**Supplementary material to accompany**

# THE MATHEMATICAL SCIENCES IN AUSTRALIA

# A VISION FOR 2025

**Recommendations from the subcommittees of the**

**Steering Committee for the**

**Decadal Plan for the Mathematical Sciences 2016-25**

# Supplementary material to accompany the Decadal Plan for the Mathematical Sciences 2016-25

## Contents

# Introduction

Under the umbrella of the National Committee for the Mathematical Sciences of the Australian Academy of Science, key representatives of the mathematical sciences community worked together over a three-year period to identify the main issues Australia faces in the field over the decade 2016 to 2025 and to make recommendations on how these issues should be addressed. The process included seven expert subcommittees, each with a particular focus such as education, research, government instrumentalities or business and industry.

The publication *The Mathematical Science in Australia: A Vision for 2025,* available at [www.science.org.au/mathematics-plan-2016-25](www.science.org.au/mathematics-plan-2016-25) *,* summarised the main findings of the process. It is here referred to as the Decadal Plan.

Each expert subcommittee produced a report, containing recommendations for implementation by governments, universities, schools, learned societies and professional associations. The reports are available at [www.science.org.au/mathematics-plan-2016-25](www.science.org.au/mathematics-plan-2016-25)*.* From a total of 31 recommendations put forward by the subcommittees, 12 were selected and distilled for inclusion in the Decadal Plan.

This document summarises the subcommittees' contribution to the Decadal Plan process. It provides an overview of the work of each subcommittee and presents their recommendations and the rationale behind them. It focuses on the 12 recommendations presented in the Decadal Plan and also includes those subcommittee recommendations not developed into recommendations in the plan.

# Description of subcommittees

Each subcommittee brought together expertise from a range of professionals. The subcommittees focused on different aspects of the mathematical sciences with the purpose of identifying both opportunities and challenges facing discipline specialists, researchers, those working in business and industry, and mathematics teachers in schools, technical and further education, and universities.

The subcommittees received and considered submissions from a range of stakeholders across a number of themes pertinent to their area. A variety of activities were undertaken by committee members and others to seek and encourage submissions including presentations, exhibition booths, workshops and stakeholder meetings.

Below is a brief outline of each subcommittee, including membership and background information.

## I—EDUCATION IN SCHOOLS AND COLLEGES SUBCOMMITTEE

Associate Professor Judy Anderson (The University of Sydney)
Professor Kim Beswick (University of Tasmania, Chair)
Professor Shelley Dole (University of the Sunshine Coast)
Professor Lyn English (Queensland University of Technology)
Dr Rhonda Faragher (Australian Catholic University)
Associate Professor Linda Galligan (University of Southern Queensland)

Professor Barry Hughes (The University of Melbourne)
Mr Dan Mornement (St Mark's Anglican Community School, Perth)
Mr Jon Roberts (Loreto College, Adelaide)
Associate Professor Gloria Stillman (Australian Catholic University)

Subcommittee I: Mathematics and statistics education in schools and colleges (including TAFE colleges), identified its overarching goal as to achieve world-leading mathematics teaching and learning for all Australian students. Key to achieving this goal is to increase the supply of well-qualified teachers of mathematics, ensuring that all secondary school students have access to specialist mathematics teachers and improving the overall achievement of Australian students within an equitable mathematics education system.

The themes addressed by this subcommittee were: strengthening the supply and support of teachers of mathematics and statistics; closing achievement gaps in mathematics and statistics; and increasing the numbers of students studying advanced mathematics and statistics at senior secondary school.

## II—EDUCATION AND TRAINING IN UNIVERSITIES SUBCOMMITTEE

Professor Nigel Bean (The University of Adelaide)
Professor Kim Beswick (University of Tasmania)
Professor Barry Hughes (The University of Melbourne, Chair)
Professor Michael Johnson FAustMS (Macquarie University)
Associate Professor Deborah King (The University of Melbourne)
Associate Professor Don Taylor (The University of Sydney)
Professor Jo Ward (Curtin University)
Professor Ole Warnaar FAA FAustMS (The University of Queensland)

Subcommittee II: Mathematics and statistics education and training in universities, reported on undergraduate and coursework postgraduate mathematical sciences education. Mathematical sciences majors attracted particular attention for three reasons: 1) the existence of honours or coursework postgraduate programs is critically dependent on an adequate supply of well-prepared, enthusiastic graduates with mathematical sciences majors; 2) students who have proceeded at least as far as an undergraduate major are the graduates who will be attributed to the mathematical sciences profession; and 3) mathematical sciences majors recruited into postgraduate teaching degrees are a promising source of future senior secondary mathematics teachers. However, it would have been remiss to pay too little attention to the teaching of mathematical sciences material to broader cohorts (i.e. service teaching). Modern society requires many university graduates who are not mathematical sciences specialists to be mathematically literate in a variety of ways.

The themes addressed by this subcommittee were: curriculum for specialist mathematics and statistics coursework-based programs; service teaching; collaboration and cooperation; and diversity in student recruitment and retention.

## III—RESEARCH SUBCOMMITTEE

Professor Andrew Bassom (The University of Western Australia)
Professor Nigel Bean (The University of Adelaide, Co-Chair)
Associate Professor Ben Burton (The University of Queensland)
Professor Andrew Hassell FAA (Australian National University, Co-Chair)

Associate Professor Stephen Lack (Macquarie University)
Professor Michael Murray (The University of Adelaide)
Associate Professor Mary Myerscough (The University of Sydney)
Dr Todd Oliynyk FAustMS (Monash University)
Professor Louise Ryan (University of Technology, Sydney)
Professor Martin Savelsbergh (University of Newcastle)
Professor Terry Speed FAA FRS (Walter and Eliza Hall Institute)

Subcommittee III: Mathematics and statistics research (including interdisciplinary research) in universities and related institutions (e.g. medical research institutes), addressed all aspects of mathematical sciences research in universities, from funding through to how to assess research depth and breadth. The scope of the subcommittee also included research higher degree programs such as master by research and doctoral programs.

