Report of Subcommittee III

Steering Committee for the development of

The Mathematical Sciences in Australia

A Vision for 2025

The Decadal Plan for the Mathematical Sciences 2016-25

Mathematics and statistics research

in universities and related institutions

Decadal Plan Research Subcommittee: Full Report
Report to the Steering Committee on 18th January 2014

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Recommendations:

1) We recommend that the Australian universities collaborate to offer enhanced training for postgraduate research students in the mathematical sciences through the provision of additional coursework. This will address a growing concern with the current level of training for Australian HDR students, and will strengthen the quality of students' research work. The intended result will be to make our students more competitive in the international academic job market, and for those students who move into industry it will broaden their high-level mathematical and interdisciplinary skills.
   a) To allow universities to integrate this coursework into what is currently a relatively short degree, we recommend that the standard PhD programme 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., APAs). An increase in student funding due to the additional year of candidature would also be required.
   b) 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. Ideally, there might be approximately 60 courses delivered per year.
   c) The format would be kept deliberately flexible. Students should be encouraged (or even required) to pursue breadth as well as depth. Students would also be able to take courses in other disciplines related to their research (e.g. bioinformatics students could take undergraduate biology and/or computer science courses). Doctoral training could also take the form of short projects in other research groups related to their research topic, or in industry, similar to the Industry Doctoral Training Centre (IDTC)[1] currently in operation.
   d) Mathematical Science courses would be targeted at both mathematical scientists and other researchers looking to improve their skills and knowledge in the mathematical sciences.
   e) Such a program could be coordinated by AMSI while being led by a senior academic with responsibilities to develop a suitable and broad program and ensure appropriate standards are maintained.
2) We recommend that the mathematical and statistical community adopts measures to increase the visibility and prestige of interdisciplinary research within the community. Actions include:
   a) working with the appropriate professional societies (e.g. Statistical Society of Australia and the Australian Mathematical Society) to develop ways to recognize

[1] See http://www.uts.edu.au/research-and-teaching/future-researchers/research-degrees-uts/atn-industry-doctoral-training-centre

outstanding mathematical scientists who have built their careers around applied problem solving in government, in industry and in scientific research beyond the physical sciences, including introducing awards;

b) introducing a program of eminent visiting lecturers who have built their careers around applied problem solving in government, industry and scientific research outside the physical sciences;
c) introducing special sessions and/or plenary speakers at the Societies' regular conferences focused on research related to applied problem solving in government, industry and scientific research outside the physical sciences;
d) commissioning a series of profiles of very high profile, highly successful mathematical scientists who have built their careers around applied problem solving in government, industry and scientific research outside the physical sciences;
e) developing an educative public document explaining the role of these researchers and how to interpret their level of research performance to encourage universities to value more applied accomplishments when they are considering applicants for jobs or considering promotion of existing faculty; and
f) encouraging Vice Chancellors to offer flexible funding to enable like-minded departments to create joint appointments, when appropriate opportunities arise.

3) We recommend that significant efforts be made to close the gap in gender–equity in research in the Mathematical Sciences. Actions include:
   a) the 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 - other sorts of leave, including long service leave, are portable but maternity leave is not, and this can discourage women from moving institutions during child-bearing years;
   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-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; and
   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.
4) We recommend that the major funding agencies improve certain areas of the assessment process. Action 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 NH&MRC 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 (eg mathematical sciences, physics) to support the NH&MRC’s assessment processes; this could be achieved by collaborating with the ARC.
5) We recommend that the ARC develop a portfolio-approach to its programs that is designed to better meet the needs of all researchers. Actions 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; and
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.
6) We recommend that the breadth and depth of mathematical sciences research in Australia is monitored and regularly reviewed, to ensure appropriate coverage. Actions 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; and
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.

Process

Four main themes were identified in order to frame the work of this subcommittee, as detailed below.

1. Enhancing our PhD program: A National Graduate School:
   The major purpose would be to provide graduate level courses equivalent to those offered in the US at a major research university, or (to give a UK analogy) similar to Cambridge's Part III.
2. Breadth and Depth of mathematical/statistical research:
   With a relatively small population Australia faces challenges in covering the breadth of modern mathematics/statistics with a depth that makes it sustainable.
3. Structure of Government Research funding:
   How well do the current government-funded research funding schemes suit mathematics/statistics?
4. Mathematical/Statistical Technology-transfer:
   Mathematical/statistical expertise is in growing demand in other research areas and throughout industry and society. How do we go about improving our approach to this transfer of mathematical/statistical technology?

Pleasingly the work of the sub-committee revealed many interactions across these themes.

We also took significant note of the submission from the Women in Mathematics Special interest Group of the Australian Mathematics Society.

1. Enhancing our PhD Program

Summary

We recommend a coordinated effort across Australian universities to offer high-quality graduate coursework for postgraduate research students in mathematics. This will address a growing concern with the current level of training for Australian HDR 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, we recommend that the standard PhD programme 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., APAs) and a corresponding increase in student funding.

