to see how the Sydney rock oyster selective breeding programs have impacted the genetics of wild oysters. These studies, collaboratively conducted with the DPI, have shown that farmed oysters do not compromise the genetic structure of wild populations as they do not persist in the wild. Additionally, follow-up studies on triploid Pacific oysters have shown that the risk of them becoming reproductively capable and becoming the 'cane toad of marine waters' is low.

QX disease outbreaks in the 2000s threatened the long-term viability of the iconic NSW oyster industry. Macquarie's work on introducing pair-mated breeding has increased Sydney rock oyster survivorship by 30 per cent after one generation. Key to this was characterising oyster genes in relation to the QX disease and the parasite that causes it.

Above:
Photo by Chris Stacey.

Information and computing sciences

There is also substantial activity in artificial intelligence (AI) and image processing, which includes contributions across many fields including language sciences and human interaction.

Macquarie's primary research strengths in Information and Computing Sciences are split between computation theory and mathematics, distributed computing, and information systems. There is also substantial activity in artificial intelligence (AI) and image processing, which includes contributions across many fields including language sciences and human interaction.

Macquarie's research draws from the University's Centre for Language Sciences – an integral part of the ARC Centre of Excellence in Cognition and its Disorders – and the Centre of Australian Category Theory. Professor Michael Sheng provides leadership in distributed computing and information systems. An ARC Future Fellow and past recipient of the prestigious Chris Wallace Award, Sheng is one of the leading scientists working on the 'Internet of Things' in Australia.

The strength of research in natural language process is evidenced by the investment of \$270,000 from Google and \$133,000 from CSIRO Data61 – and by US company Voicebox's contribution towards a Centre of Excellence to work on technologies that understand the human voice in a way that will enable richer interactions between computers and humans.

Significant interdisciplinary collaboration within the University (Education, Linguistics and Mathematics) is evidenced by joint publications, grants and higher degree research supervision. Collaborations are enhanced through visiting professorships from ETH Zurich, the National Institute for Research in Computer Science and Automation, the Fudan University and the Harbin Institute of Technology, and project-based fellowships in collaboration with CSIRO Data61.

More than \$3 million has been invested in spanning theory, distributed computing (the Internet of Things), machine learning and natural language processing. Although this is generated through primary research, much of that research is focused on real-world problems and some result in non-academic outputs that are publicly shared. Macquarie has produced open source software including the Kiama software for programming language analysis, which has been used by Kapow Software for analysis of their robotics software.

2018 ERA OUTCOMES

Information and Computing Sciences	4
Computation Theory and Mathematics	5
Information Systems	4
Artificial Intelligence and Image Processing	3
Distributed Computing	3



MACHINE LEARNING FOR DATA, VOICE AND SOCIAL NETWORKS

There is a strong presence at Macquarie in machine learning and natural language processing. Academics have worked on systems that expand the capacity for human-computer communication via speech. These activities have been supported by an ARC Linkage Grant with partner KS Computers; there has also been significant funding from Google, Voicebox Australia technologies, the Capital Markets Cooperative Research Centre and Microsoft to work on problems regarding the extraction of information from texts and speech.

Meanwhile, other academics have constructed large datasets for use in applied research; for example, eight years of building fire alarm data has been compiled from the Fire and Rescue NSW in order to understand and reduce the number of false alarms.

In the health domain, academics have applied their expertise in virtual agents to solve problems associated with enhancing wellbeing; much work in this domain has direct impact in providing advisory systems, and funding from the Australian Bladder Foundation has contributed to this. Researchers have looked at how technology can help the ageing population live better in their own homes. End users have included South Australian aged care service providers such as the SA Innovation Hub, ACH Group, Aged and Community Services Australia and Barossa Village and Helping Hand, Southern Cross Care.

CYBER SECURITY AND TRUSTED COMPUTING

Macquarie's research in the theory of computer science has many applications in distributed computing and security. Academics have been active in projects that involve the computing industries, with examples including Bell Labs, Covata, Semantic Software Asia Pacific, and Oracle Labs. These activities range from mentoring students to supervising research-style projects that enable young researchers to interact with industrial problems.

In 2016, the University established the Optus Macquarie Cyber Security Hub, which is a multidisciplinary research, education and thought leadership organisation that seeks solutions to societal problems in the cyber security domain. As well as engaging with Optus directly, academics have looked at topics that require a multidisciplinary solution, and therefore the hub, which is led by the Department of Computing, also includes academics from Finance and Law.

Hub members have researched questions related to electronic voting in Australia, which is a typical multidisciplinary challenge as it includes both a social and security perspective. Academics have collaborated with the NSW Electoral Commission via the Electoral Regulation Research Network Research Collaborative Initiative, and hub members have participated in the NSW Electoral Commission's decryption ceremony of iVote tallies. Researchers are engaged in the analysis of cyber threats in the computing industry more generally and are actively looking at how to price those threats for insurance purposes. An early partner in this space is Risk Frontiers, now a University spin-off company.