The themes addressed by this subcommittee were: enhancing our PhD programs: a graduate school offering a full year's graduate coursework delivered across Australia?; breadth and depth of mathematical/statistical research; structure and form of research funding; interdisciplinary mathematics/statistics; and a research centre in mathematics/statistics.

## IV—GOVERNMENT INSTRUMENTALITIES SUBCOMMITTEE

Dr Peter Crossman (formerly Queensland Government)
Ms Melissa Gare (Australian Bureau of Statistics)
Professor Bronwyn Harch FTSE (formerly CSIRO, now QUT)
Dr Tom Karmel (National Centre for Vocational Education Research)
Mr Geoffrey Lee (formerly Australian Bureau of Statistics, Chair)
Dr Nicholas McConnell (Defence Science and Technology Organisation)
Dr Blair Trewin (Bureau of Meteorology)

Subcommittee IV: Mathematics and statistics (including education, training and research) in government instrumentalities, both state and federal (including government laboratories such as CSIRO and the Defence Science and Technology Group), considered that government instrumentalities view the mathematical sciences from the perspective of employers of professional staff, who apply the skills and knowledge embodied in their formal qualifications to the goals of each individual agency. There is a strong interest from specialist agencies and bureaus in maintaining an on-going supply of staff, educated and up to date in the latest developments in the mathematical sciences, capable of adapting and applying that technical knowledge to specialised and difficult real-world problems. As well, general agencies require staff capable of adapting and applying quantitative skills founded on a mathematical sciences education to the business of the agency. Rigorous logic and sound and innovative analysis of data are indispensable to policy and decision making, and knowledge and use of the mathematical sciences is indispensable to the seizing of opportunities now possible with new technologies and ideas.

The themes addressed by this subcommittee were: establishing and describing the value of the mathematical sciences for Australia's government instrumentalities; qualifying and quantifying the demand for mathematical scientists (in the public sector); creating an environment where the mathematical sciences can best contribute to Australia; and improving the effectiveness of the interactions between mathematical sciences and government (and non-government) employees from other disciplines.

## V—BUSINESS AND INDUSTRY SUBCOMMITTEE

Dr Ari Katsogiannis (KPMG)
Dr Charles Lilley (Beck Engineering)
Dr John Roumeliotis (National Australia Bank)
Dr Nick Stavrou (Q-Risk Strategies)
Mr Elliot Tonkes (Energy Edge)

Subcommittee V: Mathematics and statistics (including education, training and research) in business and industry, acknowledged that mathematical sciences have always gone hand in hand with practical application and technological success, which most often leads to economic prosperity. Indeed, mathematics is the 'foundation science' underpinning many fields of endeavour. With the advent of widespread access to inexpensive computing, the mathematical sciences have emerged as indispensable tools for studying a variety of problems in scientific research, in product and process development and manufacturing, among many others. This is an important development for the general deployment of quantitatively trained people, as quantitative skills are almost always used in conjunction with software enabling technology in business and industry.

The themes addressed by this subcommittee were: training (ensuring that components of the training of mathematical scientists reflect the requirements of business and industry; this theme has two components—(i) curriculum, and (ii) other aspects of training, for example communication skills and the capacity to work effectively in a team); research (meeting the research needs of business and industry by (i) identifying the needs, and (ii) addressing the needs in universities and other institutions undertaking research in the mathematical sciences); and linkages (exploring the best ways to establish or improve business and industry's links with the mathematical sciences).

## VI—RESEARCH CENTRES SUBCOMMITTEE

Professor Jon Borwein FAA FAustMS (University of Newcastle)
Professor Phil Broadbridge FAustMS (La Trobe University)
Professor Alan Carey FAA FAustMS (Australian National University)
Professor Thierry Coulhon (Australian National University)
Professor Peter Forrester FAA FAustMS (The University of Melbourne, Chair)
Professor Gary Froyland (University of New South Wales)
Professor Tony Guttmann FAA FTSE FAustMS (The University of Melbourne)
Professor Kerrie Mengersen (Queensland University of Technology)

Subcommittee VI: Research centres, present and future, in mathematics and statistics, recorded that Australia has never had a national research centre in the mathematical sciences. In late 2012 the then Department of Industry, Innovation, Science, Research and Tertiary Education released the report *2012 National Investment Plan* that contains many policy recommendations which, from the viewpoint of the mathematical sciences, one can argue could best be implemented through a research centre. There is no doubt that other countries with research centres in the mathematical sciences benefit from access to overseas researchers and expertise to a greater extent than those without. This gives them an advantage in being at the forefront of developments in fast-paced research areas, by having the services of international experts linked by a chosen research theme.

The themes addressed by this subcommittee were: past and present centres—motivations, justifications, aims, activities, successes—within Australia and internationally; what is presently missing from the Australian landscape in mathematical and statistical research that could be addressed by research centre(s), and what additional benefits can be identified to best make our case; what model of research centre(s) is best for our purposes, how should the activities be structured, and what administrative and governing structures should be adopted; and how to go about implementing our recommendations.