Such a program would sensibly be coordinated by AMSI while being lead by a senior academic with responsibilities to develop a suitable and broad program and ensure appropriate standards are maintained.

Background and motivation

The role of coursework in mathematics

In Australia, the typical training for a mathematics PhD student involves a three-year Bachelor's degree followed by a one-year Honours programme (typically both at the same institution). The student then moves into a three-year PhD programme that is research only, with no coursework requirements.

This can result in an unbalanced education: high-level formal courses may be limited to the interests and offerings of the student's undergraduate institution, and any additional material that the student needs to learn during their PhD must be picked up "on the fly". The short length of the Australian PhD programme (three years) means that this knowledge is often acquired on a need-to-know basis.

The outcome is that an Australian student may emerge from a PhD programme with deep knowledge only in limited areas. In the short term this can make the student less competitive in the job market (particularly for postdoctoral fellowships which are often tied to existing grant-funded projects). In the long term this can hinder a successful research career, where it is increasingly important to be able to draw on and identify links between different branches of mathematics.

These are issues are particularly relevant to students who move into interdisciplinary fields of research. Such students often need to acquire a large body of background knowledge in a secondary discipline within a short space of time, and often this is a discipline that they have not formally studied as part of their undergraduate degree.

The Group of Eight have released a discussion paper, "The Changing PhD", which discusses a range of issues surrounding modern PhD programmes in Australia and overseas. This report highlights the introduction of graduate coursework as an important response to these issues.[2]

The international perspective

To ensure that their students have a broad and rigorous mathematical background, many leading international universities require coursework as part of their PhD programmes. In some countries (such as the USA), this is a formal part of the PhD structure. In other countries (such as the UK), this is managed less formally at the university level. To illustrate:

- In the USA, PhD programmes typically run for 4-5 years, and include formal courses in the first 4 semeters that are taught and examined at the student's home university.

- In the UK, universities collaborate to offer graduate coursework through six graduate "taught course centres", funded by the Engineering and Physical Sciences Research Council (EPSRC).[3] Courses are available to all partner universities, with some offered remotely over the Access Grid and others taught face-to-face. The EPSRC has also funded several high-level Centres for Doctoral Training, which incorporate formal coursework as part of a larger PhD programme; some of these centres have a strong interdisciplinary focus.[4]

- In South-East Asia, some leading universities offer their own in-house graduate coursework programmes. For example, the University of Tokyo offers core and elective mathematics courses in both their Master's and PhD programmes which graduate students are expected to take, and the National University of Singapore

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[2] See http://www.go8.edu.au/university-staff/go8-policy-_and_-analysis/2013/the-changing-phd.

[3] See, for instance, MAGIC (http://maths-magic.ac.uk/index.php), the London Taught Course Centre (http:// www.ltcc.ac.uk), and the Oxford-led centre (http://tcc.maths.ox.ac.uk).

[4] See http://www.epsrc.ac.uk/research/ourportfolio/themes/mathematics/introduction/train/Pages/centres.aspx.

offers a wide range of courses for Master's and PhD students.[5]

Existing programmes in Australia

In response to these issues, the Australian Mathematical Sciences Institute (AMSI) has established a series of annual short-term events, aimed at broadening students' background beyond their formal undergraduate education:

- The AMSI Summer School is a four-week annual event, aimed primarily at honours students. This school offers a range of high-level short courses, with topics that change each year.
- The AMSI Winter School is a two-week annual event for graduate students and postdoctoral fellows. It offers a series of intense introductory and advanced courses, relating to a central theme that changes each year.
- The AMSI Summer Symposium in Bioinformatics is a one-week educational and outreach event that aims to introduce students and researchers to key topics in this interdisciplinary research field. These programmes are optional for students and are not formally integrated into degree structures, though classes at the AMSI Summer School may optionally be taken for honours credit.

Developing formal graduate coursework

To address the issues above, we recommend that universities across Australia collaborate to develop a rich programme of graduate coursework.

Courses should be delivered nationally, using remote technologies. This will allow students to access high-level expertise across a significantly wider range of areas than is typically available at their home university. Moreover, each individual university will only bear a small portion of the burden and costs in developing and delivering these course materials. AMSI is well-placed to coordinate these course offerings.

Topics should cover both high-level mathematical material, as well as introductory material for interdisciplinary research. Offering high-level mathematics courses will allow students to developer a broader mathematical background that gives them better flexibility and resources for core mathematical research. Interdisciplinary courses can be tailored to mathematicians who are interacting with new areas (such as biology or computer science), or to people from these other disciplines who need to acquire new mathematical skills. It might be sensible to specify a minimum number of required "Maths" courses, and hence allow for a maximum number of interdisciplinary courses – some of which might be locally-offered undergraduate courses.

