Australian Academy of Science

MATHEMATICAL SCIENCES | AUSTRALIAN ACADEMY OF SCIENCE | MARCH 2016

The mathematical sciences in Australia

A vision for 2025

Peter Gavin Hall
20/11/1951 – 9/01/2016

The development work for this decadal plan was led with characteristic energy, acumen and sensitivity by Professor Peter Gavin Hall AO FAA FRS FASSA FAustMS. His untimely death following a prolonged illness has deprived the Australian mathematical sciences community of one of its brightest stars. The remaining executive members dedicate the plan to his memory.

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Mathematics is vital for Australia's future.

Executive summary

The mathematical sciences[1] sit squarely at the centre of modern life. They underpin our financial systems and all our information and communication technologies. They form the core of our attempts to predict the future of economic, social and environmental systems. They also drive new advances across a growing array of fields in science and technology.

The importance of the mathematical sciences is expected to increase over the next decade. To ensure that Australia benefits fully from the substantial strength of its mathematical sciences community during this decade, this plan sets out the following four objectives.

- Give all Australian schoolchildren access to outstanding mathematics teachers.
- Guarantee high standards of mathematical sciences teaching at Australian tertiary institutions.
- Achieve both global and local impact for Australian research in the mathematical sciences.
- Ensure that Australian society is capturing the benefits of mathematics-based technologies.

The plan makes 12 recommendations that align with these objectives. These recommendations are the product of extensive consultation with mathematical scientists working in schools, universities, government agencies and industry. They are based on an analysis of opportunities and challenges and are accompanied by commitments made by the mathematical sciences community. The discipline, through the Australian Academy of Science's National Committee for Mathematical Sciences, will be formally monitoring progress on the recommendations on an annual basis.

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1 These encompass mathematics, statistics and the range of mathematics-based disciplines including teaching, teacher education and educational research.

Of the 12 recommendations, the following three stand out for their particular urgency and importance.

1.1 Australian governments, schools and universities should urgently increase their provision of professional development for existing out-of-field school teachers of mathematics and enhance their commitment to the recruitment and retention of new, properly qualified staff.

2.1 Australian universities should immediately plan for the staged reintroduction of at least Year 12 intermediate mathematics subjects as prerequisites for all bachelors programs in science, engineering and commerce.

3.1 Australian universities should collaborate with the discipline to source seed funding for a new national research centre in the mathematical sciences with the objective of enhancing connectivity with industry and strengthening the international collaboration and visibility of Australian research in mathematics and statistics.

These are the plan's three key priorities. In pursuing the objectives of this plan, the mathematical sciences community makes the following commitment.

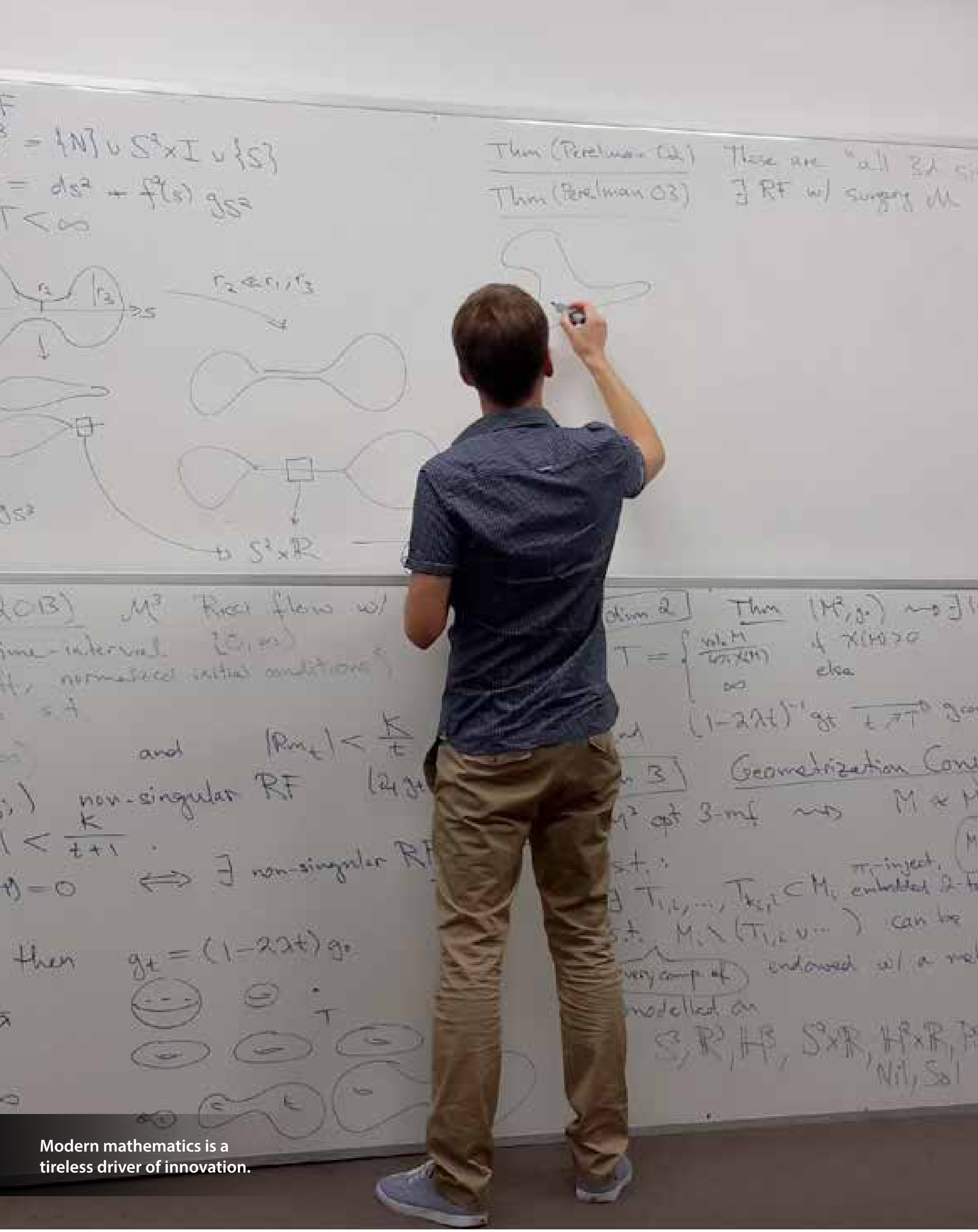
> ***We undertake to work closely with universities, school authorities and the Australian Government to achieve our objectives for mathematics education in schools and universities, and to ensure the growth and impact of Australian research and its social benefits. We take principal responsibility for creating public awareness and understanding of our work, to enable the realisation of its benefits and to inspire tomorrow's teachers, students and researchers.***

It is the strongly held belief of Australia's mathematical sciences community that by implementing the decadal plan with specific emphasis on these three key priorities, we can achieve the following outcomes.

- Australian students at all levels will receive the mathematical education they need to lead fulfilling lives and to maximise their contribution to Australian society in an increasingly mathematical world.
- There will be a vibrant community of mathematicians and statisticians who advance the frontiers of the discipline for the broader benefit of Australian society.

These outcomes will contribute significantly to Australia's growth through to 2025 and beyond.

Contents



Modern mathematics is a tireless driver of innovation.

1 The mathematical sciences in Australia

"THE MATHEMATICAL SCIENCES HAVE LONG BEEN LINKED TO NATIONAL COMPETITIVENESS, BUT THEIR SIGNIFICANCE FOR AUSTRALIA IS ACCELERATING."

The mathematical sciences sit squarely at the centre of modern life. They underpin our financial systems and all our information and communication technologies. They are fundamental to our attempts to predict the future of economic, social and environmental systems. They also drive new advances across a growing array of fields in science and technology.

What are the mathematical sciences?

The term 'mathematical sciences' is used to encompass mathematics, statistics and the range of mathematics-based disciplines including teaching, teacher education and educational research.

The mathematical sciences have long been linked to national competitiveness, but their significance for Australia is accelerating. This is largely a consequence of two trends.

1. Widespread and inexpensive computing means that the mathematical sciences are developing indispensable tools in commerce and industry.
2. A new and global interest in the interaction between the mathematical sciences and other areas of intellectual inquiry is advancing the frontiers of knowledge.

Evidence for these trends is all around us: in the products we use, in the technological innovations that are underpinned by mathematics, and in the commercial and economic returns available to those with strong quantitative capabilities.

Support from key industries

'I keep saying the sexy job in the next 10 years will be statisticians. People think I'm joking, but who would've guessed that computer engineers would've been the sexy job of the 1990s?' (Hal Varian, chief economist at Google.)

'I benefited from the encouragement others gave me to study maths. So I am a strong advocate of the opportunities that mathematics offers.' (Andrew Mackenzie, CEO, BHP-Billiton)

The mathematical sciences have been estimated to contribute 10% of jobs and approximately 16% of gross value added to a modern national economy (Deloitte 2012). In Australia, mathematical scientists have excellent employment prospects, especially in finance, resources, information technology, manufacturing industries and teaching.