### VII—INTERNATIONAL PERSPECTIVES SUBCOMMITTEE

Professor Danny Calegari (University of Chicago)
Professor Peter Cameron (University of London)
Professor John Coates FRS (Cambridge University)
Professor Roger Grimshaw FAA FAustMS (Loughborough University)
Professor Andrew Hassell FAA FAustMS (Australian National University)
Professor Iain Johnstone NAS (Stanford University)
Professor Mark Kisin FRS (Harvard University)
Professor Terry Tao FRS FAA FAustMS NAS (University of California, Los Angeles, Chair)
Professor Ruth Williams NAS (University of California, San Diego)

Subcommittee VII: The view of the Australian mathematics diaspora abroad, focused on quantifying the extent to which Australian mathematics and statistics was represented in the international scientific community, and on identifying areas in which Australian mathematics could learn from international best practices.

The themes addressed by this subcommittee were: internationally recognised strengths and successes of Australian mathematics; comparison between career opportunities for Australian mathematicians at all stages with international standards and benchmarks; some analysis of the value provided by mathematics institutes and networks, based on international examples; and interfaces with the international community.

## Recommendations adopted for the Decadal Plan from consideration of subcommittees' reports

To advance Australian mathematical sciences over the decade 2016 to 2025, 31 recommendations were put forward by the subcommittees. From these, 12 recommendations were distilled and summarised for inclusion in the final publication.

The Decadal Plan sets out four objectives to ensure that Australia benefits fully from the substantial strength of its mathematical sciences community during this decade, and positions the final recommendations within this framework. Three recommendations were put forward under each of the objectives. Each of the 12 recommendations adopted in the Decadal Plan is set out below, and is followed by the rationale describing the basis for its inclusion in the plan.

## Objective I—Giving all Australian school children access to outstanding mathematics teachers

*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*.

On-going professional learning that is focused on improving teaching and learning is a hallmark of high performing education systems. It is a requirement for all teachers throughout their careers to stay abreast of developments in research concerning effective mathematics teaching and curriculum developments, and to share effective practice and engage in collaborative planning and other activities directed at improved teaching and learning. The particular needs of beginning teachers and out-of-field teachers must be attended to with additional support to become integrated into the profession of mathematics teaching and to develop repertoires of knowledge and practice necessary for the effective teaching of mathematics. Meeting workforce demands for appropriately qualified teachers of mathematics means that for the foreseeable future professional learning for out-of-field teachers will need to include formal re-training in courses appropriate to the existing qualifications of these teachers.

Primary and early childhood teachers are necessarily generalists. These teachers must all have ready access to expertise in mathematical content and mathematics pedagogical content knowledge relevant to their contexts. Secondary teachers with an undergraduate mathematics degree also require opportunities to maintain the currency of their knowledge and understanding of mathematics, which is a dynamic discipline.

Anecdotally (including in submissions to the subcommittees), there is evidence of needs for professional learning in relation to specific topics. Examples include: the teaching of statistics in meaningful ways that provide students with the capacity to be quantitatively literate citizens whilst equipping them with the conceptual foundations for further study of statistics; and the effective teaching of mathematics classes catering for students with diverse histories of mathematical attainment, particularly in secondary school. A systematic approach is recommended to the provision of professional learning based on a national audit of needs and existing programs, and including the identification of areas where further research is required in order to provide robust and practical advice to teachers.

*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.*

Initial teacher education (ITE) for teachers of mathematics should use evidence-based practices to develop pre-service teachers' relevant knowledge and affective characteristics. It should be characterised by collaboration among mathematicians, mathematics education researchers, and the mathematics teaching profession. Mathematics teacher educators should have appropriate qualifications and school teaching experience.

Ensuring that Australian ITE is first class will require attention to curriculum and structure of ITE programs, the characteristics of prospective teachers entering ITE programs, and the characteristics of teacher educators both within and beyond education entities.

High quality mathematics teaching requires comprehensive development of knowledge for teaching mathematics at the ITE level. An important inclusion is Shulman's (1987) knowledge types in the context of mathematics teaching: knowledge of mathematics; general pedagogy; pedagogical content knowledge for teaching mathematics; knowledge of how students learn mathematics; knowledge of curriculum, knowledge of educational contexts; and knowledge of ends and purposes that underpin the teaching of mathematics. In addition, teachers need to also develop belief sets about mathematics teaching that are compatible with provision of high quality mathematics learning for all students. Fundamental is the belief that all students can learn mathematics. Appropriate access for all students to the entire mathematics curriculum is imperative. ITE should also engender in teachers an appreciation of the discipline of mathematics and belief in its inherent value as an object of study and realm of creative endeavour, and its value to society.

Efforts to improve ITE must be collaborative, including the range of stakeholders involved in their delivery (mathematicians and mathematics educators) and concerned with their outcomes (employers and professional associations). The importance of collaboration between mathematicians and mathematics educators is emphasised by Seaman and Szydlik (2007) who claimed that teachers of pre-service primary teachers in particular must themselves share the culture of both the community of mathematics teachers and the community of mathematicians. That is, they must have both an appreciation of mathematical ways of thinking and knowing and also of the students' intuitive understandings, the school curriculum, and appropriate tasks, representations and examples for teaching primary school mathematics. This would necessarily also be the case for ITE of pre-service secondary mathematics teachers.