This coursework programme should retain significant flexibility. Individual lecturers should retain flexibility over how the courses are structured and assessed, and individual universities should retain flexibility over how they are formally incorporated into their postgraduate degrees. A simple pass/fail mechanism for students could ensure that

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[5] 4 See http://www.ms.u-tokyo.ac.jp/kyoumu_e/courses_e.html and http://ww1.math.nus.edu.sg/undergrad.aspx? f=stu-modules.

coursework is taken seriously without taking too much focus away from the central research component of the degree. It would also lessen the impact of the variable backgrounds of students and variable standards of the courses.

A senior academic should take leadership of the National Graduate School with responsibility for arranging a broad and appropriate range of courses, and ensure appropriate standards are maintained. Ideally a program of approximately 60 courses would be delivered each year.

Funding and resources

For students, the most significant drawback to graduate coursework is that it takes valuable time away from what is already a short PhD (typically three years). If graduate coursework is to be incorporated without compromising students' research projects, we recommend extending the typical PhD programme by an extra year. This could involve either (i) extending the length of the PhD programme from three to four years; or (ii) replacing the one year Honours degree before the PhD with a two year Master's degree that incorporates this richer body of graduate coursework. Indeed, some individual universities are already exploring the two year Master's option.

Either of these options has implications for student scholarship funding. For the four-year PhD option, the term of the Australian Postgraduate Award (and similar scholarships) would need to be extended from three years to four. For the two-year Master's option, the Master's degree would need to be incorporated into the postgraduate scholarship model, extending the effective length of such awards from three years to five.

As the formal candidature would be increasing by 1 year, it is also essential that an additional year of student funding be provided to the home institution of each student. Over the entire nation, that should provide sufficient additional funding to enable the deliver of sufficient courses to make the National Graduate School very beneficial. To enable students to take the individual courses most relevant to them, it is essential that all courses be offered via a remote technology, as travel to attend such courses would be prohibitively expensive.

Beyond mathematics

We note that the issues listed here are not specific to mathematics. Indeed, the Group of Eight report "The Changing PhD", which likewise raises the issues of graduate coursework and a longer timeframe for PhD completions, is written broadly without focus on any one discipline. Likewise, any change to the funding model for Australian Postgraduate Awards and similar scholarships, and student funding, would need to be made across the higher education sector. Such changes would dramatically strengthen the opportunity for students to train at the highest level in interdisciplinary research.

2. Breadth and Depth of mathematical/statistical research:

Discussion about research breadth and depth is complex because it can be considered at both a systemic and at an individual level. By systemic, we refer to the totality of research in the mathematical and statistical sciences. For example, it is important to assess the traditional aspect of how our research in Australia relates to that being undertaken by our peers internationally. It is also important to assess how our research relates to the needs of the Australian community including; are we covering areas of research particular to Australia such as Australian aspects of climate change and are we covering areas needed by Australian science and industry. From an individual level perspective, it is important to ask the question of whether individual students emerge from their training with the appropriate levels of breadth and depth needed for them to succeed in their chosen career path.

The Systemic Level

The committee spent quite some time focused on the problem of how we can measure the current depth and breadth of Australian research and on the question of what we do with that information once we obtain it. So this part of the Decadal Plan is not an assessment of the current state of the breadth and depth of Australian research but rather a plan for how we can collect data in the future and what we should do with it.

Available Data

Very fruitful discussions were held with the Director of AMSI and a number of sources of data were recommended:

AMSI related data:

- Data from member institutions collected via membership survey
- PhD completion data: topics and areas of focus
- AMSI summer workshops: topics and areas of focus
- AMSI summer scholarships: topics and areas of focus

Government data:

- ERA: it would be extremely helpful to get the 6-digit FoRC publication data
- ARC: it would be extremely helpful to get the 6-digit FoRC publication data
- HERDC: it would be extremely helpful to get the 6-digit FoRC publication data

Data held by learned societies:

- American Mathematical Society publication data for Australian mathematicians held on MathSciNet
- Australian Llearned societies (eg AustMS, Stat Soc, ANZIAM) membership data and information on the talks given at annual conferences, particularly that for special sessions.
- There was a survey conducted in 2004 on behalf of the Biostatistics Collaboration of Australia designed to assess how well the needs of various employers were being met with current graduates. It would be useful to get hold of this survey and perhaps recommend that similar surveys be repeated in the future.

It needs to be noted that the data we can collect from some of these sources is variable across the disciplines in mathematics and statistics. In particular MathSciNet has excellent coverage in pure mathematics but less so in mathematical physics and much less so in applied mathematics and statistics. Any use of this data has to be done with great care to avoid the problem of drawing conclusions that reflect not reality but the choice of tools we use to measure it.