Voicebox research and development

Voicebox has supplied natural language technology worldwide, with conversational agents deployed in many of Toyota's vehicles and Samsung's smartphones and tablets. The technology has been translated into more than 20 languages and has enabled millions of people to interact with their devices using their voice.

The proof-of-concept development for this technology was completed on campus at Macquarie University. Voicebox Australia is a research and development subsidiary of the Seattle-based firm.

The firm chose to establish their Australian office at Macquarie due to the University's international reputation in natural language processing, which has had global impact on voice technology interfaces and the underpinning translation of natural language to device function calls.

Voicebox's natural language technology has had a fundamental impact on the conversational artificial intelligence (AI) market and has enabled hundreds of millions of people to interact with their devices using their voice. Macquarie has been integral to this impact, as hosts of the research and development office of Voicebox Technologies in Australia.

Voicebox's technology is ranked among the most creative and impactful in the world, and it has shipped millions of products in more than 20 languages. These technology solutions are akin to the Google Assistant, Apple's Siri and Amazon's Alexa. Voicebox supplies conversational agents to third parties that do not want to rely on the technological solutions of Google, Apple, Microsoft or Amazon.

Voicebox's technological solutions are commercialised, packaged and branded by third parties as competitive alternatives to the major conversational agent offerings in the automotive, mobile and home markets.

AHEAD OF THE CURVE

Voicebox entered the conversational AI market more than a decade before many of their contemporaries. However, in 2014–15 the executive management of Voicebox knew that their technology required research and development to remain competitive with emerging entrants into the market. Management began exploring locations that had the necessary technical capabilities as well as a mature pipeline of higher degree research graduates.

The University's world-leading expertise in natural language computation made it an attractive location for Voicebox. The company also required a commercially minded research group that could take not only their research but also the best research, and translate this research into proof-of-concept product offerings for the company's prospective clientele.

2018 EI RATINGS

Engagement Effective

Macquarie relieved Professor Mark Johnson of 80 per cent of his academic load at short notice, so he could start as chief scientist at Voicebox Australia. This collaboration was the result of Macquarie's support for decades of world-leading capability in natural language computation. The research concentration built and sustained by the University has enabled a pipeline of world-ready higher degree research candidates. This ensured that Voicebox Australia had a skilled workforce of potential recruits. The University's internationally recognised reputation for basic research persuaded Voicebox that it was the right partner for creating global impact.



RAPID TRANSLATION

The speed at which research is completed within academia and industry is vastly different. In 2016, Voicebox had acquired a major client and needed to offer them proof-of-concept within a short timeframe. With executive sponsorship from Macquarie's Deputy Vice-Chancellor (Corporate Engagement and Advancement) and Deputy Vice-Chancellor (Research), Macquarie was able to meet and match the short turnarounds required.

Professor Mark Johnson was relieved of 80 per cent of his teaching and research so that he could establish an Australian office for Voicebox and develop a proof-of-concept model immediately. The Australian office is a research and development subsidiary of the Seattle-based firm. The team used basic research in natural language translation (eg English to French) to develop AI models that translate natural language into device function calls, such as with the command 'call home'.

COMPETING WITH GIANTS

Macquarie's work with Voicebox enables the company to operate alongside global technology behemoths such as Google and Apple. Voicebox fills a niche in the market, and Macquarie has assisted in the company's program of technology modernisation. This is a rare academic-corporate match.

Voicebox Australia not only enables companies like Samsung and Toyota to offer conversational AI product alternatives, they innovate world-leading approaches to the technology. Macquarie's contribution to this has fundamental impacts on the structure and competition of the conversational AI market, which has upstream and downstream impacts for Voicebox's clients.

If Samsung were to use a conversational AI solution provided by Google, they would cede control of their data and their customers' data to Google. Macquarie's work with Voicebox enables Samsung to maintain ownership and control over their proprietary data.

Companies such as Toyota are concerned that software defines the customer's experience of hardware. Similar to the difficulties which Hewlett-Packard and Intel face in differentiating their product for customers, companies such as Toyota fear this scenario in the automotive sector. Ensuring that third-party applications for voice technology are available enables companies to control the risks around customer experience and preserve their brand identity separate to that of Google or Apple.

THE LONG ROAD TO IMPACT

Voicebox's Australian office is an example of how basic research can be leveraged to generate global impact on a massive scale. While this impact was generated on a corporate project timeline that occurred in a matter of months, the academic pathway to this impact was decades long.

The global impact cannot be separated from the decades of work Macquarie has done on natural language computation. Nor can it be separated from the University's commitment to sustaining this world-class research capability. When companies look to partner with and leverage university research, they seek capability and commitment.