**References**

Seaman, CE and Szydlik, JE 2007, 'Mathematical sophistication among pre-service elementary teachers', *Journal of Mathematics Teacher Education* 10: 167–182

Shulman, LS 1987, 'Knowledge and teaching: foundations of the new reform', *Harvard Educational Review* 57(1): 1–22

*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 on-going development of mathematics teaching within their school, across school clusters, and at regional and state/territory levels.*

Enhancing the status of mathematics teaching will address issues of both attracting and retaining well-qualified teachers of mathematics. Shortages of mathematics teachers are well recognised and increasingly acute (Australian Mathematical Sciences Institute 2013), particularly in regional and remote schools (Lyons et al. 2006). They result from both the undersupply of specialist secondary mathematics teachers and high rates of attrition in the early years of teaching, particularly from hard-to-staff schools in which graduate teachers are over-represented. Research in the US has shown that rates of attrition are affected primarily by working conditions (e.g. availability of resources and administrative support, teaching loads, poor quality of facilities, and perceived lack of influence on school organisation) and salary differentials, with student demographics making a much smaller contribution to teachers' decisions to leave the profession (Darling-Hammond and Sykes 2003). Darling-Hammond and Sykes (2003) noted that the difference in salary for graduates who become teachers compared to those with the same qualifications who pursue other careers is greater for mathematics and science teachers than for teachers of other subjects such as English and social studies. Well-qualified mathematics teachers have marketable skills and hence options that make the provision of satisfying working conditions and rewarding career paths imperative.

Excellent teachers of mathematics need opportunities for promotion that allow them to lead mathematics teaching and learning at school level, across school clusters, and at regional and state/territory levels. This will require a commitment to: (1) enhance the status of mathematics teaching by rewarding the development and sharing of expertise; (2) develop a pool of expert teachers of mathematics able to contribute to the professional development of colleagues; (3) keep the best teachers of mathematics engaged in the teaching of mathematics; and (4) contribute to improving the attractiveness of teaching as a career for those with appropriate mathematics qualifications. Further, every school (early childhood, primary, and secondary) must have a mathematics leader whose responsibility includes leading on-going improvement of mathematics teaching and learning in that school.

**References**

Australian Mathematical Science Institute 2013, *Discipline profile of the mathematical sciences 2013*, AMSI, Melbourne

Darling-Hammond, L and Sykes, G 2003, 'Wanted: a national teacher supply policy for education: The right way to meet the "highly qualified teacher" challenge', *Education Policy Analysis Archives* 11(33): 1–55

Lyons, T, Cooksey, R, Panizzon, D, Parnell, A and Pegg, J 2006, *Science, ICT and mathematics education in rural and regional Australia: the SiMERR national survey*, National Centre of Science, ICT and Mathematics Education in Rural and Regional Australia, University of New England, Armidale

## Objective II—Guaranteeing high standards of mathematical sciences teaching at Australian tertiary institutions

*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.*

An undergraduate major in at least one area of specialisation in the mathematical sciences is available at a majority of Australian universities, though the assessment of the exact situation is sensitive to the precise definition of what a major means. Where majors are not offered, the continuing existence of the mathematical sciences on the campus is in jeopardy and pathways to further studies in which mathematics and statistics pay a major role are closed. Minimalist majors give access only to a very restricted set of options for advanced study.

While some universities retain strictly enforced mathematics prerequisites for entry into some of their degrees, many have adopted a declared 'assumed knowledge' (but no enforced prerequisite) approach for degree entry, but may or may not control entry to specific individual subjects, post-enrolment, and some do not even declare assumed knowledge. Anecdotal evidence suggests that university administrations tend to prefer minimising prerequisites for entry to degrees as a whole or between university subjects.

It was found that the general move away from enforced prerequisites for entry to undergraduate degrees, or for entry into subjects within degrees, threatens the viability of senior secondary school mathematics, transfers work (but not resources) to university departments, and lowers the quality of graduates produced.

The continued decline of participation in intermediate and advanced mathematics relative to elementary mathematics at senior secondary level must be reversed and an enforced minimum prerequisite of intermediate mathematics (Mathematical Methods in the proposed National Curriculum) is needed for all undergraduate degrees with significant mathematical sciences content. Evidence was noted that better school mathematics preparation has positive benefits for undergraduate study in all science, technology, engineering and mathematics (STEM) areas. Put simply, to fix STEM problems, start by fixing school mathematics problems.

*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.*

In his review of some mathematical sciences issues for the Group of Eight (Go8) universities, Professor Gavin Brown (2009) recommended collaboration between Go8 universities to 'develop a systematic structure of enabling programs to counter the drop in students entering with low mathematics experience', noting that this proposal 'has a strong equity dimension and should include careful lobbying for government support'. In its submission to the Decadal Plan, the Australian Mathematical Sciences Institute (2015) concurs with Professor Brown: ' . . . study pathways for students, mature-aged and otherwise, need to cater for those without adequate preparation for university study in the discipline. A collaborative approach to the delivery of the subjects required is highly desirable and, with the advent of the national curriculum, more achievable than before.'

While endorsing efforts to support present students disenfranchised by the inaccessibility of appropriate school mathematics or by poor guidance in subject selection, such efforts should not be seen as an acceptable alternative to the more challenging, but in the long term much more satisfactory, campaign to reverse the decline in school mathematics.