Science and technology require mathematics as never before. Mathematics has always been the language of science, and statistics is at the heart of good evidence and experimentation. But across an ever-expanding range of fields, the mathematical sciences are now essential even to do research at a basic level, let alone make seminal discoveries.

Moreover, science, engineering and the social sciences are in turn stimulating the mathematical sciences, leading to advances in foundational areas of the discipline. For example, mathematics is increasingly being influenced by advances in fields such as medicine and information technology.

These trends are global, but they are highly pertinent for Australia. The growing role of the mathematical sciences in global commerce and innovation, and the interplay between the mathematical sciences and other areas of intellectual inquiry both present vital opportunities for our country.

They accentuate the urgent need for planning the future of mathematical sciences in Australia.

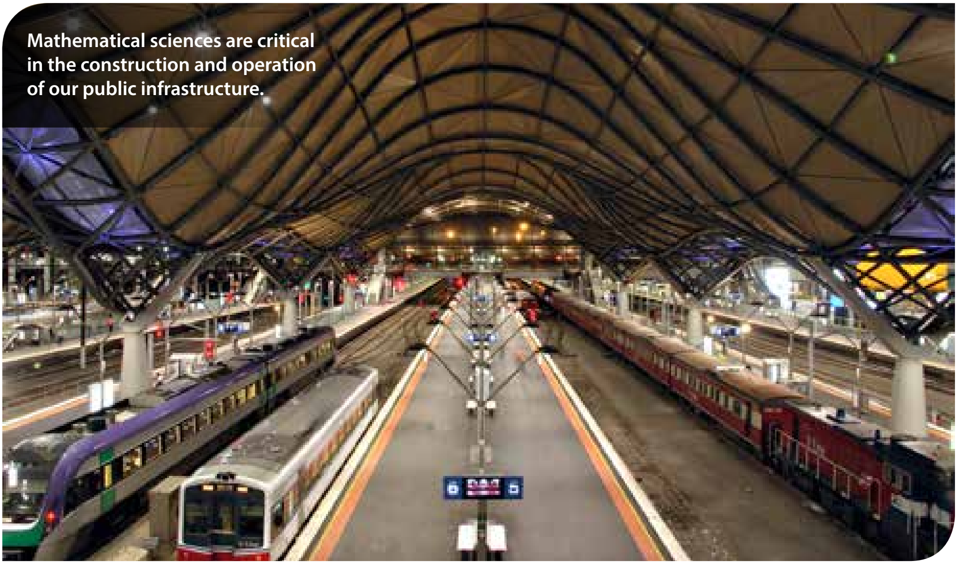
Sophisticated mathematics increasingly underpins commercial performance.

Vital to Australian industry

A report from the Office of the Australian Chief Scientist and the Australian Academy of Science estimated that global advances in physical and mathematical sciences over the past 20 years directly underpinned 11.2% of Australian activity and indirectly supported a further 11.3%. Advances in mathematical sciences alone were estimated to directly support approximately $57.3 billion worth of economic activity, with key sector contributions including:

- Banking – $5.4 billion
- Computer system design and related services – $4.8 billion
- Wired telecommunications network operation – $4.6 billion
- General insurance – $3.8 billion
- Road freight transport – $3.7 billion
- Other telecommunications network operation – $2.9 billion
- Electricity distribution – $2.8 billion
- Financial asset investing – $2.2 billion
- Iron ore mining – $2.1 billion
- Gold ore mining – $2.0 billion
- Superannuation funds – $1.8 billion
- Supermarket and grocery stores – $1.6 billion
- Air and space transport – $1.5 billion
- Rail passenger transport – $1.0 billion

(AAS 2015), Table A1.1.



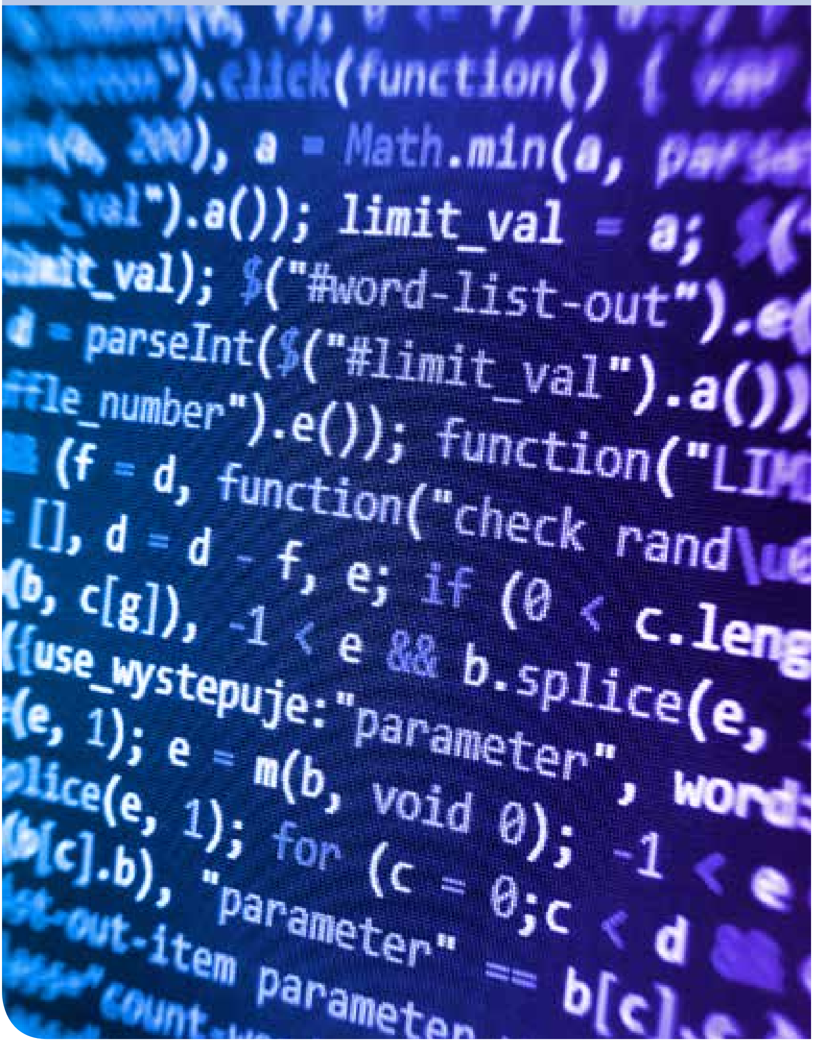
Mathematical sciences are critical in the construction and operation of our public infrastructure.

Three big trends driving the uptake of the mathematical sciences in the Australian economy

1. **Big Data**—More and more data is being generated by health, social security and other government services, in business and industry, in the social sciences and in biomedical and biological sciences, all of which can be distributed easily by electronic communications. The mathematical sciences are pivotal for those who need to analyse these data, to understand what they mean, and to test new ideas through simulation and modelling.
2. **Service Economy**—Many companies are switching focus from providing equipment, software and other technology to providing related services. In a knowledge economy, such services are often underpinned by mathematical or statistical expertise. In its most innovative form, a service economy is always a mathematical economy.
3. **Quantification**—As our economy becomes increasingly sophisticated and complex, the mathematical sciences become integral both in the development and exploitation of new technologies and products. In particular, digital technology is now driving quantification—translating observations and experiences into sets of numbers—across nearly every sector of society, increasing the importance and relevance of mathematical sciences.

Mathematical improvements are vital for computing performance

In a period of 16 years, from 1988 to 2004, linear programming algorithm development improved performance by a factor of roughly 3300, far in excess of the improvement factor of about 1600 in the speed of computing machines. (Bixby 2012, p.114)



2 A vision for 2025

"A STRONG RESEARCH AND EDUCATION INFRASTRUCTURE IN THE MATHEMATICAL SCIENCES IS FUNDAMENTAL FOR AUSTRALIA'S FUTURE."

New technology and knowledge are transforming the mathematical sciences. At the same time, a proliferation of new quantitative tools means that the mathematical sciences are finding indispensable application across a broad range of sectors and across all fields of science and technology.

Consequently, a strong research and education infrastructure in the mathematical sciences is fundamental to Australia's future. Mathematics and statistics are more important than they have ever been—for the Australian economy, for Australian society, and for young Australians particularly.