Macquarie was able to demonstrate this capability and commitment. At the heart of this project's impact is the ability of Macquarie to be nimble when required to and to maintain a long-range and unwavering strategic focus founded in basic research.

Engineering

Research is dominated by electrical and electronic engineering, with emerging strengths in biomedical, mechanical and materials.

Engineering research at Macquarie University is dominated by electrical and electronic engineering, with emerging strengths in biomedical, mechanical and materials engineering. The majority of publications come from microwave and wireless communications activities in the School of Engineering, which has undergone considerable growth. The addition of mechanical and mechatronic undergraduate engineering has resulted in significant research activities in various branches of engineering: biomedical, resources, materials, mechanical, chemical, and environmental.

The area of microwave and wireless communications was seeded by a joint research program with CSIRO, which resulted in the commercial development of wi-fi through Radiata Communications and its subsequent sale to CISCO Systems. This has been a significant source of commercialisation income.

The strengths of the various groups within this discipline are reflected by:

- the electromagnetic and antenna group having developed strong links with CSIRO in the areas of smart materials and propagation
- the nonlinear electronics group having established several external partnerships and built a world-class facility for test and measurement
- the nonlinear optics group having close collaborations with the University's Photonics Research Centre
- the wireless communications and networking group having developed a strong link with CSIRO and Telstra in the area of 5G mobile and the Internet of Things.

Academic excellence is further reflected by the School of Engineering's Institute of Electrical and Electronics Engineers (IEEE) fellows as well as executive and committee members of IEEE societies and local chapters. Several senior academics are regular grant assessors for the ARC and international granting bodies, and are active members of technical review boards of international journals.

Macquarie undertakes collaborations and linkage programs with CSIRO Data61, Agilent, NHEW Research, the Defence Science and Technology (DST) Group, the US Air Force, WIN Semiconductors, and MACOM. In conjunction with these collaborations, there has been international support from Cadence and from Applied Wave Research, which provide significant in-kind support in the form of commercial design suites.

2018 ERA OUTCOMES

Engineering	4
Electrical and Electronic Engineering	5
Materials Engineering	5
Biomedical Engineering	3



WIRELESS

The Future Wireless Networking group has partnered with Telstra in a multi-year project modelling and optimising aspects of their 3G/4G mobile networking operations. The project is a true collaboration with researchers from both Macquarie and Telstra working closely together to solve practical big-data challenges across its nationwide network.

The research group also engages with Optus through an Optus-Macquarie cadetship program, which partners Macquarie researchers with Optus engineers in the supervision of final-year undergraduate thesis projects. This scheme delivers on a number of engagement fronts, including partnering researchers with industry and engaging students on practical real-world projects.

The group maintains very strong links with CSIRO Data61 in the areas of 5G mobile, Internet of Things, and defence applications in further partnership with the DST Group. They host a professorial chair in Wireless Communications, funded from a \$2 million Science Industry Endowment Fund award, and have ongoing funded projects, including a multi-year project on wireless position location. Through this, Macquarie researchers contribute directly to projects with end-user industry companies that are working with the CSIRO on industrial research and development projects. These engagements have been a real partnership with researchers from the external organisations working closely together, and have led to new research outcomes, and many co-authored papers in the top international journals and conferences in the area, including winning two prizes for best paper.

These engagement activities build on fundamental research advances made on a number of ARC Discovery Projects funded in the group, which have also included further partner investigator engagements with leading researchers at international universities. The group's strong international track record of fundamental research work in the area of mobile communications has been key to developing its external partner engagements.

ANTENNAS

The Antenna group partnered with BCS Innovations to develop a method that converts a wireless biotelemetry system to an implantable wireless telemetry system. With results being published in the top refereed journal on microwave technology, *IEEE Transactions on Antennas and Propagation*. The group had a long three-part project to investigate antenna issues associated with the next generation hearing implant devices developed and marketed by Cochlear, an Australian company and the world leader in the hearing implant market.

The group has worked with small-to-medium enterprises including Silicon Controls, for whom they modelled the electromagnetics of gas control wireless units. On the international front, the group has had a three-year joint research project funded by Australian and Indian governments under the Australia-India Strategic Research Fund. In addition to many academic outcomes, the group produced commercially valuable intellectual property, which is being commercialised by Macquarie.

Among the end users expected to benefit from research on innovative antenna beam steering are billions of people worldwide who do not have regular internet access at present: regional Australia where internet is relatively slow, emergency services including fire fighters and ambulances in regional areas, and trains, buses and caravans travelling through remote areas where fast wireless broadband services do not exist. The group has also contributed to radio telescope focal-plane antenna arrays research conducted by CSIRO staff. This research has contributed to the Australian Path Finder telescope and forthcoming Square Kilometre Array radio telescope.

Above:
Photo by Chris Stacey.