**References**

Australian Mathematical Sciences Institute 2015, 'Submission by AMSI Management Committee 2: Mathematics and statistics education and training in universities', www.mathscidecadalplan.org.au/submission-by-amsi-management-committee-2-mathematics-and-statistics-education-and-training-in-universities

Brown, G 2009, *Review of education in mathematics, data science and quantitative disciplines*, Report to the Group of Eight Universities, December 2009, www.go8.edu.au/__documents/go8-policy-analysis/2010/go8mathsreview.pdf

*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.*

It has long been recognised that there can be financial advantages to other faculties in teaching mathematics and statistics in-house, rather than using the services of the local mathematical sciences discipline, and that financial preoccupations can over-ride educational imperatives. Prudent high-level oversight and clear policies are needed if these financial pressures are to be overcome. However, tensions over service teaching issues are not always solely over cost. There can be significant practical expertise in narrow mathematical areas (often to a high level of sophistication) residing in staff outside mathematical sciences departments, and in some cases, staff with excellent mathematics credentials are employed in other departments. Proposals to teach discipline-specific useful mathematics and statistics efficiently, in context and with minimal class time, can be seen as very attractive alternatives to contracted service teaching.

Tensions over service teaching issues may be lessened in cases where there are joint appointments shared between the teaching department and the department being serviced, or where interdisciplinary collaborations between the departments exist. There need not be a conflict between the aspiration to promote interdisciplinary work and the need to sustain the fundamental disciplines.

Mathematical sciences departments wishing to provide service teaching need to be able to do it very well. A mutually satisfactory service teaching arrangement requires good faith from all parties, realistic syllabus design and realistic expectations on student performance and the level of service provided, given the available class time and the fee for service.

It was observed that mathematics and statistics play an increasingly large role in science, technology, medicine and commerce. Active involvement of mathematical sciences departments in teaching mathematics and statistics to these and other disciplines is important for the development of the disciplines, and for the long-term viability of mathematical sciences departments themselves.

## Objective III—Achieving both local and global impact for Australian research in the mathematical sciences

*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.*

A national research centre integrating different research bodies has the potential to encourage, enhance and provide practical support towards research translation. This translation may take many forms, including: inspiring and capturing the imagination of a new generation of researchers; assimilating new methodologies which may then be relayed to business and industry; and/or facilitating communications between theoreticians and practitioners.

A facility such as this will optimise Australia's ability to develop strategic and coordinated research partnerships, both nationally and internationally; enhance and provide practical support towards research translation; and leverage significant funds to the mathematical sciences from other sources. A national research centre will allow Australia to play a leadership role among our neighbours with similar and emerging aspirations in research in the mathematical sciences, and as such would represent a strategic investment for our future as a more knowledge-based society.

*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.*

A coordinated effort across Australian universities to offer high-quality graduate coursework for postgraduate research students in mathematics will address a growing concern with the current level of training for Australian higher degree research students, and will strengthen the quality of students' research work. The intended result will be to make our students more competitive in what is now a very tight international academic job market, and for those students who move into industry it will broaden their high-level mathematical and interdisciplinary skills.

Courses would be delivered remotely, so that students can access material and expertise from outside their home university, and so that costs can be managed. Topics would span core mathematics as well as interdisciplinary material (such as biology and computer science), and the format would be kept deliberately flexible. Ideally, there might be approximately 60 courses delivered per year.

To allow universities to integrate this coursework into what is currently a relatively short degree, it is recommend that the standard PhD program be lengthened from three years to four years, or else that the honours year be replaced with a two-year master's course. Either option would require a corresponding extension to scholarship funding (e.g. Australian postgraduate awards) and a corresponding increase in student funding.

Such a program would sensibly be coordinated by the Australian Mathematical Sciences Institute (AMSI) while being led by a senior academic with responsibilities to develop a suitable and broad program and ensure appropriate standards are maintained.

*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*.

There is high demand for mathematicians and statisticians to apply their knowledge in areas beyond traditional mathematics and statistics; indeed, in areas beyond traditional applications such as engineering and the physical sciences into areas such as business, geosciences, service industries and the biomedical sciences. While there is a need for more interdisciplinary workers with high-level mathematical and statistical skills in Australia, there are also structural and cultural barriers to a successful career in interdisciplinary research.

Successful interdisciplinary mathematical researchers are characterised by an ability to synthesise information, and to produce useful mathematical and statistical tools such as models or data analyses. These researchers need to be mathematically trained to do their job well, but may not have a strong research track record in 'traditional' mathematics research or publish in journals that are labelled 'mathematical' or 'statistical'. To be effective, a mathematically or statistically trained researcher also needs specific knowledge of the area of application that they work in. At the very least, this presupposes a willingness to learn about a new area, but it may also entail informal or formal training.

There is a tendency in mathematics and statistics and in the area of application for each discipline to think that the interdisciplinary researcher belongs to the other. Applications for Australian Research

Council (ARC) grants for interdisciplinary projects can be deemed 'too mathematical' for the panel that oversees the area of application, yet the Mathematics, Physics, Chemistry and Earth Sciences panel may say that there is not enough new mathematics or statistical methods to justify funding and the application should go to the panel in the area of application. National Health and Medical Research Council (NHMRC) grant review panels may not be currently not well-equipped to judge biostatistical, bioinformatics and other mathematically oriented research.

It is generally agreed that research will tend to follow the money—that is, people will tailor their research so that it is able to attract grant funding. If this is true and we want to see mathematics in Australia engage with other disciplines and in contexts outside universities, then we must give some thought to providing funding opportunities for interdisciplinary research.

## Objective IV—Ensuring that Australian society is capturing the benefits of new mathematics-based technologies

*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*.

Gender differences in mathematics achievement have received considerable attention with the focus of research moving from helping girls to think differently, to the impacts of differential impacts of curriculum and other factors on boys and girls, to how teachers can create mathematics classrooms in which girls and boys can all succeed (Forgasz et al. 2000). A necessary condition creating such classrooms is that the teacher has equally high expectations of boys and girls in relation to mathematics achievement.