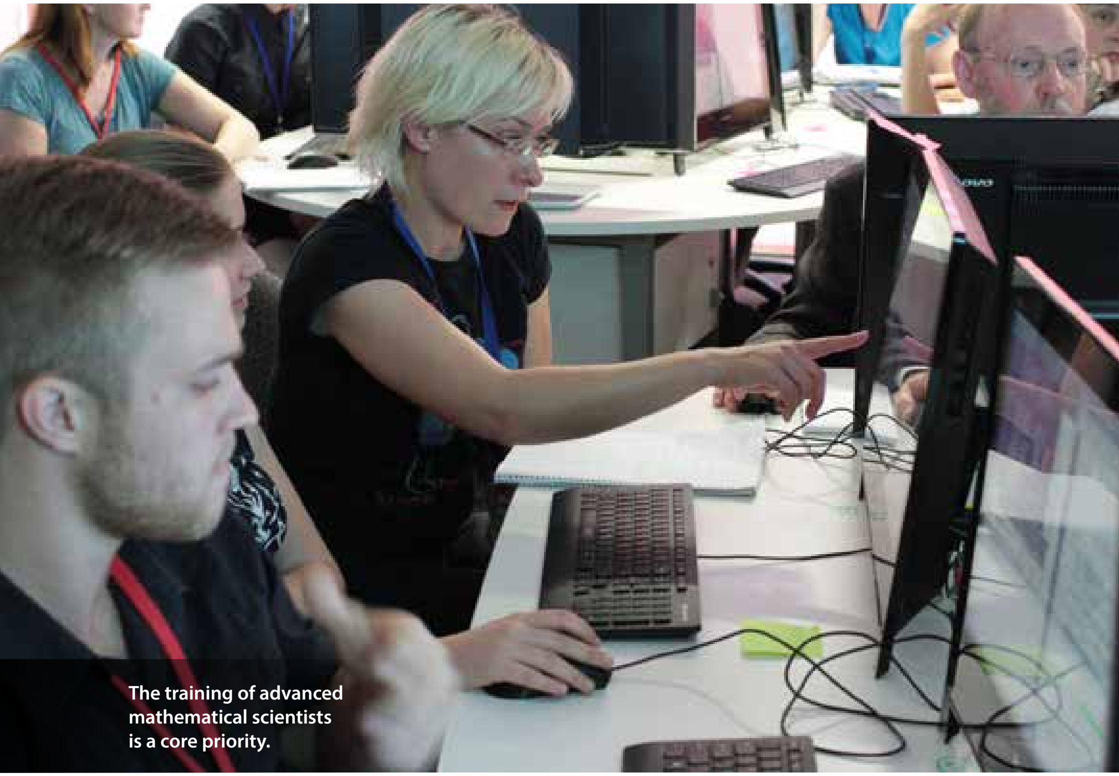
In this context, this decadal plan is more than just a roadmap for the mathematical sciences discipline. It represents a vision for Australia, based on five core principles:

1. The mathematical sciences are critically important for Australia's future—especially in light of ongoing technological change.
2. All young Australians need a strong foundational education in mathematics and statistics.
3. Australia needs to be able to train an appropriate number of advanced mathematical scientists.
4. Our schools and tertiary institutions need teachers who are equipped with the knowledge and skill to teach mathematics and statistics well and to inspire their students to pursue the discipline.
5. The mathematical sciences must also be an essential focus for public research investment, both in their own right and as contributors to a range of other fields.

If Australian policymakers and public institutions accept these principles and implement a few simple actions, Australia will harvest profound benefits.

Having more mathematicians, statisticians and expert mathematics teachers will produce more productive workers able to bring strong mathematical capabilities to diverse fields of endeavour. It will improve our society's prospects for exploiting advances in computational power and the widespread growing availability of data and information systems. Above all, it will make the Australian economy more dynamic and innovative.

Our vision is to ensure that Australia benefits from new technology and the growing importance of the mathematical sciences. Our plan builds on existing strengths and addresses a number of clearly identifiable challenges over the coming decade. Our goal is to transform the expertise, educational opportunities and international linkages in the mathematical sciences in Australia.



The training of advanced mathematical scientists is a core priority.

Visions from outside the discipline

'In business and industry, we are seeing a steady increase in the importance of quantitative skills. In such an environment, countries with a strong educational system in mathematics will thrive while those without it will be left behind.'
(Innes Willox, CEO, Ai Group)

'Australia needs students at all levels who are prepared to take an interest in maths. The importance of the subject has been steadily growing across a whole range of industries. We need to ensure that our country's future workforce is equipped with the skills to benefit from this trend.'
(Jenny Lambert, Australian Chamber of Commerce and Industry)

'The mathematical sciences are a foundational capability for the organisation, essential both to deliver our current program and also to provide generic skills and capabilities to take us into a changing future.'
(Defence Science and Technology Group)

'Mathematical sciences are critical to the future development of the minerals sector in Australia. They underpin the ability to successfully explore, finance, construct, operate and close mining operations productively and competitively.'
(Australasian Institute of Mining and Metallurgy)

'The successes of engineering in transforming modern society through manufactured products, systems and infrastructure have been due in large part to reliable mathematical models of materials and processes, increasingly encapsulated in software of increasing scale and complexity.'
(Australian Council of Engineering Deans)

'Maths allows us to solve problems with new methods and principles, and creates much higher added value by converging with various fields such as science and technology, industry, and culture and art.'
(Park Geun-hye, President of South Korea)

'Mathematics contributes to biology, medicine, social sciences, business, advanced design, climate, finance, advanced materials, and many more. This involves integration of mathematics, statistics, and computation in the broadest sense and the interplay of these areas with areas of potential application.'
(Ian Chubb, former Australian Chief Scientist)

3 Australian strengths in the mathematical sciences

1. Australia has a well-educated population of which a significant proportion have had at least foundation-level training in mathematics.

There are only about 27 000 people in Australia with a mathematics or statistics post-secondary qualification (ABS 2011). But in the broader community, there are hundreds of thousands of Australians who have completed at least intermediate-level mathematics courses through to the final year of high school.

Many of these people are now pursuing careers in areas such as engineering and finance, where an understanding of mathematical ideas is indispensable. Many have also studied mathematical sciences courses at university, as part of their degree. This is a community that understands and values the mathematical sciences.

In a broader cross-section of Australian society, there is emerging awareness of the advantage of mathematical skills as a foundation for everyday life and work, including outside of mathematically intensive careers.

Foundation skills are needed in the workplace

The Australian Industry Group (Ai Group) has recently identified the need to strengthen foundation skills—including mathematical skills—in the workplace, highlighting the link between skill levels and productivity outcomes. In particular, the Ai Group identifies:

- the importance of mathematical skills
- skills shortages in the mathematical practitioner workforce
- the need for measures to raise the mathematical capabilities of the Australian workforce
- the need to establish the mathematical capability of the vocational education and training workforce.

Australian industry understands the importance of mathematical sciences for a broad cross-section of Australian society.

2. There are many outstanding mathematics teachers in Australian schools, vocational education and training, and universities.

There are many Australian teachers with the skills and discipline knowledge to inspire their students about mathematics. Almost 5000 people with a post-school qualification in mathematics or statistics currently work in education and training (ABS 2011), many of them teachers in secondary schools and universities.

Australia also has a large number of teachers specialised in other fields with considerable personal experience and expertise in teaching practice. Some of these teachers have the potential to respond to the significant unfilled teacher demand in mathematics, if they can be provided with the discipline knowledge and mathematics teaching expertise to teach the subject well and with confidence.

This is important for many areas of education in the mathematical sciences, including primary, secondary, and vocational education and training.

Mathematics of guitar making. Guitar maker—David Poulter.

Vocational education and training

Vocational education and training (VET) is a critical component of Australian education. The opportunity for students in VET courses to improve their mathematical skills is essential if Australia is to have the skilled workforce it needs. It is also essential for students to complete their training.

VET is delivered in schools and by registered training organisations (RTOs). RTOs include public providers such as TAFE colleges and many more private providers. Yet the opportunity for students to improve their mathematical skills is limited in many RTOs.

In this context, Australian industry has welcomed the formation of a National Foundation Skills Strategy for Adults (FS 2012). This strategy, which has been endorsed by the National Skills Standards Council, has established a target that at least two-thirds of working-age Australians should have mathematical skills that reach basic benchmarks.

3. Many Australian universities continue to provide excellent opportunities for higher education in mathematical sciences.

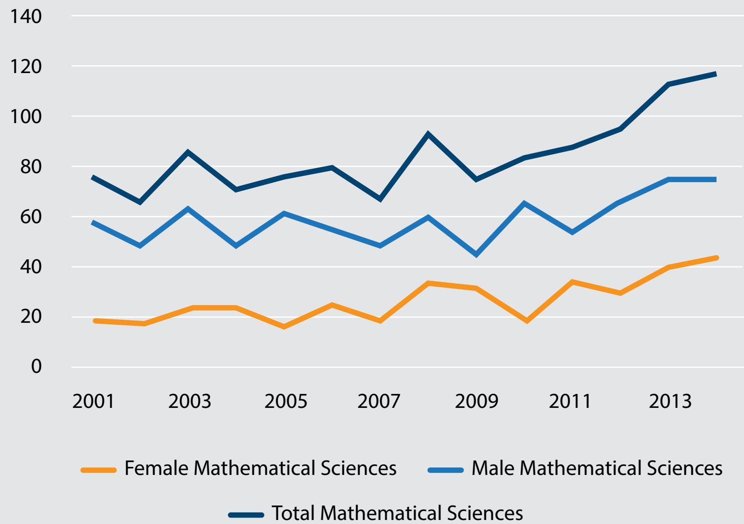
Although the first decade of the 21st century was a turbulent one for mathematics and statistics departments in Australian universities (AAS 2006), the discipline has gained new momentum in recent years.