Faster and more powerful wireless data transfer

Affordable automotive radars, mobile (5G) systems, wireless high-definition video, and handheld security scanners all require superior integrated circuits (ICs) operating at higher frequencies and powers than the systems they replace. Telecommunication companies around the world are creating these new ICs using Macquarie's modelling methodologies in wireless integrated circuit design.

Macquarie's methodology is available commercially and has provided major benefits to telecommunication providers, medical technologies

and defence. For consumers, this has led to faster internet access, more efficient medical scanning and more accurate airport security scans.

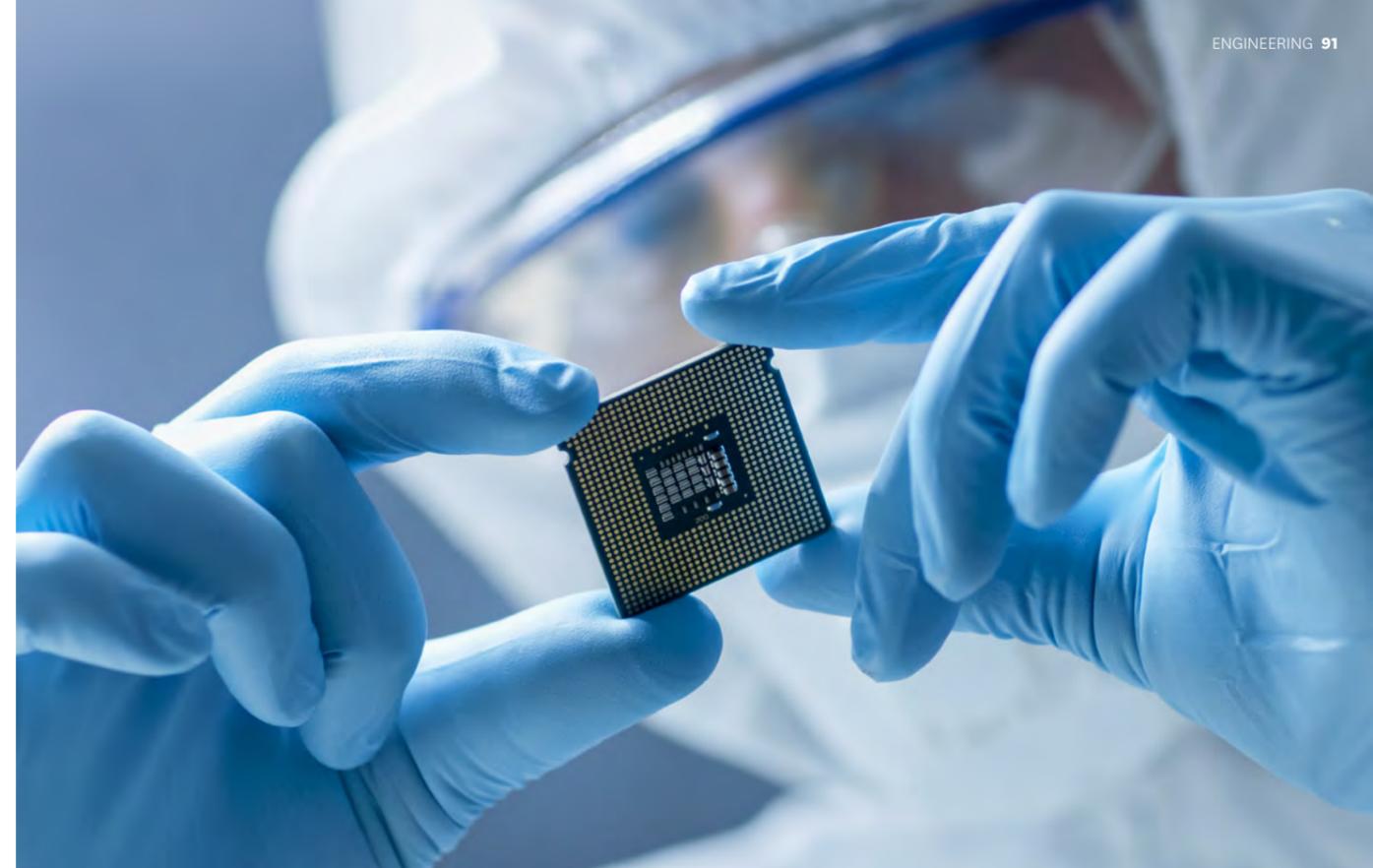
Integrated circuit designers and manufacturers from around the world use technology developed at Macquarie to produce wireless ICs. The technology is used in products ranging from digital computer chips to analogue sensors, which translate to faster internet access, more efficient medical imaging and more accurate airport security scans for consumers.

Macquarie's Reconfigurable Electronics group includes a unique combination of world-leading experts in measurement technology, mathematics modelling and circuit design. This specialised expertise has led to a series of innovative transistor models, including the Parker-Skellern model (released in the early 2000s), Meerkat (2010 – present) and ASM-HEMT (2016 – present). These models are available commercially and have been adopted in test equipment circuits and commercial software by semiconductor manufacturers and defence-sector users.