Classification

A secondary question is how do we assess what part of mathematics the research is occurring in. There are two possible ways of coding data that spring immediately to mind. The first is the Mathematics Subject Classification (MSC) used by MathSciNet: http://www.ams.org/mathscinet/msc/msc2010.html

The second, in an Australian context, is the ABS Fields of Research Codes (FoRC): http://www.arc.gov.au/applicants/codes.htm

The MSC suffers from the same problem as MathSciNet in that it offers excellent coverage and granularity in pure mathematics but much less so the other disciplines. Coverage in the area of statistics is particularly poor. Again any use of this needs careful interpretation to avoid falling into the same trap highlighted above. The FoRC offer much less granularity and the granularity at the 6-digit FoRC level seems rather arbitrary. Nevertheless they are important in an Australia political context.

Motivated by our discussions the Director of AMSI has commenced a project to:

- Assign 6 digit FoRCs to the ARC DP data from 2002 onwards
- Assign FoRC and MSC to AMSI workshop topics and attendees from 2004
- Assign 4 digit FoRCs and class sizes for Summer School subjects from 2004
- The American Mathematical Society has agreed to provide Australian publication data from MathSciNet

ForC and MSC data will be requested for all future AMSI activities.

Recommendations

As a consequence of our investigations we would like to make a number of recommendations:

- That the Australian Mathematical Sciences community establish a Research Breadth and Depth Monitoring Committee. The role of the RBDMC would be to co-ordinate collection of relevant data and to publish 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.
- That the Australian Learned Societies follow the lead of AMSI and collect MSC and FoRC for all their activities in particular for special sessions at conferences.
- That the Australian Learned Societies commit to a one-off expenditure to have MSC and FoRCs assigned to historical data.

The Individual Level

We then spent some time thinking about the issue of whether Australian mathematics and statistics graduates have the right depth and breadth needed to succeed. We started out by considering what it is that government and industry are looking for in a mathematics graduate.

Government and private enterprises consistently express a strong need for enhanced capacity in the mathematical sciences. For example, applied research organizations such as the CSIRO, the Australian Institute for Marine Science, the Bureau of Meteorology and countless smaller research institutions such as the George and Garvan Institutes in Sydney rely on sophisticated mathematical, computational and statistical modelling. What are the qualities that such organizations look for in a mathematics graduate at the hiring stage and what are the qualities of the mathematical scientists who prove to be successful and even thrive in those organizations?
Employers are looking for

- Problem solvers – people who are able to use their mathematical and statistical training to tackle complex modelling or data analysis problems and help answer real world questions. Such people often have a natural curiosity about areas outside their immediate expertize and are willing to learn about the subject matter area of interest.
- Good communicators – people who are able to effectively translate their thinking, their methods and their conclusions. Such people don't rely on the use of too much technical jargon and can explain complex ideas in ways that are understandable to experts from other disciplines as well as to managers and decision makers.
- Team players – people who work well with others and especially in a multidisciplinary team context. People who understand that the mathematical sciences, while certainly important in their own right, have a critical enabling role throughout virtually all aspects of scientific endeavour as well as in business and society. Team players embrace the enabling aspect of their mathematical expertise, while still appreciating the inherent elegance and beauty of mathematical sciences as an end itself.
- Good computing skills – people who can implement effective solutions in a robust and timely manner. Ideally, solutions should be implemented in ways that others can use. While mathematical scientists don't need to be computing specialists, they need to have a strong working knowledge of computing and be abreast of latest trends, able to use modern tools, designed to "get the job done".

Unfortunately, graduates rarely have all these skills and many have none of these skills! Too often we see a fresh PhD who might be the world's expert in a particular area (for example, solving differential equations or developing theory for non-parametric regression modelling), but who struggle to effectively contribute their knowledge in the real world. Too often we see talented mathematical scientists who, when faced with a challenging practical question, will morph that question into something that can be solved with their favourite tool or technique. This is the phenomenon that when someone has a hammer, everything looks like a nail. A former Chief of CSIRO's Division of Mathematics, Informatics and Statistics commented that she saw on countless occasions where a talented applied mathematician or statistician would frustrate their applied colleagues by solving a problem that was only peripherally related to the one originally posed. This kind of thing gets everyone frustrated, including the applied mathematician or statistician who feels unappreciated. Eventually the subject matter scientists stop asking and just end up doing things themselves.

Recommendations

We believe that there are a number of strategies that can be put in place to help alleviate some of the problems described above and to enhance national capacity for the kind of problem-solving mindset that I believe is needed within the mathematical sciences. Obviously, it makes sense to think of strategies that will help better equip graduates to become effective problem solvers. Another broad class of strategies have to do with changing our own perceptions and belief systems so that a more problem-based approach is appreciated and valued appropriately. So what can we do?