Our universities' capacity to teach mathematical sciences has been strengthened by the creation of an Australian Mathematical Sciences Institute. At the same time, recent policy changes have remedied a longstanding deficiency in Australian Government support for mathematics courses at universities.

At one end of the achievement spectrum, many thousands of students study university mathematical science subjects every year and, at the other, there is a steadily growing output of mathematical science PhD graduates, now totalling about 120 each year.

This reflects an invaluable capability in Australian higher education—a level of teaching talent and expertise that is poised to develop the mathematical abilities of our country's future workforce over the coming decade.

PhD completions 2001–2014 by gender



Source: Supplied by the Commonwealth Department of Education and Training, September 2015.

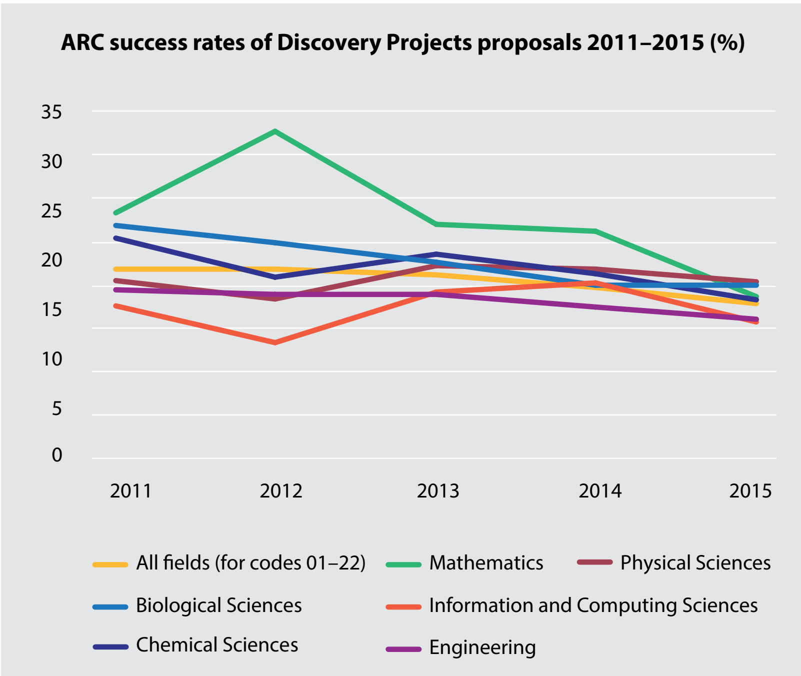
3 AUSTRALIAN STRENGTHS IN THE MATHEMATICAL SCIENCES

4. Australia has globally significant research strengths in the mathematical sciences.

Australia accounts for just over 2% of the world's research in the mathematical sciences—a slightly lower proportion than its share of output in many other fields (OCS 2014, Table 2-2). This low volume of relative output reflects the enormous strategic priority that has been placed on the mathematical sciences in several Asian nations in the past decade.

Yet Australian research is recognised globally for its quality. Our output is cited disproportionately in the world's mathematical sciences literature—with average citation rates higher than for the leading 15 European economies (OCS 2014, Figure 2-5). There are various subfields of applied mathematics, pure mathematics and statistics where Australian research maintains a disproportionate share of global output (MSN 2014).

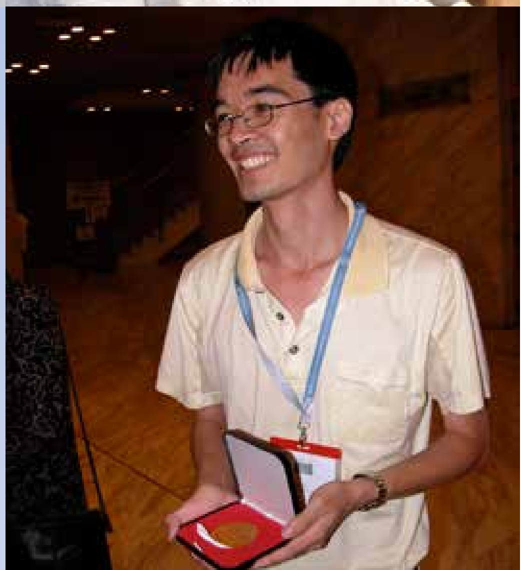
Within Australia, the mathematical sciences have achieved a high success rate in the Australian Research Council Discovery Programme.



Source: ARC, Field of Research Collection and ARC Funded Research Projects —Trends Data Set

Three world-leading Australian mathematical scientists

"AUSTRALIAN RESEARCH IS RECOGNISED GLOBALLY FOR ITS QUALITY."



Clockwise (from above): Professor Gilah Leder FASSA, winner of the Felix Klein Award*; Professor Terence Speed FAA FRS, winner of the Pitman Medal and the Prime Minister's Prize for Science; Professor Terence Tao FAA FRS, winner of the Fields Medal* and many other awards. Photos: AMSI

*The Felix Klein Award (for outstanding lifetime achievement in mathematics education) and the Fields Medal (for outstanding mathematical achievement by 40) are premier research awards of the International Mathematics Union; see www.mathunion.org/icmi/activities/awards/introduction/

Professor Ian Chubb AC FTSE, stressing the importance of mathematics at an AMSI event.

5. Australian mathematical scientists build collaborations with each other, across industries and with other disciplines.

Mathematics departments in Australian universities have a long history of cooperation outside the discipline through the provision of service teaching into other degrees. In recent years, our campuses have also expanded their industry linkage, with several institutions now providing industrial experience to research students—for example, via the Australian Technology Network's Industry Doctoral Training Centre, and through the Australian Mathematical Sciences Institute's industry internship program.

More broadly, there is a strong history of constructive collaboration in Australia between mathematical scientists, government agencies and schools. This spirit is exemplified by CSIRO's Mathematicians in Schools project, by the Biostatistics Collaboration of Australia's postgraduate courses, and by the Australian Mathematical Sciences Institute's summer schools and internship program.

A key strength of the mathematical sciences discipline in Australia is the willingness of its practitioners to work across institutional and sectoral boundaries for the national interest.

"A KEY STRENGTH OF THE MATHEMATICAL SCIENCES DISCIPLINE IN AUSTRALIA IS THE WILLINGNESS OF ITS PRACTITIONERS TO WORK ACROSS INSTITUTIONAL AND SECTORAL BOUNDARIES FOR THE NATIONAL INTEREST."

Australian Mathematical Sciences Institute (AMSI)

AMSI is a unique innovation in Australian higher education, created by the members of the discipline to facilitate cooperation among mathematical scientists working in schools, universities, government agencies and industry.

Funded through member subscriptions and contracts, as well as government, industry and philanthropic grants, AMSI provides support for all aspects of the mathematical sciences from primary schools through to advanced research.

AMSI's members include 30 universities, four government agencies and several professional societies. This willingness to work together has been pivotal to the vitality of the mathematical sciences in Australia during the past decade.

The spirit that drove the success of AMSI—the eagerness to innovate and cooperate—will be equally important in the coming decade.

4 Australian challenges in the mathematical sciences

1. The Australian school system has an acute shortage of properly qualified mathematics teachers.

Although Australia has many excellent mathematics teachers, it suffers from a shortage of properly qualified teachers—that is, those trained in both mathematics teaching and mathematical sciences. This shortage is well recognised and although there has been improvement in recent years it remains acute (AMSI 2014).

This situation is due both to an undersupply of specialist secondary mathematics teachers and high rates of attrition in the early years of teaching, particularly from schools that are hard to staff.

Educational background of secondary mathematics teachers

	Percentage of mathematics teachers, 2013		
Level currently teaching	**With no 3rd-year level tertiary education in mathematics ***	**With NO methodological training in mathematics education**	**With NO tertiary education in mathematics***
Years 7–10	40%	26%	12%
Years 11–12	28%	14%	5%

Source: ACER 2013, Table 5.32 on p.67. * Note that tertiary education in mathematics can include mathematics subjects of any type.

The acute shortage of qualified mathematics teachers has created inequalities in our school system.