Advanced measurement tools from Macquarie enable users to more accurately pinpoint the performance of specific

elements in a circuit. These tools form the basis of the Agilent (now Keysight) radio frequency measurement system, which was commercialised in the 1990s and subsequently made more accurate. The system has been widely adopted by telecommunications, medical and defence industries since 2011 and helps to measure radio frequencies more accurately by removing unwanted electronic 'noise'. More precise radio frequency readings have resulted in faster and more accurate airport security scans, medical imaging and radar technology.

Close collaboration with industry and the reinvestment of a large funding windfall enabled the international impact of models, measurements and methodologies pioneered by the Reconfigurable Electronics group. Early on, the University recognised that it could maximise adoption of these technologies by making its intellectual property freely available while retaining the rights. This far-sighted approach has sustained collaborations across multiple industry partners. Macquarie complemented this approach by providing end users with research, teaching, training and technical expertise. The flexible structure of higher degree research programs at Macquarie encourages employees of end users to undertake postgraduate research at the University and translate this research into practice.



SAVING INDUSTRY TIME AND MONEY

The Macquarie tools deliver competitive advantage to industry. This is demonstrated by Macquarie's relationship with MACOM Technology Solutions, a US-based producer of semiconductor technologies for optical, wireless and satellite networks. The Macquarie-MACOM relationship began when publications by Macquarie's Professor Tony Parker caught the attention of Mimix Broadband, a supplier of high-performance semiconductors.

Parker's research explored thermal and trapping effects, known to contribute to inaccurate radio frequency readings. This was a key concern for Mimix at the time, which was leading to rising design costs due to inaccurate models. In 2008, Mimix implemented Macquarie's models in various electronic devices and found them superior to those provided by its IC manufacturer, despite the manufacturer's more intimate knowledge of the transistors. Due to the accuracy of Macquarie's methods, Mimix's designs could function as specified the first time after manufacture, cutting months and years from new product development.

Mimix then collaborated with Macquarie on research to advance the measurement and modelling capability beyond what was available in commercial simulators. The result of this collaboration was a faster design cycle and improved product performance, contributing to Mimix being acquired by MACOM in 2012. Announcing the merger, MACOM's CEO referred to Mimix's "deep expertise" in developing high-performance, multifunction solutions.

MACOM has spread the Macquarie models and measurement techniques internationally. The Macquarie model enabled MACOM to be the first to market in 2013 with an entirely new product capable of sending the highest rates of data over long-distance transmissions. For the consumer this meant higher data rates and longer-distance transmission, meaning faster download rates. The product was sold to telecommunication providers from 2015, and in 2016, demand for the Macquarie-MACOM product grew tenfold from one customer alone.

MACOM then designed an even faster product that performed at four times the frequency at which the manufacturing process had been measured. This took these products well beyond the manufacturer's expectations. This gain in performance was purely based on the increased accuracy of Macquarie models and measurements.

In 2016, MACOM promoted its North Sydney design centre manager – who originally championed the Macquarie models – to a new role focused on internally and externally commercialising the benefits derived from the Macquarie partnership.

The Mimix/MACOM success led to other industry and government groups starting to work closely with Macquarie on measurement and modelling. Linear Technology, now part of Analog Devises (US), partnered with Macquarie in 2016 to apply the University's measurement and model methodology to traditional silicon complementary metal-oxide-semiconductor processing, a fundamentally different technology. WIN Semiconductors (Taiwan, 2010–15) and packaging manufacturer Lintek (Queanbeyan, NSW, 2014 – present) used Macquarie's models to enhance the way their products and services work with design flows, from manufacturing ICs to product development.

Macquarie's work has fundamentally impacted high-performance electronic design and revolutionised the design process for IC manufacturing. This research has impacted on billions of people around the world.

2018 EI RATINGS

Engagement	Effective
Impact	Significant contribution
Approach to Impact	Effective

Global Mercury – time to act

The United Nations Minamata Convention on Mercury is a global multilateral environmental agreement that addresses the adverse effects of mercury. It does this through practical actions to protect the environment and human health from anthropogenic mercury emissions. The convention was drafted after extensive intergovernmental, industry and civil society consultations and now has 128 signatories and 89 ratifying parties.

Macquarie took a lead role in mercury research, in national and international expert groups, in reports that facilitated the negotiation of the convention, and in the Australian Government's policy position with respect to the convention. Macquarie's research has contributed to the impact the convention has had on mercury exposure worldwide.

Mercury is a major global, regional and national challenge in terms of threats to human health, particularly to the health of pregnant women and babies worldwide through the consumption of contaminated fish. As seafood provides 2.5 billion people with at least 20 per cent of their animal protein, this can have major impacts on the global burden of disease. In small island states and coastal regions, this amount can increase to 50 per cent of animal protein consumption.