It was recognised that initiatives that make the mathematical sciences more attractive generally are likely to increase the diversity of students that are attracted, and that well-resourced, well-taught and well-structured programs that students have a realistic possibility of performing well in are more likely to retain students. There are opportunities for staff to modify teaching styles to hold the interest and boost the confidence of students likely to abandon mathematics early in their undergraduate experience (Deshler and Burroughs 2013), and the practices of institutions in other countries that have been successful in recruiting and retaining female students and students from low socio-economic groups are worth studying.

Inspirational examples of institutions in the USA that have responded effectively to these challenges can be found in the American Mathematical Society (AMS) awards for 'Exemplary Program' (see www.ams.org/profession/prizes-awards/ams-awards/department-award) and 'Mathematics Programs that Make a Difference' (see www.ams.org/programs/diversity/emp-makeadiff). The selection criteria for the latter awards bring out the issue very nicely: they seek programs that 1) aim to bring more individuals from underrepresented minority backgrounds into some portion of the pipeline beginning at the undergraduate level and leading to an advanced degree in mathematics, or retain them in the pipeline; 2) have achieved documentable success in doing so; and 3) are replicable models.

**References**

Deshler, JM and Burroughs, EA 2013, 'Teaching mathematics with women in mind', *Notices of the American Mathematical Society* 60: 1156–1163

Forgasz, H, Leder, GC and Vale, C 2000, 'Gender and mathematics: changing perspectives', in K Owens and J Mousley (eds), *Mathematics education research in Australasia: 1996–1999*, MERGA, Turramurra, NSW, pp. 305–340

*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*.

An on-going campaign is recommended that can inform and excite potential students, and those who influence their education and career choices, about the variety, range and rewards of careers and occupations which are accessible as a consequence of a solid mathematical sciences base in their education; and about the many different ways that the mathematical sciences contribute to sustaining and advancing the well-being of people.

This is part of an over-arching objective to pursue a thriving and vigorous mathematical sciences education sector in Australia (primary, secondary and tertiary levels) which is attracting and educating people capable of applying their quantitative skills to the major challenges facing Australia, and also educating a generally more numerate population capable of applying basic quantitative skills in their work and lives.

The campaign should not be limited to 'pure' or 'specialist' mathematical science occupations; rather, it should encompass the breadth of job options and career pathways that stem from an education with a base of solid quantitative skills. There are numerous examples which demonstrate wide, interesting and rewarding career opportunities. The recommendation is about on-going efforts to ensure this information is accessible and visible to students before they make decisions about the subjects they will study.

*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.*

This is part of an over-arching objective to pursue a strong and innovative mathematical sciences research culture in Australia, connected within and across disciplines in Australia and internationally, with a keen interest in applying their knowledge and skills to the private and government sectors.

While there is much the mathematical science community can and should do for itself, some key factors are not within the community's power to control. Therefore, for the Decadal Plan to be implemented successfully, those who have influence and authority must be convinced.

There should be an on-going, high-level dialogue to impress key policy and decision makers of the ways that the mathematical sciences generate benefits for Australia's economy, society and environment and to brief them on emerging useful applications.

The campaign would require on-going engagement from the most senior and well-respected members of the community's disciplines, with the highest levels of executives in governments, private enterprise, and the education sector. Ideally this would be an enduring dialogue over the next decade and would create a feedback loop which could be used to adapt and refresh the Decadal Plan itself. The initial version of the Decadal Plan could be used as a trigger for commencing dialogue at this level, and building opportunities and forums for further engagement.

## Additional recommendations from the subcommittee reports

The recommendations discussed above were summarised and refined from a total of 31 recommendations made by the 7 expert subcommittees. The recommendations which were not developed further for explicit inclusion in the Decadal Plan should be noted for further consideration in future internal and external policy development.

These additional recommendations are presented below under their relevant objective. The specific subcommittee putting forward each of these additional recommendation is identified, along with a brief rationale for considering it.

### Objective I—Giving all Australian school children access to outstanding mathematics teachers

*1.4 Raise expectations for the mathematics achievement of all Australian students*—Subcommittee I

Australian students are capable of mathematics achievement that is the equal of students anywhere in the world. Our students should be able to succeed in mathematics wherever they live, and whatever their ethnicity or their gender. Achieving this goal involves eliminating practices that convey low expectations of mathematics achievement to students, and enabling students to develop a belief in their capacity to solve mathematics problems and to learn mathematics.

*1.5 Increase the sophistication of public discourse regarding mathematics and the role of teachers of mathematics*—Subcommittee I

Teaching mathematics well at any level of schooling is complex and demanding work that requires considerable knowledge and skill. The profession should continue to intensify its efforts to communicate what teachers of mathematics know and can do, using language that is accessible to lay people and that respects the informed perspectives of all stakeholders.

### Objective II—Guaranteeing high standards of mathematical sciences teaching at Australian tertiary institutions

*2.4 Every undergraduate mathematical sciences major should:*

- *have at least 50% of final-year credit devoted to mathematical sciences subjects*
- *have both depth in one specialised area of mathematical sciences and reasonable breadth across areas of the mathematical sciences*
- *develop the student's understanding of the context and applications of the mathematical sciences*
- *develop the student's ability to communicate mathematical or statistical concepts or results to both specialists and lay people*
- *develop facility with appropriate information technology and professional software*—Subcommittee II

The subcommittee notes that it does not favour being prescriptive as to the content of mathematical sciences undergraduate majors, and also recognises that degree rules covering degrees within which majors sit may prevent aspirational proposals on total mathematical sciences content being realistic. The subcommittee does have some concerns on the type of teaching and assessment that occurs and on the associated learning strategies of undergraduate students. It draws a distinction between a learning style based purely on rote learning and developing facility with algorithmic processes and one based on developing insight and understanding.