Unfilled secondary teaching positions on day 1 of the school year

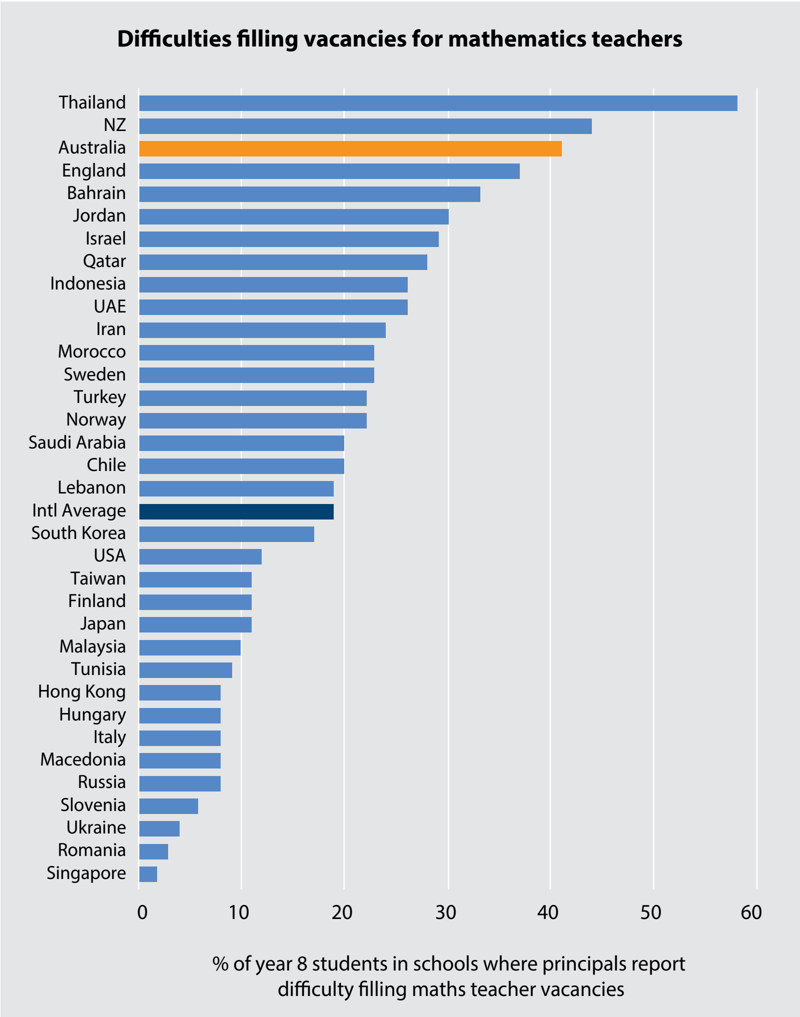
Subject	2010		2013	
	Unfilled positions	% of schools affected	Unfilled positions	% of schools affected
Mathematics	400	8.3%	270	8.7%
Science	190	7.2%	190	5.9%
English	350	7.5%	60	1.7%

Source: ACER 2013, Table 12.8 on p.127.

The shortage of mathematics teachers has a profound effect on the provision of mathematics teaching at all levels of schooling and for vocational education. Meeting the mathematical needs of students in vocational education poses additional challenges for teachers. There is also a lack of teachers with mathematical skills to provide leadership and mentoring in primary schools and in many secondary schools.

The problems are especially pronounced in regional areas (Lyons 2006). In part, this reflects the inadequate availability of undergraduate majors in mathematical sciences in regional universities—and the absence of any university able to train expert mathematics teachers in the Northern Territory.

"THE SHORTAGE OF MATHEMATICS TEACHERS HAS A PROFOUND EFFECT ON THE PROVISION OF MATHEMATICS TEACHING AT ALL LEVELS OF SCHOOLING AND FOR VOCATIONAL EDUCATION."



Source: TIMSS 2011, Exhibit 5.12 on p.236.

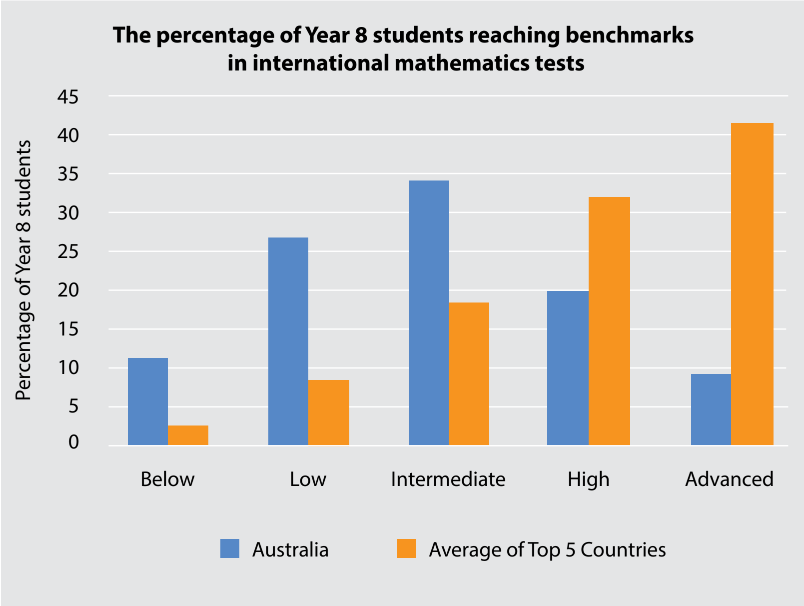
2. Australia has experienced a decline in student performance in internationally standardised tests.

According to data from the OECD Program for International Student Assessment (PISA), Australia is slipping in global rankings of school student performance in mathematics. And, in absolute terms, the mean mathematical literacy of our 15-year-olds has declined significantly in the past decade, with more than 40% of Australian 15-year-olds now failing to meet minimum national standards in the subject and with many students struggling to apply mathematics to real-world situations (PISA 2012).

This is consistent with the evidence of teacher shortages, especially in regional areas. The mean performance of students in rural and regional Australia (where teacher shortages are most severe) now lags almost three-quarters of a school year behind that of their peers at metropolitan schools, while mean student performance in remote schools lags almost two years behind the mean performance in metropolitan schools (PISA 2012).


Our students must be able to apply their mathematical knowledge.

The Trends in International Mathematics and Science Study (TIMSS) shows a similar trend among fourth-grade students. Students in 17 countries outperformed Australian students in these tests in 2011, up from 13 countries in 2003 (ACER 2012). This same study also shows that more than a third of Australian Year 8 students do not have the skills to apply basic mathematical knowledge in straightforward situations, compared with only a tenth of Year 8 students in high-performing countries (TIMMS 2011).



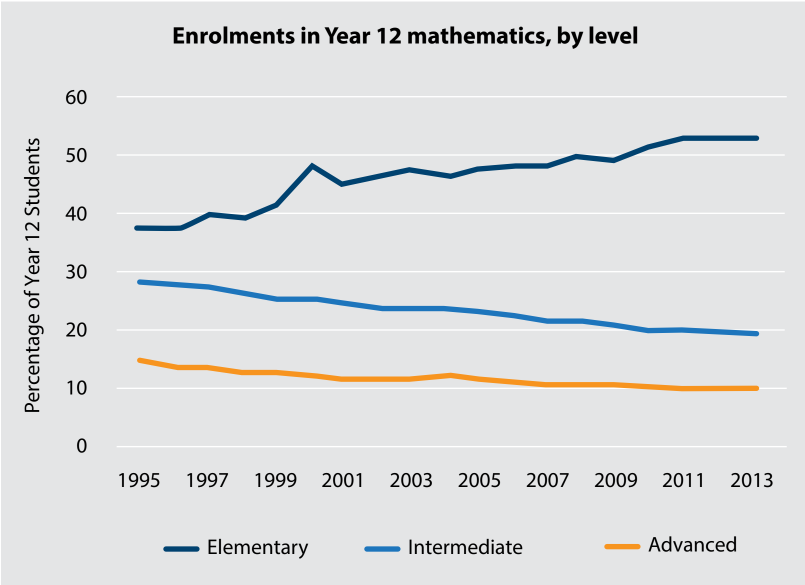
Source: TIMSS 2011, Exhibit 5.12 on p.236. The top five countries are South Korea, Singapore, Taiwan, Hong Kong and Japan.

How do we compare with our international peers?

'The performance of Australian school students in science and mathematics literacy is now lower than important international peers. The success of our top performers cannot conceal the gap in the achievement levels of students from Indigenous and disadvantaged backgrounds compared with those from more affluent families.'
(Ian Chubb, former Australian Chief Scientist)

3. Student enrolments in advanced mathematics courses have been in decline.

Australian schools still graduate a large number of students with an excellent grounding in mathematics. But participation rates in advanced mathematics courses are dropping. Nationally, the percentage of Year 12 students taking higher-level (i.e., advanced and intermediate) mathematics subjects fell from 41% in 1995 to 34% in 2004 to 29% in 2012. (Barrington 2005, Forgasz 2006, Barrington 2014).



Source: Barrington 2014.

Participation rates in advanced mathematics courses at high school are even lower for females and regional students, suggesting an acute problem for these groups. During the same period, our universities have been dropping intermediate and advanced high school mathematics prerequisites for entry to several degree programs, implicitly encouraging students to favour elementary options.

4. Australia is not graduating specialist mathematicians or statisticians at the same rate as its competitors.

In proportion to its population, Australia should be graduating numbers of mathematical scientists similar to those in comparable countries such as New Zealand, the UK, South Korea and Sweden. Yet only 0.4% of Australian university students are entering into tertiary education to pursue degrees in mathematics or statistics, less than half the OECD average of 1% (OECD 2014).

This is a particular problem for female students, whose participation in university mathematics and statistics degrees continues to lag behind male students, and who consequently may be missing opportunities for career development and personal fulfilment. At Australian universities, twice as many men as women are taking undergraduate courses in the mathematical sciences, and four times as many men as women are taking fourth-year honours courses (AMSI 2014 and Johnston 2014).