The benefits of reducing exposure to mercury are large. A US study estimated that by 2050, cumulative lifetime benefits from the convention for affected individuals would be valued at \$339 billion. The United Nations showed leadership and commitment by leading an intergovernmental process and high-level meetings via intergovernmental negotiating committees to develop the legally binding convention, which was agreed in 2013 and has now come into force.

Professor Peter Nelson, together with a Macquarie team including Professor Vladimir Strezov and Dr Tony Morrison, initiated a research program on mercury with the support of government and industry to explore the contribution of industrial emissions sources such as coal combustion in Australia. Nelson identified a major error in global estimates of Australian emissions and was instrumental in having the estimates reduced by about tenfold. He was engaged by the Australian Government to undertake studies of our mercury sources, transport and fate, and of existing legislation and guidelines relevant to mercury control. The resulting reports were influential in informing Australia's response to the development of the convention, including the Final Regulation Impact Statement on the National Phase down of Mercury. This statement estimated a benefit: cost ratio to Australia of 2.5:3.5 of ratifying the convention.



Macquarie's work on the convention identified the importance of industrial sources including coal combustion in large coal-fired power stations. It also revealed that the smelter at the Kalgoorlie Gold Mine was responsible for 50 per cent of Australia's mercury emissions. The magnitude of this contribution was a leading driver for the mine owners to develop new process technology, which replaced the smelter and eliminated the mercury emissions.

Macquarie's research and reports to government led to Nelson's membership invitation to the expert group led to the Global Mercury Assessment 2013 (GMA) report. The GMA is facilitated by the United Nations every five years and is a major study of sources, emissions, releases and transport of mercury as well as its impacts in the environment. Nelson contributed expert advice on emissions in Australia and Oceania, and corrected another error in the way coal combustion emissions were estimated globally. In 2016, he was invited to join the expert group preparing the GMA 2018 report.

Macquarie has operated as a platform for engagement, enabling policy change and its associated impacts. The University has supported collaborative research partnerships with agencies such as the CSIRO, the Cooperative Research Centre for Coal in Sustainable Development and the Australian National Low Emissions Coal Research and Development organisation. Macquarie's support has contributed to the downstream impacts on national and international policy.

The text of the convention is accompanied by a range of guidance documents to support its implementation. One of the most substantial of these relates to industrial emissions from the coal, smelting, cement and waste incineration sectors. Nelson was nominated by Australia as one of only three experts to represent the JUSCANZ group

of nations – comprising Andorra, Australia, Canada, Iceland, Israel, Japan, Liechtenstein, Monaco, New Zealand, Norway, Switzerland and the United States – for the development of this guide. The United Nations approved his appointment and the expert group worked throughout 2014–15 on drafting the guidance documents, which were ultimately approved by the Intergovernmental Negotiating Committee in Jordan in 2016. Nelson was chosen to be the lead author for the guide on smelting and roasting, and contributed to the drafting and finalisation of the overall document.

Macquarie's contribution to the GMA and to the international guidance on non-ferrous smelting and roasting, and industrial sources of mercury more broadly, directly supports the implementation of the convention. This has had subsequent public health benefits in both the short and long term by establishing an internationally agreed process for eliminating or reducing the total stocks of background mercury in the environment. National and global reductions in mercury emissions have far-reaching impacts. As mercury has a long life in the environment, any reduction contributes to environmental quality and human health in the future.

INTERDISCIPLINARY IMPACT

Macquarie's contributions to national and international policy on the management of mercury emissions has impact across multiple domains. The environmental impacts of a global reduction in mercury emissions realise benefits for human health but are also built on engineering approaches to mercury control in industrial processes. This includes specialised analytical chemistry for measurement of trace quantities of mercury and global atmospheric models of mercury transport. These environmental and public health outcomes have been achieved by Professor Nelson, with the support of Macquarie, through a deep and sustained engagement with an international framework underpinned by international chemical policy, treaties and law.

Macquarie's contributions draw from foundational interdisciplinary research in the chemical, earth, environmental and engineering sciences, linked to a long and sustained engagement in the policy processes of both Australia and the United Nations. The mechanisms of international law that connect Australia to the United Nations further facilitated and amplified the global impacts of the convention.

INTERDISCIPLINARY

2018 EI RATINGS

Impact	Significant contribution
Approach to Impact	Effective

Cross-cultural biodiversity surveys in eastern Arnhem Land

Macquarie, in collaboration with the remote community of Ngukurr in South East Arnhem Land, has combined Indigenous and Western biodiversity data through a relationship with the Atlas of Living Australia and The Nature Conservancy. Indigenous knowledge of regional biodiversity made significant contributions to ways of knowing and managing biodiversity.