1) Develop new approaches to training that provide hands-on experience with collaboration and problem solving. There are some excellent models for this at various overseas universities. Recently, the Australian Technology Network (comprising UTS, QUT, RMIT, Uni SA and Curtin University) have launched the innovative Industry Doctoral Training Centre[6] which is loosely modelled after a similar program in the UK. Participants undertake doctoral research whilst being imbedded with an industry partner and tackling a problem of relevance to that partner and motivated by their work with that partner. Trainees have supervisors from both the university and the industry partner. Trainees are also required to undertake coursework that ensures that they have a strong and appropriately broad foundation in addition to specialized knowledge related to their specific doctoral research area. Perhaps it would be wise to consider expanding the IDTC concept to additional universities, as well as broaden the interpretation of "industry partner". For example, someone may undertake a PhD in Statistics, developing new approaches to adjusting for measurement error, but as part of their training, be imbedded with researchers in the social sciences school of their university, serving as part of an interdisciplinary team studying a compelling issue in the social sciences.
2) Require that PhD students graduate with a broad knowledge base that includes a) an appropriate range of foundational courses in their discipline; b) a "cognate minor" where they are required to take one or two courses in a potential application area; c) some training in communication and collaboration skills; d) exposure to high profile, high achieving mathematical scientists who do collaborative and interdisciplinary work. This would be an important aspect of starting to change the mindset of our graduates.
3) Find ways to help Australian universities to more effectively share their resources to ensure that they can effectively provide some of the breadth described above. There are several existing strategies that could be more broadly developed and adapted:
    a. The IDTC – see above
    b. The innovative Biostatistics Collaboration of Australia (BCA) which is "a consortium of biostatistical experts from around Australia with representatives from universities, government and the pharmaceutical industry who have combined to offer a **program of postgraduate courses**." Students can enrol for their masters degree through any of a number of partner universities and take

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[6] See http://www.uts.edu.au/research-and-teaching/future-researchers/research-degrees-uts/atn-industry-doctoral-training-centre

   courses, either in person or via distance learning, from any other partner university.
   c. The proposed National Graduate School, see Section 1.

4) There are several examples of industry-based initiatives where new graduates undergo training not only in technical areas, but also the "softer" skills of communication and collaboration. An excellent example is the biostatistical trainee program run through NSW Health. Participants do coursework in technical subjects through the BCA (see above), are assigned to various applied projects to gain practical experience and also received training in communication, business principles etc.
5) Raise the prestige associated with being a problem-based mathematical scientist[7] through various initiatives that would increase people's understanding of what such work entails, increase their appreciation for the importance of such work, increase appreciation for the skill involved in doing good problem-based work. This might be done though things such as
   a. Fund a series of national lecture tours by very high profile, highly successful mathematical scientists who have built their careers around applied problem solving. There is a long list of people who could be drawn on.
   b. Commission a series of profiles of people such as the ones described in the above bullet point
   c. Develop some recommended guidelines for university departments that encourage them to value more applied accomplishments when they are considering applicants for jobs or considering promotion of existing faculty. These guidelines might include lists of activities of accomplishments that go beyond simply publishing in the mathematical journals.
   d. Develop some specialized funding mechanisms (administered through ARC or perhaps NHMRC) that can support applied and interdisciplinary research. In the US, there are a number of grant schemes of this nature.
   e. Work with the appropriate professional societies (e.g. Statistical Society of Australia, the Australian Mathematical Society) to develop ways to recognize outstanding mathematical scientists who excel in the problem solving skills described above. The societies have a number of medals and honours that are regularly given out. However, these generally reward the more narrowly defined, academically-oriented and technical accomplishments. Some of the US societies have mechanisms in place to recognize and reward mathematical scientists who excel more broadly.

3. Decadal plan: research funding

Summary of existing ARC system

The vast majority of money available in the mathematical sciences is through Discovery Projects. These are typically of the order of $100,000 per year. This means that it is possible to hire a postdoc, at least for some of the period of the grant, and often this is the main way (in mathematics) to spend a grant of that size. This process also provides a significant contribution to the available post-doctoral positions available for early career researchers

[7] See Section 4: Knowledge/Transfer/Interdisciplinary Research

in Australia. The success rate is roughly 30% (2007-2011).

There are also various fellowship schemes: Laureate, Future Fellows, DORA and DECRA. The DECRA scheme is targeted towards early career researchers who are eligible to apply if they have been awarded a PhD within five years and up to 8 years if there was a career interruption. In 2011 and 2012, a total of 15 and 12, respectively, were awarded with FoRC corresponding to the Mathematical Sciences, and the average period[8] since their PhD of the award winners was 3.1 and 4.1 years, respectively. Of these awards, 5 went to applicants who were 0-2 years out from their PhD.

Comparison to other countries

We have looked particularly at the NSERC in Canada, since in many ways it is one of the most similar to our system.

• similar total funding pool (roughly $15-20 million per year)

• NSERC has higher success rate (66-74%)

• NSERC has smaller grants (typically $20,000-30,000) • NSERC has many more postdocs

• NSERC has longer grants (typically 5 years rather than 3)

• In Canada there are also the major Research Institutes (PIMS, Fields, BIRS, etc.) which are funded separately.