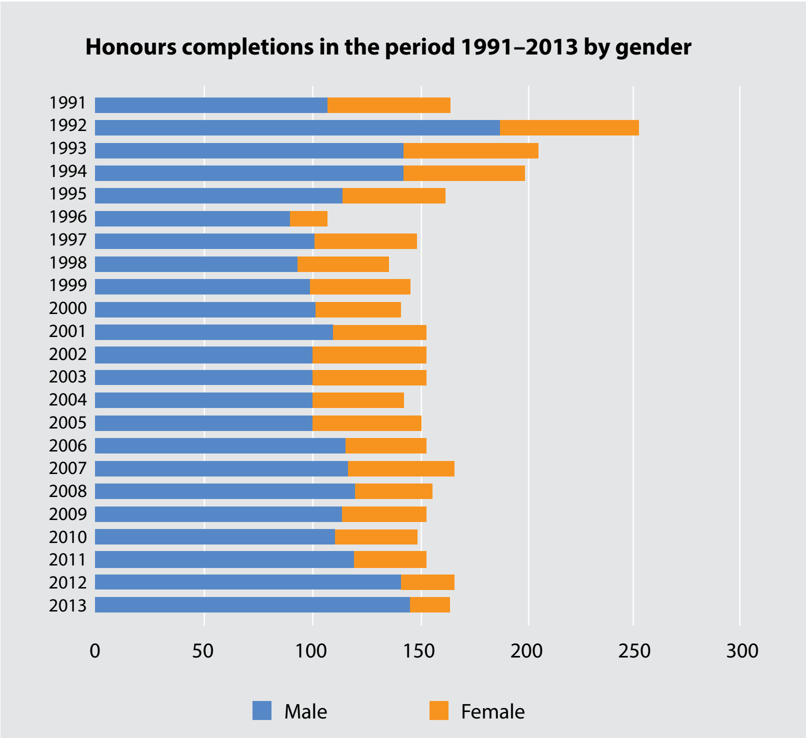
If more female students were to pursue higher education in the mathematical sciences, Australia would benefit from a substantial increase in the mathematical capability of its labour force.

Are there enough mathematical scientists?

Percentage of new tertiary entrants by field of education, 2012						
	Engineering*	Sciences	Life sciences	Physical sciences	Maths and statistics	Computing
Australia	9	12	5	3	0.4	4
Denmark	12	8	1	1	1	5
Finland	25	9	1	3	1	4
Germany	17	13	2	4	2	4
Ireland	11	17	5	2	1	7
New Zealand	7	17	5	3	3	7
South Korea	25	7	2	2	1	3
Sweden	18	11	2	2	2	5
United Kingdom	8	15	5	4	2	4
OECD average	15	10	2	2	1	4

*Including manufacturing and construction
Source OECD 2014 Table C3.3a

“IF MORE YOUNG WOMEN WERE TO PURSUE HIGHER EDUCATION IN THE MATHEMATICAL SCIENCES, AUSTRALIA COULD BENEFIT FROM A SUBSTANTIAL INCREASE IN THE MATHEMATICAL CAPABILITY OF ITS LABOUR FORCE.”



Source: Johnston 2014.

5. Australia needs a major research centre in the mathematical sciences to connect public research with industry and project Australian research onto the world stage.

Other countries have established national research centres in the mathematical sciences as an essential part of their national research infrastructure. These centres facilitate connections between local researchers and outstanding researchers in other parts of the world, and between publicly funded researchers and industry. However, Australia has no equivalent capability.

A national research centre will enable strategic and coordinated research partnerships, nationally and globally.

This limits the scope for our mathematical scientists to form strategic and coordinated research partnerships nationally and internationally. It limits the scale and international visibility of Australian research. It also restricts our capacity both to engage and compete with rapidly emerging mathematical sciences communities throughout the Asia-Pacific region.

International research centres in the mathematical sciences

Many of Australia's competitors have realised that advancement in the mathematical sciences requires the creation of a new type of research centre that is not often seen in other disciplines. These centres are characterised by the following attributes:

- They are nationally coordinated to support the research capabilities of the nation as a whole rather than just a few institutions.
- They are broad in their discipline focus, offering opportunities in a wide-ranging spectrum of fields at the leading edge.
- They are agile and responsive to the needs of fast developing research and collaboration.
- They are a cost-effective way of supporting individuals and institutions.
- They facilitate linkages across the innovation system in the mathematical sciences—among universities, government agencies and industry.
- They are tailored to national geography and discipline demographics.

Australia currently has no funding mechanism to support a centre along these lines. (The ARC Centre of Excellence scheme and the Cooperative Research Centres scheme are both designed to concentrate capability in a restricted range of fields.) Key examples, of various types, in other countries are listed in Appendix B.

5 Our plan for mathematical sciences in Australia

To deliver our vision for 2025, the mathematical sciences community in Australia has developed a detailed plan.

It builds on our existing strengths in the mathematical sciences and addresses the challenges we have identified.

It is the product of an extensive consultation across mathematical scientists working in schools, universities, government agencies and industry (Appendix A).

It builds on two decades of careful reviews of the discipline (AAS 1996, SSA 2005, AAS 2006, AAS 2009), and is based on the premise that mathematicians, statisticians, mathematics educators in education faculties, teachers, policymakers, and professionals whose work involves mathematics and statistics must collaborate to ensure that Australia remains a mathematically sophisticated society.

It also reflects our fundamental optimism about the mathematical sciences in this country, and their ongoing importance for Australia's future.

Above all, it seeks to implement our vision for Australia by addressing four critical objectives.

Objective I—Give all Australian schoolchildren access to outstanding mathematics teachers.

Objective II—Guarantee high standards of mathematical sciences teaching at Australian tertiary institutions.

Objective III—Achieve both global and local impact for Australian research in the mathematical sciences.

Objective IV—Ensure that Australian society is capturing the benefits of mathematics-based technologies.

The opportunities and challenges we face in meeting these four objectives are described below, along with 12 strategic actions recommended for implementation by governments, universities, schools, learned societies and professional associations.

Lessons from the UK

In developing policies for the mathematical sciences, Australian decision-makers could learn from recent trends in the UK.

- The UK Government has launched a conversion scheme to bring former mathematics and physics teachers back into the classroom and to provide 15 000 out-of-field teachers with the domain knowledge to teach mathematics and physics (Cameron 2015).
- The implementation of the Wolf Report on vocational education and training for 16-19 year-olds in the UK requires that any student who has not achieved a grade A* – C in GCSE mathematics must continue to study the subject as a condition of ongoing student funding (Wolf 2015).
- The House of Lords Select Committee on Science and Technology urged higher education institutions to introduce more demanding maths requirements at entry for STEM courses (Lords 2012).

I. Giving all Australian school children access to outstanding mathematics teachers

Aim: Our first strategic priority is to give all Australian students a globally competitive education in mathematics and statistics while at school.

Main challenges: Australia suffers from a shortage of properly qualified mathematics teachers—that is, those trained in both mathematics teaching and mathematical sciences. This shortage is well recognised and is becoming increasingly acute, particularly in regional and remote schools. As a consequence, not all secondary school students have access to specialist mathematics teachers and there are growing inequalities across Australian schools. There is also a shortage of mathematics teachers in vocational education and training. The problem results from the undersupply of specialist mathematics teachers, high rates of attrition in early years of teaching (in particular from hard-to-staff schools), and a lack of appropriately resourced retraining options for those teaching out of field.

"THERE IS ALSO A HISTORY OF CONSTRUCTIVE COLLABORATION IN AUSTRALIA THROUGHOUT THE MATHEMATICAL SCIENCES TEACHING COMMUNITY AND THERE IS NO SHORTAGE OF TALENTED PEOPLE WITH THE MATHEMATICAL ABILITY TO BECOME WONDERFUL TEACHERS."

Inspiring teachers are vital to our children's mathematical education.

Main opportunities: Tempering these challenges, there are many outstanding mathematics teachers, mathematical scientists and mathematics teacher educators in Australia. These individuals have the potential to engender in pre-service and early career teachers an appreciation of the discipline of mathematics, a belief in its inherent value as an object of study and realm of creative endeavour, and an understanding of its importance to society. There is also a history of constructive collaboration in Australia throughout the mathematical sciences teaching community and there is no shortage of talented people with the mathematical ability to become wonderful teachers.

Our commitment: The Australian mathematical sciences community will work closely with universities and school authorities to increase the number of properly qualified mathematics teachers in our schools. In conjunction with faculties of education and science we will actively review our strategies to attract school students and undergraduates to the teaching profession over the lifetime of this decadal plan.

Recommendations:

1.1 Australian governments, schools and universities should urgently increase their provision of professional development for existing out-of-field school teachers of mathematics and enhance their commitment to the recruitment and retention of new, properly qualified staff.

1.2 Universities, governments and the mathematics teaching profession should set national standards to ensure that mathematics teachers are properly qualified and to ensure that there are universities capable of preparing mathematics teachers in every state and territory.

1.3 Governments and other teacher employers should ensure that there are rewarding career paths for mathematics teachers in primary and secondary schools by providing excellent teachers with opportunities for promotion, allowing the best to lead the ongoing development of mathematics teaching within their school, across school clusters, and at regional and state/territory levels.

Our universities provide a vibrant undergraduate experience.