*2.5 Mathematical sciences departments should offer an appropriate sequence of subjects for each of the following undergraduate cohorts:*

- *students seeking mathematical sciences knowledge to assist them in pursuing other majors or other degrees ('service teaching')*
- *students seeking to develop perspectives and skills for employment on graduation ('mathematics or statistics as a mindset')*
- *students seeking mathematical sciences careers, who need pathways to postgraduate coursework study and to research higher degrees ('mathematics or statistics as a profession')—* Subcommittee II

University mathematical sciences departments should ensure that necessary resources are allocated to each of these cohorts, that each cohort is valued, nurtured and taught with enthusiasm, and that staff are recognised and rewarded for contributions to the proper education of any of these cohorts.

*2.6 Universities should seek to ensure that all Australian students completing undergraduate mathematical sciences majors have pathways to subsequent higher-level study. Where individual universities are unable on their own to support such pathways, and to enhance the diversity of higher-level study that is available, universities should cooperate in the provision of pathways to further study—* Subcommittee II

It may be possible for capstone subjects in higher-level programs to be developed in collaboration with AMSI or other stakeholders. Opportunities for cooperation within undergraduate programs are also worthy of consideration, especially in service teaching, in the context of the national senior secondary school curriculum, and given the urgency in providing upskilling for school mathematics teachers. Cooperative activities with a variety of stakeholders are also likely to be helpful in developing the curriculum (both at undergraduate level and at higher levels) for modern applications and in providing on-going professional development opportunities for graduates.

*2.7 Mathematical sciences departments should develop practical strategies to deal with the diversity of background and prior mathematical achievement of their students and to increase the attractiveness of continuing mathematics and statistics study to all students, but especially to female students—* Subcommittee II

Even if the school mathematics preparation of students is strengthened overall in the near future, the challenge of significant diversity in the level of mathematics preparation of incoming students will long remain an issue. Large, well-resourced departments may be able to deal with the diversity of background and prior mathematical achievement of their students by streaming students on entry, but such streaming should not close off pathways to more-advanced study. Where streaming is unaffordable or impractical, other solutions to the challenges of cohort diversity need to be sought.

*2.8 To improve the quality of graduates, improve the proportion of commencing students who graduate and ensure the availability of mathematical science undergraduate majors and pathways to research higher degrees across the nation, adequate per-student funding needs to be available and to reach mathematical sciences departments*—Subcommittee II

Economies gained through large-group lecturing or alternative methods of material presentation have to be balanced against investment in individual attention in one or several of tutorials, laboratory classes, in-office consultations and individualised on-line or email attention. Provision of effective pathways for students with past educational disadvantage or on-going difficult personal circumstances (important for reasons of equity) entails additional expense. When revenue per student is small, maintaining upper-level undergraduate subjects and research higher degree pathways becomes difficult.

## Objective III—Achieving both local and global impact for Australian research in the mathematical sciences

*3.4 Significant efforts should be made to close the gap in gender equity in research in the mathematical sciences*—Subcommittee III

Actions to address this recommendation should include:

a) funding agencies allowing the use of grant money to pay for the costs of additional caring assistance at home while the researcher is away at a conference, or at a conference if it is necessary for the child to travel
b) all universities ensuring the portability of maternity leave across universities
c) all research institutions ensuring that parenting leave is sufficiently flexible to enable researchers to maintain a level of activity, should they wish
d) the societies establishing cross-institutional mentoring programs for early and mid career female staff to assist them with their career development
e) all conferences/workshops in the mathematical sciences ensuring that the number of female invited/keynote speakers are approximately half of the total number, and similarly for all visible leadership roles, such as session chairs
f) undertaking a review of the issues facing women in Australian mathematics and statistics by a panel of experts from Australia and overseas, in order to leverage the international expertise and experience in this area.

*3.5 The major funding agencies should improve certain areas of the assessment process*—Subcommittee III

Actions to address this recommendation should include:

a) devoting resources to educate assessors in order to remove the 'memory' from the grant assessment system, whereby old perceptions remain. Examples where education could be needed include: i) the ARC assessors regarding a proposal as 'too clinical' and the NHMRC assessors regarding a proposal as 'too theoretical'; and ii) interdisciplinary proposals being regarded as 'not sufficiently strong' by assessors from each supporting discipline, rather than being considered holistically
b) developing advisory groups in the relevant major disciplines (e.g. mathematical sciences, physics) to support the NHMRC's assessment processes; this could be achieved by collaborating with the ARC.

*3.6 The ARC should develop a portfolio-approach to its programs that is designed to better meet the needs of all researchers*—Subcommittee III

Actions to address this recommendation should include:

a) developing a separate program where researchers could apply to the ARC for smaller grants with a streamlined application process and a higher success rate, to enable them to leverage international schemes
b) establishing a separate program for interdisciplinary proposals with different aims to the other schemes, including fostering collaboration, and enabling researchers to move into new areas (such as pure mathematicians moving into bioinformatics) and different selection criteria, including a proven track record of collaborative work that is 'out of field' rather than an extensive track record in the particular domain.