Macquarie employed more than 50 people from Ngukurr who were previously unemployed, and in 2016, with the local Aboriginal Yugul Mangi Rangers established the Yangbala Ranger group, a youth empowerment project which continues today. Fifty young people aged 18–35 were paid to work on the project while mentoring senior school children. Three young people went on to study at Macquarie, and they are the first people from the Ngukurr community to attend university in more than 30 years.

Through collaborative fieldwork with the Yugul Mangi Indigenous Rangers, Elders and young people in the remote community of Ngukurr in South East Arnhem Land, Macquarie created two-way information exchange with the Atlas of Living Australia (ALA).

The team demonstrated the value of the biodiversity data held in the ALA to Indigenous Australians and has also demonstrated the value of Indigenous knowledge to non-Indigenous Australians through promotion through the ALA. Overall, Macquarie has promoted cross-cultural ways of knowing and managing biodiversity through many communication channels including the ALA website.

The work completed by the community of Ngukurr and Macquarie features on the ALA website and includes film and photos. The website details how a remote Aboriginal community used and contributed to the ALA for the benefit of their community, local land management and Australian conservation.

Macquarie continues this work with ongoing funding from the ALA, The Nature Conservancy and an Australian Government Citizen Science grant. We have also expanded this collaboration into neighbouring communities and Indigenous Protected Areas of eastern Arnhem Land spanning about 30,000km². The project has involved more than 300 Aboriginal people of eastern Arnhem Land, some of whom have gone on to study at university.

In each survey conducted several times each year since 2014, Macquarie ran western scientific and Indigenous surveys of plants and animals. The Indigenous methods include searching for animals, searching for plants, tracking, and looking for scats. Elders taught the people involved about the language and cultural knowledge associated with the species found and the places visited.

SOCIO-ECONOMIC IMPACT

Local community members were involved in the project from start to finish. Their engagement in the project transferred skills and confidence in project management, digital literacy, finding and learning about plants and animals, speaking traditional languages, speaking English to stakeholders and conducting training.

CULTURAL IMPACTS

The project team synthesised multiple language names and cultural knowledge about plants, animals and places. Traditional languages and cultural knowledge are highly endangered in the South East Arnhem Land region, which was recently declared an Indigenous Protected Area. More than seven traditional language groups live in the centralised town of Ngukurr. The main language of Ngukurr is now Kriol, which draws on English, Marra and some other language groups.

Macquarie developed a 140-page multilingual field guide for use in surveys. The guide includes 275 species and known language names for each species. Macquarie created an innovative online version of these plant and animal language names with accompanying descriptions. Development of these products has built local capacity in word processing, PowerPoint, online data entry and an understanding of the biodiversity of the region.



Since early 2017, Macquarie's Indigenous engagement service Walanga Muru has provided support for the students who now study at the University and other Aboriginal staff associated with this project. Macquarie acknowledges the important contribution of all Aboriginal and Torres Strait Islander peoples to the University and the nation, and respects the knowledge of the oldest surviving culture in the world.

ENVIRONMENTAL IMPACT

In partnership with local organisations, Macquarie has substantially increased the documented locations of species in eastern Arnhem Land and added these to the national ALA online database. The team found new populations of near-threatened species, expanded the known range of threatened species and found two species undescribed by Western science. By building local biodiversity knowledge, local people are learning firsthand about the increasing environmental threats to the region, including altered fire regimes, weeds, climate change, depopulation and invasive animals such as cats, cane toads, buffalo, pigs and horses.

Through the Australian Government's Working on Country program, local Indigenous rangers who manage the South East Arnhem Land Indigenous Protected Area were integral to the research. With Macquarie, they built a stronger evidence base for local land management decisions and assisted in improving local knowledge about the condition of species across the Indigenous Protected Area. There is now an enhanced local understanding about how to best protect regional biodiversity from new threats to Country, such as altered fire regimes, feral animals and weeds. Elders, rangers, other Aboriginal collaborators and non-Aboriginal participants also learned some traditional language associated with these species and places that were not widely known or shared before.

Macquarie recognises the diversity of Indigenous peoples – including the more than seven traditional language groups that live in the centralised town of Ngukurr – who contributed to this project.

Macquarie recognises the rights of these communities to self-determination and works to empower Aboriginal collaborators in the project. This project builds a stronger evidence base for local land management decisions to maintain, control, protect and develop local cultural heritage, including the traditional knowledge of the South East Arnhem Land region.

Macquarie acknowledges the intellectual property of those who have contributed to the research and also works to ensure ongoing mutual benefits arising from this partnership.