The NSF is so much larger as to be difficult to compare directly with Australia. The number of different schemes is enormous: there are many different schemes announcing results every week.

The EPSRC in the UK also has a much wider range of grants than exist in Australia. These include PhD scholarships, postdocs, ECR grants, funding for short-term visits, right up to programme grants for up to six years.

Many European countries have permanent research-only positions, al- though sometimes these have a ceiling in terms of promotion.

In Belgium, PhD students are generally employed as teaching assistants for a period of 6 six years. This gives greater flexibility in moving into the first postdoctoral position.

Postdoctoral positions

1. **Scarcity of independent postdoctoral positions:** most postdoctoral positions are funded by senior researchers' DP grants. For early career researchers, DECRA represent the only targeted funding opportunity from the ARC and these awards are small in number and difficult to get, particularly for postdoctoral researchers who are 0-2 years out from their PhD. Some universities have their own postdoctoral schemes, but these are generally even harder to get than those with the

[8] This average is based on 22 of the successful DECRA applicants whose PhD award dates could be confirmed.

ARC.

2. **Fellowships vs research associateships:** In view of this scarcity, for many people the first postdoctoral position has the form of a research associateship attached to a senior academic’s grant. This sometimes results in good. It also often results in less independence for the researcher. Depending on the circumstances this may or may not be an advantage.
3. **Effects of existing fellowship program:** Recipients of the various fellowships (Future, DORA, Laureate, and to a lesser extent DECRA) are typically people with existing teaching positions. When they take up their fellowships their salaries are then freed up, and generally used in part to hire more junior people to cover their teaching load. This provides employment opportunities for these more junior people, which can be valuable if it leads to future continuing employment. On the other hand there is a risk that such people are over-burdened with teaching and then unable to obtain a continuing position, or end up on a back-fill roundabout.

Issues with current ARC system

4. **Low success rate:** many strong researchers receive no funding. This has implications for new appointees whose probation may be tied to a successful grant application, and also for more senior researchers where successful grant applications are a requirement for promotion. It also, of course, can limit the productivity of researchers at any level.
5. **Issues relating to postdocs:** Having postdoctoral positions that are tied to a senior academic’s research program can be problematic for the following reasons:
   a. difficulty in finding postdocs with the required research expe- rience, which is especially true for specialized areas or narrow research programs, and
   b. opportunities to recruit outstanding postdoctoral researchers who do not directly fit into established research programs into the Australian system are missed.
6. **Suboptimal allocation of resources:** for some researchers, especially in more theoretical areas that do not have the overhead costs associated with running a lab or large scale computations, large grants are not always necessary and smaller grants with a higher success rate would be a more effective use of funding.

A proposal for changes to the ARC

1. Maintain the existing DP scheme in terms of sizes of grants and conditions, but award fewer of them.
2. Take the savings realized from awarding fewer of the large DP grants and use it to fund a small grant scheme.
3. The precise mechanics of the scheme are still to be determined (it would not just be the old “small grant scheme”). Key features would include:
   a. Higher success rate
   b. streamlined application process
   c. greater flexibility
   d. designed particularly to facilitate collaboration
   e. could also be pooled or banked to enable the hiring of postdocs

Benefits

1. By breaking a portion of the larger DP grants into a number of smaller grants, the total number of grants available will increase, and consequently, so will the success rate.

2. Small grants would be a more effective method of distribution funding to researchers who do not have the overhead costs associated with running a lab or large scale computations, and for whom hiring a post-doctoral researcher is not necessary to sustain their research program.

3. If the success rate of the small grant scheme was made high enough so that in any particular institution it was likely that a number of researchers in a given group had a grant, then this would open up the opportunity for academics in similar fields to pool their small grants in order to hire a postdoc, if they desired. Furthermore, by allowing the small grants to be routinely banked over multiple years, it would be possible for even individual small grant winners to employ postdocs.

Disadvantages

1. An even lower success rate for large DP grants. This would negatively impact mathematicians whose research programs rely on large DP grants.
2. A possible reduction in the number of postdoctoral positions due to the decrease in the number of large grants. The actual size of the reduction would depend strongly on how the small grants were used.

Question to address

1. How/where are small grant proposals to be assessed?
2. What should the duration of the small grants be?

4. Mathematical/Statistical Technology-transfer: or The Mathematical/Statistical contribution to Interdisciplinary Research

The current situation

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. There is an increasing demand for mathematical sciences in these areas. For example, mathematicians and statisticians who work in biological applications all seem to be very busy with more interesting research opportunities than they have time to address. There is a need for more interdisciplinary workers with high level mathematical and statistical skills in Australia, but there are structural and cultural barriers to a successful career in interdisciplinary research.

This document will use the definition that *interdisciplinary research* is where mathematics and statistics are applied in pursuit of aims that are not purely, or even mainly, mathematical. For example, the purpose of mathematical modelling is often to produce a model that throws light on the underlying system rather than to create an interesting, analysable set of equations. Successful interdisciplinary mathematical researchers are characterized 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 labeled "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.