*3.7 The breadth and depth of mathematical sciences research in Australia should be monitored and regularly reviewed, to ensure appropriate coverage*—Subcommittee III

Actions to address this recommendation should include:

a) collecting data on the breadth and depth of research in mathematical sciences in Australia by collecting the Field of Research Codes (FoRCs) assigned to ARC grants, and the FoRCs or Mathematics Subject Classification codes for talks given at Australian conferences, in particular the conferences of the societies
b) the National Committee for the Mathematical Sciences co-ordinating the collection of relevant data and publishing regular reports on the breadth and depth of research in the mathematical sciences in Australia. Such reports should highlight areas where there appears to be a significant shortfall in activity, particularly where our ability to supply the demands of industry/society is in doubt.

*3.8 There should be a significant and sustained number of fixed-term postdoctoral positions for new PhDs that are competitive with similar positions overseas, in order to attract top junior mathematicians internationally, to help retain domestic talent, and to invigorate the research environment in Australian institutions*—Subcommittee VII

Having a guaranteed and significant number of postdoctoral positions in each school (even at the cost of one or two permanent positions) would yield a number of advantages: 1) mathematically it means that there are more people moving through the school, keeping the research activity there more energetic and less narrow; 2) a postdoctoral position that is competitive with similar positions overseas will help attract young people to Australia at a time when they might be more willing to move there; and 3) once such people are in the country on a postdoctoral position, they will often be more willing to stay.

*3.9 Due to geographical isolation, it can take significant time for the latest developments in the international mathematical community to be disseminated locally. There should therefore be increased support for Australian academics to travel abroad to attend research conferences, and conversely for international academics to visit Australian institutions. Sharing of information about visitors between universities, as well as utilisation of videoconferencing technology, should also be encouraged*—Subcommittee VII

There are existing programs in Australia for this purpose (e.g. the Mahler lectures), but more could be done in this area, for instance by sharing information between different departments regarding their international visitors. To contrast with other countries: China is heavily investing in bringing back expatriate researchers to visit during the Northern hemisphere summer to collaborate and give short courses. This is having a significant effect on the preparation and breadth of their students.

## Objective IV—Ensuring that Australian society is capturing the benefits of new mathematics-based technologies

*4.4 There should be periodic meetings of relevant executive level staff from specialist government instrumentalities to share experiences and coordinate approaches to improving the quantity and quality of mathematical sciences knowledge in their staff, including in the pool of potential recruits. The objective of the dialogue is to enable good ideas and activities which already exist within individual agencies to be mobilised on a wider scale*—Subcommittee IV

The specialist government instrumentalities (CSIRO, ABS and DSTO especially) have been concerned about future supply of mathematical scientists for quite some time now, and are implementing a number of strategies to address their concerns. Other (smaller) specialist agencies face similar challenges, but lack the critical mass and resources to act. The proceedings of the dialogue should be publicised to enable all government instrumentalities to benefit.

*4.5 There should be an on-going effort to provide leadership and central participation by the mathematical sciences in the emerging opportunities for what has become known as 'big data', i.e. the combination of computational power, burgeoning data generation and new analytics, to be applied to policy and decision making in government instrumentalities*—Subcommittee IV

Information technology and advances in instrumentation are changing the cost equations for data acquisition and analysis. The current challenge is to manage and interpret data correctly, and then to analyse and model effectively and rigorously. The potential pay-off for policy and program administration is huge.

*4.6 Emphasis and recognition should be placed around the fact that mathematical scientists are 'problem solvers'*—Subcommittee V

This aspect of a mathematical scientist is in our experience one of the more valuable skills in the workplace. These skills can be bolstered and given broader areas for training by providing educational opportunities to develop a portfolio of supporting skills. This can be achieved by well-defined project work or more-sophisticated assignments that can showcase the problem-solving ability.

*4.7 The mathematical sciences should engage in brand creation to make the communication as simple as possible with the wider business community*—Subcommittee V

Australia has a world-class education system and this extends to the mathematical sciences. Australia should further develop this competitive advantage by leveraging its educational and research strengths and if necessary seek to reposition them. A key responsibility for the academic and policy communities will be to ensure that the community's investment is not underutilised.

*4.8 An extended dialogue should be established with the industries that already have a tradition of engaging mathematical scientists*—Subcommittee V

Some practical ways to engage will be to create secondment opportunities or summer internships for students, participation in research programs and broader cross-fertilisation of ideas. This will provide an understanding of what mathematical scientists do, help with brand creation and recognition and assist students thinking where to go with a mathematical science degree.

*4.9 An independent study should be undertaken in Australia to better understand Australia's leverage to the mathematical sciences*—Subcommittee V

This should be similar to the recent UK study conducted by Deloitte. Our experience strongly implies that Australia also depends on a strong mathematical sciences culture but it would be better for policy and certainly business to quantify, as accurately as possible, the similarities and differences to other nations, both in our neighbourhood and farther afield. This study should also seek out lessons learned from Australian success stories that companies attribute to a mathematical sciences foundation.

# Conclusion

The work of the seven expert subcommittees helped identify opportunities and challenges for mathematical sciences discipline specialists, researchers, those working in business and industry, and mathematics teachers in schools, technical and further education, and universities.

Our rapidly changing world presents both challenges and opportunities. It is becoming increasingly technological and significantly more mathematical. For Australia to prosper under these circumstances, it will need:

- citizens who have been taught mathematics and statistics well while at school
- a steady flow of similarly 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.

The subcommittees put forward 31 individual recommendations, and these were combined and refined into 12 recommendations for how the mathematical science community could move forward into the next decade. The intention is that the ideas and recommendations distilled and summarised from the subcommittee reports and presented in *The Mathematical Science in Australia: A Vision for 2025,* available at www.science.org.au/mathematics-plan-2016-25 , 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.