INDIGENOUS

2018 EI RATINGS

Impact	Highly significant contribution
Approach to Impact	Highly effective

APPENDIX A

UNIVERSITY RESEARCH CENTRES

Macquarie University Planetary Research Centre
Director: Assoc/Prof Craig O'Neill
E: craig.oneill@mq.edu.au

Centre for Elite Performance Expertise and Training (CEPET)
Director: Prof John Sutton
E: john.sutton@mq.edu.au

MQ Photonics Research Centre
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APPENDIX B

CHANGES AT 2-DIGIT FOR CODE

2-Digit FoR Code	Description	ERA 2012 Rating	ERA 2015 Rating	ERA 2018 Rating	As a % of each Rating	At or above world standard	Above or well above world standard
02	Physical sciences	5	5	5	ERA rating 5		
05	Environmental sciences	5	5	5			
07	Agricultural and veterinary sciences	-	5	5			
06	Biological sciences	4	4	5	ERA rating 4	ERA rating 3, 4 and 5	ERA rating 5 and 4
01	Mathematical sciences	2	4	4			
04	Earth sciences	5	4	4			
11	Medical and health sciences	2	4	4			
20	Language, communication and culture	4	4	4			
22	Philosophy and religious studies	4	4	4			
03	Chemical sciences	3	3	4			
08	Information and computing sciences	3	3	4			
09	Engineering	3	3	4			
13	Education	3	3	4			
17	Psychology and cognitive sciences	3	4	3	ERA rating 3		
18	Law and legal studies	4	4	3			
21	History and archaeology	4	4	3			
14	Economics	3	3	3			
15	Commerce, management, tourism and services	2	3	3			
16	Studies in human society	3	3	3			
19	Studies in creative arts and writing	3	3	3			

CHANGES AT 4-DIGIT FOR CODE

4-Digit FoR Code	Description	ERA 2012 Rating	ERA 2015 Rating	ERA 2018 Rating	As a % of each Rating	At or above world standard	Above or well above world standard
0101	Pure mathematics	3	5	5	ERA rating 5	ERA rating 3, 4 and 5	ERA rating 4 and 5
0201	Astronomical and space sciences	5	5	5			
0205	Optical physics	4	5	5			
0401	Atmospheric sciences	3	5	5			
0502	Environmental science and management	5	5	5			
0602	Ecology	4	5	5			
0603	Evolutionary biology	5	5	5			
0604	Genetics	2	5	5			
0607	Plant biology	4	5	5			
1103	Clinical sciences	2	5	5			
1109	Neurosciences	1	5	5			
1112	Onocology and carcinogenesis	-	5	5			
0608	Zoology	3	4	5			
0802	Computation theory and mathematics	4	4	5			
0906	Electrical and electronic engineering	3	4	5			
2203	Philosophy	4	4	5			
0303	Macromolecular and materials chemistry	-	-	5			
0706	Horticultural production	-	-	5			
0912	Materials engineering	-	-	5			
0301	Analytical chemistry	4	4	5			
0501	Ecological applications	5	4	5			
0206	Quantum physics	5	5	4	ERA rating 4		
0406	Physical geography and environmental geoscience	5	5	4			
0304	Medicinal and biomolecular chemistry	-	-	4			
0402	Geochemistry	5	4	4			
0403	Geology	5	4	4			
0404	Geophysics	5	4	4			
0605	Microbiology	4	4	4			
1102	Cardiovascular medicine and haematology	3	4	4			
2001	Communication and media studies	4	4	4			

CHANGES AT 4-DIGIT FOR CODE

4-Digit FoR Code	Description	ERA 2012 Rating	ERA 2015 Rating	ERA 2018 Rating	As a % of each Rating	At or above world standard	Above or well above world standard			
2004	Linguistics	4	4	4	ERA rating 4 and 5	ERA rating 3, 4 and 5	ERA rating 4 and 5			
2005	Literary studies	3	4	4						
2201	Applied ethics	3	4	4						
0806	Information systems	2	3	4						
1303	Specialist studies in education	4	3	4						
1502	Banking, finance and investment	3	3	4						
1601	Anthropology	3	3	4						
1608	Sociology	3	3	4						
1113	Ophthalmology and optometry	-	-	3				ERA rating 3		
1117	Public health and health service	2	-	3						
1302	Curriculum and pedagogy	-	-	3						
1701	Psychology	3	4	3						
1801	Law	4	4	3						
1505	Marketing	2	2	3						
2103	Historical studies	4	4	3						
0102	Applied mathematics	-	-	3						
0601	Biochemistry and cell biology	3	3	3						
0801	Artificial intelligence and image processing	3	3	3						
0805	Distributed computing	3	3	3						
0903	Biomedical engineering	-	3	3						
1301	Education systems	3	3	3						
1402	Applied economics	3	3	3						
1503	Business and management	3	3	3						
1604	Human geography	3	3	3						
1606	Political science	3	3	3						
1902	Film, television and digital media	-	3	3						
1904	Performing arts and creative writing	3	3	3						
2002	Cultural studies	3	3	3						
2003	Language studies	3	3	3						
2101	Archaeology	3	3	3						

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