Getting the requisite understanding of the area of application takes time; establishing research credibility in that area usually takes more time again. A track record of working with outstanding scientific or industrial collaborators can be very valuable in establishing credibility and demonstrating the usefulness of the mathematical sciences in a particular area.

Interdisciplinary researchers also need excellent communication skills and the ability to interpret their work simply and clearly to others.

Status of interdisciplinary research in University Mathematics and Statistics Departments.

The application of mathematics outside the physical sciences may not be highly regarded by academic mathematicians and statisticians. Rigorously proving some small point about differential equations may be regarded as "proper" mathematical work, while collaborative work to answer a question in medical science using mathematical tools may be regarded as "soft" or "easy" or "not real mathematics" or "just computational and algorithmic". This point has been alluded to in Section 2, where a very senior person was shocked when encouraged to play down their more applied, problem solving work on an important document describing their career achievements.

The outcome of this is that it becomes difficult to attract students into interdisciplinary areas and mathematics and statistics departments avoid employing people with interdisciplinary expertise. This is at a time when people who can apply mathematics in industrial, financial, biological, biomedical and other contexts are demonstrably in demand!

Challenges of working in interdisciplinary contexts in Industry

Joint research with industry brings additional challenges. These include relationship management, expectation management, intellectual property arrangements, reporting requirements and more.

While the ARC's linkage scheme encourages research collaboration with industry, the focus tends to be on delivering value to industry, rather than addressing fundamental mathematical questions that arise from this research. Additional challenges arise when universities seek to expand the funding that they obtain from industry and place pressure on mathematical and statistical staff who are able to attract industry funding to go after more industry funding. This requires major time and effort which is usually unmeasured and not fully appreciated. Building relations with industry and convincing them of the benefits of engaging with universities to explore business opportunities is enormously time-consuming.

Mathematics departments need to value colleagues who work on industry-motivated research as should universities. This type of research does not fit well with most current methods of performance evaluation.

Neither one Thing nor the Other 1: Funding for Interdisciplinary Research.

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 ARC grants for interdisciplinary projects can be deemed "too mathematical" for the panel that oversees the area of application, yet the Engineering, Mathematics and Informatics panel says 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.

NHMRC grant review panels are currently not well-equipped to judge biostatistical, bioinformatics and other mathematically oriented research.

The most successful solution to this dilemma is for researchers to submit grant applications with collaborators in the area of application and often to make experiments, or other work done by the collaborator, rather than the mathematically oriented research, the main focus of the proposal. Established credibility in a field, such as bioinformatics and strong, ongoing, productive collaborations enhance the probability of funding success, particularly with NHMRC, but this suggests that it can be hard for early career researchers to get a foot in the funding door.

There are ways around this dilemma, but *there shouldn't have to be*. In fact this problem should not exist and is probably because of the discipline-driven nature of grant assessment in Australia. Other overseas funding schemes are more amenable to interdisciplinary research. The Human Frontiers of Science Program grant scheme explicitly encourages cross-disciplinary work, for example and anecdotally a number of Australian researchers in interdisciplinary areas get funding from US schemes when they cannot obtain it locally.

Neither one Thing nor the Other 2: Careers in Interdisciplinary Research.

This problem of researchers and research falling between two stools becomes more severe when mathematically trained researchers using mathematics or statistics in nontraditional applications seek permanent employment. If a young researcher has spent time, for example, in biological sciences research groups or working on industrial or business problems embedded in the industry, a mathematics department may regard them as out-of-touch and not having a sufficiently mathematical track record to be employable. Likewise a biomedical department may reject them because of their lack of undergraduate training in the discipline. Career paths are not clear and may not exist at all.

Pleasures and Pitfalls of the "Service" Role.

When a mathematical or statistically trained researcher goes to work in a non-mathematical context, it is easy for them to become solely a provider of mathematical/statistical services, rather than a researcher in their own right.

This service role is valuable, if handled well, as it enables mathematical and statistical researchers to see what other researchers need and enables contact with other researchers which may transform into collaboration. It also gives the opportunity to help other researchers quickly and well which may lead to a growth in reputation and valuing both of the researcher and the mathematical sciences. However, care needs to be taken so that researchers (particularly early career researchers who may have less power over their circumstances) do not become unnecessarily trapped by the service role

Opportunities for Interdisciplinary Work

Wherever there is quantitative research being done, there will be opportunities, although some are, of course, better than others. Below is by no means an exhaustive list.

Big data: More and more data is being generated in the social sciences, in business and industry and in biomedical and biological sciences which can be distributed more easily by electronic communications. Researchers in many areas are seeking help from the mathematical sciences to find new ways to analyse data, to create new quantitative models and theories and to explore ideas with simulations and modelling.

The Change to the Service Economy: Many companies are switching focus from providing equipment, software and other technology to providing services. There is a need for skilled personnel to provide mathematical and statistical expertise to apply to clients' problems.