II. Guaranteeing high standards of mathematical sciences teaching at Australian tertiary institutions

Aim: Our second strategic priority is to guarantee that Australian students have access to outstanding mathematical sciences courses at tertiary institutions.

Main challenges: In all Australian universities, there has been a decline in the number of bachelor degrees (including bachelor of science and bachelor of engineering degrees) that require even intermediate high school mathematics as a prerequisite for entry. This has prompted students to avoid school mathematics subjects or else to favour elementary options, leading to a decline in high school enrolments in intermediate and advanced mathematics courses. This puts pressure on standards in universities, has led to a reduction in the content taught and in the achievement levels needed to pass a subject, and has contributed to the closure of mathematics departments in several universities. Consequently, the availability of undergraduate majors in the mathematical sciences is vulnerable or excessively narrow in scope in many capital city institutions and is inadequate in regional universities.

“LEADING UNIVERSITIES IN AUSTRALIA CONTINUE TO PROVIDE EXCELLENT UNDERGRADUATE MAJORS, WITH SOME CHOICES AS TO AREA OF MATHEMATICAL SPECIALISATION AND GOOD PATHWAYS TO POSTGRADUATE STUDY.”

Main opportunities: Mathematics and statistics are fundamentally important in a range of careers and the demand for mathematically trained graduates in the Australian economy is very strong. Leading universities in Australia continue to provide excellent undergraduate majors, with some choices as to area of mathematical specialisation and good pathways to postgraduate study. At the same time, many mathematical science departments in Australian universities have a strong track record of cooperation in teaching—both across faculty boundaries (as evidenced by the provision of service teaching into other degrees) and across institutional boundaries (as evidenced by the creation of the Australian Mathematical Sciences Institute).

Our commitment: The Australian mathematical sciences community will communicate the importance of our discipline to the Australian public, to counter the widespread ignorance of the extensive range of careers pursued by mathematical sciences graduates. We will continue to maintain the very highest standards of teaching and engagement and will support the viability of mathematical sciences programs in all our universities.

Recommendations:

2.1 Australian universities should immediately plan for the staged reintroduction of at least Year 12 intermediate mathematics subjects as prerequisites for all bachelors programs in science, engineering and commerce. This will send an unequivocal message to school communities and significantly improve educational outcomes for tertiary students.

2.2 Universities and state tertiary admissions centres should ensure that subject scaling does not discourage students from choosing advanced subjects while at high school, and universities and governments should introduce mathematical awareness programs demonstrating the career choice benefits and financial and social advantages of completing advanced courses.

2.3 University deans and heads of schools in disciplines outside the mathematical sciences should facilitate liaison between university mathematics departments and those expert in the mathematical needs of these disciplines to see that appropriate mathematics is being taught to students in fields such as engineering, science, commerce, economics and education.

"GIVEN OUR SCALE AND GEOGRAPHIC ISOLATION, AUSTRALIA FACES CHALLENGES IN COVERING A BREADTH OF MATHEMATICAL SCIENCE FIELDS AT A GLOBALLY SIGNIFICANT DEPTH."

III. Achieving both local and global impact for Australian research in the mathematical sciences

Aim: Our third strategic priority is to achieve increasing global significance for Australian research in the mathematical sciences.

Main challenges: Given our scale and geographic isolation, Australia faces challenges in covering a breadth of mathematical science fields at a globally significant depth. This is manifest particularly in the high quality but low scale of Australian research in the more fundamental and theoretical subfields of mathematical sciences, and is exacerbated by the structure of public funding. Research council grants do not provide a sufficient range of funding options for fields of low capital intensity like mathematics. Broader support for international interactions and exchange is limited. Career paths are often difficult for mathematically trained researchers working on interdisciplinary applications. In addition, the current three-year PhD following a four-year honours degree is short by global standards, limiting the time for coursework to acquire globally competitive skills across a range of different branches of mathematics.

Main opportunities: Australia has many outstanding mathematical sciences researchers. There is rising demand in Australia for researchers who can apply specific mathematical and statistical expertise in an interdisciplinary way. At the same time, mathematical research internationally is becoming more collaborative, with major national research centres in other countries providing a stimulus for cross-border collaboration. This internationalisation affords Australia a mechanism to counter some of the disadvantages of being small and isolated. Australian universities also have experience organising short national extension schools for honours students, PhD students and postdoctoral fellows through organisations such as the Australian Mathematical Sciences Institute and the Biostatistics Consortium of Australia. New technologies will allow such activities to be expanded through remote coursework delivery.

Our commitment: The Australian mathematical sciences community will continue to maintain the very highest standards of research. We will actively lead the planning, development and establishment of the programs and resources necessary to achieve sustained local and global impact.

National postgraduate programs will enhance research training.

Recommendations:

3.1 Australian universities should collaborate with the discipline to source seed funding for a new national research centre in mathematical sciences with the objective of enhancing connectivity with industry and strengthening the international collaboration and visibility of Australian research in mathematics and statistics.

3.2 Australian universities should organise postgraduate training at a national level through the Australian Mathematical Sciences Institute, to ensure that postgraduate research students are receiving the coursework they need to broaden their high-level mathematical and interdisciplinary skills.

3.3 In their recruitment and funding decisions, universities, funding councils and government agencies should continue to nurture the growing links between the mathematical sciences and other knowledge domains such as the biological and social sciences, but not at the expense of support for the core disciplines of mathematics and statistics.

IV. Ensuring that Australian society is capturing the benefits of new mathematics-based technologies

Aim: Our fourth strategic priority is to ensure that Australian society is benefiting from mathematical sciences expertise.

Main challenges: Technologies and applications based on the mathematical sciences are becoming more sophisticated and ubiquitous across all sectors. Big data is transforming Australian commerce and industry. Yet new developments in the mathematical sciences do not always flow smoothly between industry, universities, government agencies and policymakers. Considerable ongoing effort is required to keep senior decision-makers aware of the benefits generated by the mathematical sciences and maintain their interest in the health of the discipline. Women and students at regional and rural schools remain under-represented in mathematics courses at both secondary school and university. A substantial proportion of the public does not appear to appreciate the importance of the mathematical sciences. We are not maximising the potential of our human capital to exploit the benefits of new mathematics-based technologies.

Main opportunities: There are about 27 000 people in Australia with a mathematics or statistics degree. Australian industry is hiring staff with strong statistical and mathematical backgrounds, adapting mathematical techniques to difficult, real-world problems, and becoming increasingly open to joint initiatives with public institutions active in mathematics. Government agencies are also expressing a long-term need for staff with mathematical sciences capabilities. These sectors have shared interests and common experiences. Furthermore, the applications of mathematics and statistics are expanding rapidly as mathematical knowledge becomes embedded through software. These developments will make it easier for organisations to share ideas and demonstrate the value of the mathematical sciences to students, policymakers and the community at large.

Our commitment: The Australian mathematical sciences community will strive to deliver economic and social benefit through the development and application of mathematical and statistical research. Our best efforts will be directed towards training the graduate workforce required to sustain this commitment. We will take principal responsibility for creating public awareness of our work, to enable the realisation of its benefits and to inspire tomorrow's researchers.

Computer simulation of the 2004 Indian Ocean Tsunami impact on Patong Beach compared to Post Tsunami Survey

Geoscience Australia

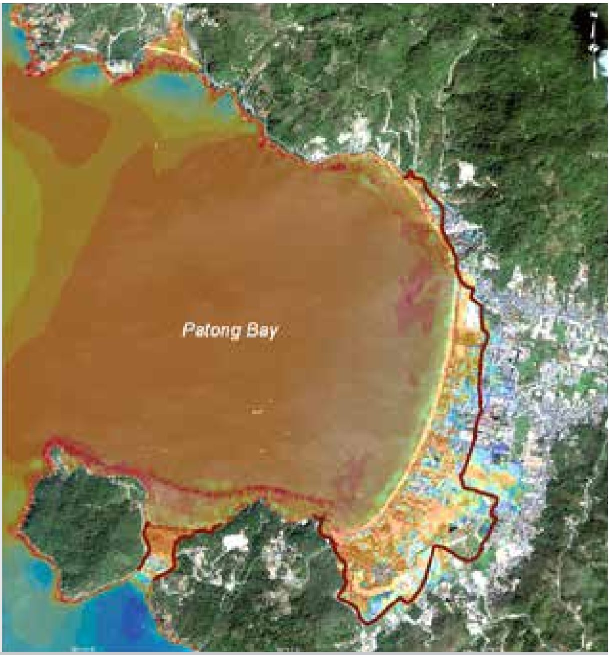
Reference

Post Tsunami Survey

Flow speed (m/s)

- 0.10–0.2
- 0.21–0.4
- 0.41–0.6
- 0.61–0.8
- 0.81–1.0
- 1.01–1.2
- 1.21–1.4
- 1.41–1.6
- 1.61–1.8
- 1.81–2.0
- 2.01–4.0
- 4.01–6.0
- 6.01≤

0 250 500 1,000m



Mathematical modelling of tsunamis leads to better design of coastal developments.