Penetration of quantitative technology into new areas: As technology becomes more and more sophisticated and ubiquitous there is a need for mathematically skilled researchers to become involved with its development and use.

For example, image processing has become a rapidly expanding area as new technologies to create images arise. Image processing is used in computer science, electrical engineering, surveying, photogrammetry and medical applications. Sometimes the mathematics involved is simple, but some types of imaging, such as PET (positron emission tomography) and fMRI (functional magnetic resonance imaging) require the solution of inverse problems or statistical modelling. FMRI, in particular, also leads to questions of brain connectivity and networks that will require mathematical tools to unpick.

This is just one area where mathematics is becoming more important. There are many others, including bioinformatics where the proliferation of "omics" data has lead to the development of important new statistical methods.

So, where is the path forward? Further thoughts and specific recommendations

There is a need for cultural change on both sides.

Mathematicians need to value colleagues who work in interdisciplinary areas. There should be an acknowledgement that mathematical success does not lie entirely in rigorous proof and intellectual beauty; it also lies in applying mathematical approaches to solve scientific, business or industrial problems, in dealing with untidy data or ideas and numerical solutions to complicated equations that are analytically intractable.

Mathematicians and statisticians who work in applications generally have broad mathematical expertise, highly developed synthetic skills and are good communicators, well-connected beyond mathematics. In a university context, they are the department members who are most likely to know and be known by staff in other departments and they form an important link between mathematics and the wider research community and, indeed the wider community in general. So from a political and strategic point of view, they should be highly desirable staff members.

From a biological or biomedical perspective there might need to be some acknowledgement that mathematically oriented researchers have different demands on them to their collaborators. They may seek, for example, not only papers in *Nature*, but also in *SIAM Applied Mathematics* and must continue to keep their mathematical skills fresh to be the most use in their area of application.

We recommend that the mathematical and statistical community adopts measures to increase the visibility and prestige of interdisciplinary research. These may include

1. **introducing awards for mathematical research in government, in industry and in scientific research beyond the physical sciences;**
2. **introducing a program of eminent visiting lecturers who have worked with mathematics in government, industry and scientific research outside the physical sciences;**
3. **introducing special sessions and/or plenary speakers at AustMS or ANZIAM to highlight mathematics research done outside mathematics departments.**

Careful development of funding schemes to recognize and foster interdisciplinary 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. It is quite likely that the converse will be true as well—if it is hard to get grant funding, then the research is unlikely to be undertaken.

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. At present cross-disciplinary research grant assessment is hampered by the silo-ed structure of grant assessment in Australia.

We recommend that the Australian Research Council introduces a cross-panel mechanism to assess applications that clearly cross discipline boundaries between panels.

There is also a need to enable and encourage mathematicians and other research workers to develop collaborations and for these collaborations to have time be able to demonstrate a track record of productivity.

We recommend that the ARC and/or NHMRC introduce a program of "seed grants" specifically for interdisciplinary research where researchers from different disciplines can apply for funding and their successful use of these funds is measured in joint papers or joint grant applications.

An educative document...

Many mathematical or statistical researchers occupy a liminal space in research; they are seldom first or last author or first-named investigator on a grant, yet their contribution is essential for the research projects that they work on and innovative and creative mathematical work can be the driving force of many projects, without being put front and centre in the subsequent publications.

We recommend that mathematicians and statisticians (perhaps via AMSI) create a public document explaining the role of these researchers and how to interpret their level of research performance.

Stronger links between mathematics and statistics departments and researchers in cross-disciplinary areas.

There is a role for joint appointments where staff can have an actual "foot in both camps". This would help researchers from both the application area and the mathematical sciences to understand the contribution, methods and expertise of interdisciplinary researchers. Hugh Possingham's position at the University of Queensland is consistently given as the prime example of this type of appointment.

Training in Interdisciplinary research in Mathematics and Statistics

Training in the area of application needs to be available for mathematics and statistics graduates and, in a research context, particularly for PhD students and postdocs. This may involve formal coursework, but also the opportunity to be embedded in the context of the application whether this is a laboratory in a biology department or a business. Funding to support this type of embedded PhD candidature or postdoc is important. The NIH in the US runs a program where mathematics graduates can work in a medical institute with a view to changing fields to biomedical applications of mathematics.

Interdisciplinary doctoral training centres exist at several UK universities (eg Warwick, Oxford) where a student receives explicit training in both fields and can try several miniprojects that span both theoretical and laboratory projects before embarking on PhD research. This enables students to become conversant, not only with the knowledge base of each field but also with their cultures and so to become more able to embark on successful interdisciplinary research.

We recommend that training for interdisciplinary research is considered when the coursework component of PhD study is under consideration. This training may include, for example, coursework on the fundamental knowledge of the area of application, such as cell biology, physiology or genetics. It may also include time spent doing a short project in a research group in another area.