Recommendations:

4.1 Universities, governments, funding councils and peak industry groups should review and seek to address the causes of low participation in the mathematical sciences among girls and young women, and among Australians living in rural and regional areas.

4.2 The discipline's learned societies and professional associations, together with AMSI and other relevant stakeholders, should embark upon a coordinated program of promotion to ensure that parents, school students and teachers understand that studying mathematics subjects at the highest level possible increases career options.

4.3 The discipline's learned societies and professional associations, together with AMSI, government agencies and other relevant stakeholders, should facilitate an annual showcase and strategic briefing to maintain a dialogue with state and federal policymakers about new developments and opportunities emanating from the discipline.

6 Three key priorities

This document has been written on behalf of a large community, with actions to be taken across many different sectors—by governments, school administrators, universities, government agencies and the commercial sector. Of our 12 recommendations, three stand out for their particular urgency and importance.

1.1 Australian governments, schools and universities should urgently increase their provision of professional development for existing out-of-field school teachers of mathematics and enhance their commitment to the recruitment and retention of qualified staff.

2.1 Australian universities should immediately plan for the staged reintroduction of at least Year 12 intermediate mathematics subjects as prerequisites for all bachelors programs in science, engineering and commerce.

3.1 Australian universities should collaborate with the discipline to source seed funding for a new national research centre in the mathematical sciences with the objective of enhancing connectivity with industry and strengthening the international collaboration and visibility of Australian research in mathematics and statistics.

These are the three key priorities of our plan. If implemented, they would contribute to ensuring that Australian students at all levels are receiving the mathematical education they need to lead fulfilling lives and to maximise the ensuing benefits to Australian society in an increasingly mathematical world.

Australia's prosperity increasingly depends on the mathematics education pipeline.

Our world is changing rapidly. It is becoming increasingly technological and significantly more mathematical. If Australia is to prosper in such circumstances it will need:

- Citizens who have been taught mathematics and statistics well while at school.
- A steady flow of well-taught university graduates with advanced mathematical sciences skills.
- A vibrant community of mathematicians and statisticians who are advancing the frontiers of the discipline for the broader benefit of Australian society.

It is the strongly held belief of Australia's mathematical sciences community that we can achieve these goals by implementing our plan.

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Appendix A
The decadal plan process

The last major review of mathematical sciences in Australia occurred in 2006.

In a world where economic growth and intellectual advancement is increasingly underpinned by data and numbers, the mathematical sciences community came together again to develop a statement of common purpose.

Under the umbrella of the Australian Academy of Science's National Committee for Mathematical Sciences, leading representatives of the mathematical sciences community worked together over a three-year period to identify the key issues Australia faces in the field.

The process was led by:

- Professor Nalini Joshi, ARC Georgina Sweet Australian Laureate Fellow and Chair of Applied Mathematics at The University of Sydney and Chair of the Australian Academy of Science's National Committee for Mathematical Sciences
- The late Professor Peter Hall, Australian Laureate Fellow and Professor of Mathematics and Statistics at The University of Melbourne
- Professor Geoff Prince, Director of the Australian Mathematical Sciences Institute
- Dr John Henstridge, Managing Director and Principal Consultant Statistician, Data Analysis Australia Pty Ltd, and President, Statistical Society of Australia.

From: L to R, Professors Nalini Joshi, Peter Hall and Geoff Prince and Dr John Henstridge

These individuals formed an executive group and were assisted by a steering committee and seven additional expert committees, the members of which are listed below. The subcommittees each produced reports, containing a total of 31 recommendations. These subcommittee reports will form an ongoing resource for internal and external policy development; a consolidated report can be found at www.science.org.au/mathematics-plan-2016-25. Associate Professor Peter Stacey acted for the executive as project officer and editor.

This document summarises the main findings from this process. It identifies opportunities and challenges for discipline specialists, researchers, those working in business and industry, and mathematics teachers in schools, technical and further education, and universities.

Our intention is that the ideas and recommendations in this plan will be conveyed to government, industry and the broader community, so that together we can ensure the future vitality of the mathematical sciences in Australia.

The discipline, through the Australian Academy of Science's National Committee for Mathematical Sciences, will be formally monitoring progress on the plan on an annual basis.

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- Commonwealth Scientific and Industrial Research Organisation (CSIRO)
- Defence Science and Technology Group (DSTG)

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Appendix B
Some notable international mathematical sciences institutes

- African Institute for Mathematical Sciences (South Africa)
- Banff International Research Station for Mathematical Innovation and Discovery (Canada)
- Centre International de Rencontres Mathématiques (France)
- Centrum Wiskunde & Informatica (Netherlands)
- Chern Institute of Mathematics (China)
- Clay Mathematics Institute (USA)
- The Fields Institute for Research in Mathematical Sciences (Canada)
- Institute for Mathematics and its Applications (USA)
- Institute for Mathematical Sciences (Singapore)
- Instituto de Ciencias Matemáticas (Spain)
- Instituto Nacional de Matemática Pura e Aplicada (Brazil)
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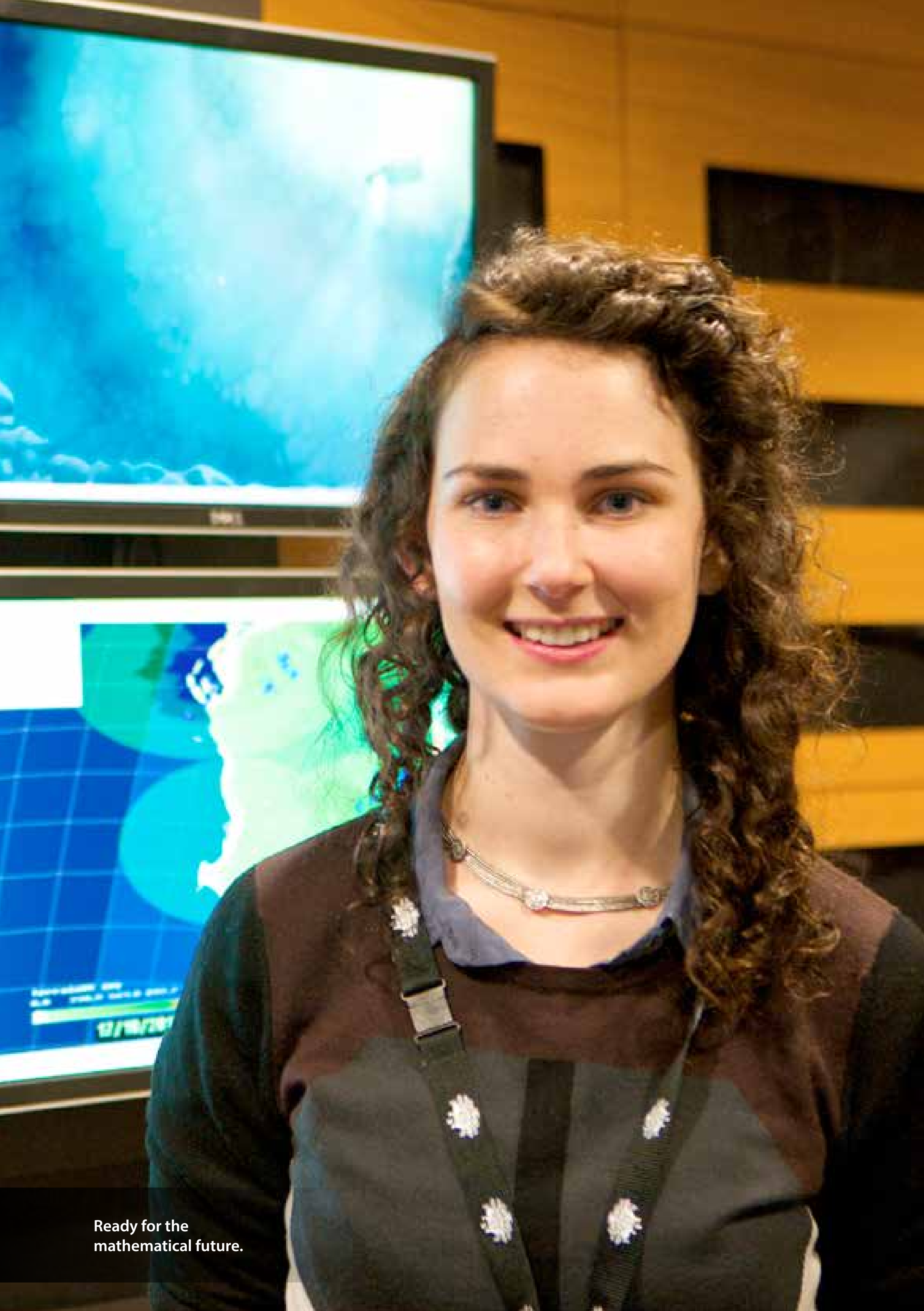
- Mathematical Sciences Research Institute (USA)
- Mathematisches Forschungsinstitut Oberwolfach (Germany)
- National Institute for Mathematical Sciences (South Korea)
- Pacific Institute for the Mathematical Sciences (Canada)
- Research Institute for Mathematical Sciences (Japan)
- The Stefan Banach International Mathematical Center (Poland)



Ready for the mathematical future.