National Strategic Review of Mathematical Sciences Research

Submission by

CSIRO Mathematical and Information Sciences (CMIS)

Summary

1. Mathematical Sciences are critical for multidisciplinary breakthroughs for both science and industry in biotechnology, ICT, materials science as well as in the Service industries in areas such as risk and logistics. Investments in research infrastructure (such as through the current NCRIS Program) should be complemented by investments to develop the related capabilities in mathematical sciences.
2. To support research and advanced application of the Mathematical Sciences and maintain current international standing, we need the education system to produce more high quality graduates in the mathematical sciences at both first degree and PhD level.
3. The Mathematical Sciences community in Australia need to work together to make greater impact and to build a "bigger pie" for research and for delivering services.

Context

CSIRO (Commonwealth scientific and industrial research Organisation) is a national R&D laboratory undertaking research in agribusiness, environment, energy, information, manufacturing and minerals. It employs more than 4000 research staff organised in 19 divisions. Roughly two thirds of its funding comes directly from the Federal government ("appropriation") and one third from industry and various arms of government through competitive contracts and grants.

One of the research divisions is Mathematical and Information Sciences (CMIS). It employs about 110 researchers with background training in mathematics, statistics, engineering or computer science at the bachelor masters or PhD level. About 70 have Ph.D.'s. While not all CSIRO mathematicians (by which is meant people working in any of the mathematical sciences) are employed in CMIS, the vast majority of mathematical research publications come from CMIS. Funding for CMIS in 2005-6 is about $15.4M Government appropriation and $8M external funding.

There has over the past five years or so, been a growing realisation of the crucial role that the mathematical sciences play in scientific endeavour. As an example, CSIRO has recently articulated broad directions for its Science Investment Process and has identified the mathematical sciences as playing a key enabling role in:

- Transformational biology – a key global science driver/trend identified by CSIRO

- CSIRO's flagship projects
- Environmental science
- Information and communication sciences
- Infrastructure, commercial and community services.

Based on proposals from across CSIRO, the level of appropriation funding in 2006-7 for CMIS will increase by 17.3% over 2005-6 funding. This planned growth is based on both recent performance and current opportunities. There are grounds for believing that further growth will occur in future years. A critical question is whether we are able to recruit people of the requisite calibre in sufficient numbers to support the planned growth.

Interactions between CMIS and the University research community are weaker than we desire, though we have some activities with universities. These include top-up scholarships for PhD students, (possible) shared post-doctoral fellowships, a vacation students scheme for 3rd year undergraduates (including a joint mini-conference involving AMSI-sponsored vacation scholarships), occasional university courses delivered by CMIS staff and the sharing of international visitors.

Response to Terms of Reference

A Mathematical Sciences Research

A1 To determine the degree to which an internationally competitive fundamental research base is required in all branches of the mathematical sciences in Australia.

There are four fairly general reasons for training and research in the mathematical sciences:

1. it is aesthetically pleasing
2. it teaches valuable ways of thinking
3. it solves important 'real' problems for the community
4. it provides the option to solve possible future important 'real' problems (capability development).

In a relatively small teaching and research community such as Australia it is important that the focus be on (3) and (4). Teaching ways of thinking (2) will follow from (3) and (4) through appropriate choice of syllabus. This leads to the conclusion that mathematicians, in order to understand the priorities now and in the future, should be significantly involved in applications particularly in multidisciplinary research. If this is to be of long-term value to national research and capability then it must involve groups of mathematicians not individuals (to achieve critical mass) and there should be ongoing dialogue between mathematicians working on mathematics for its own sake ("core mathematicians") and those undertaking multidisciplinary research.

There is a tendency for dialogue between the core and those involved in multidisciplinary research to die away to the long-term detriment of both. In the extreme form, new sub-fields develop in isolation. Examples include, on the one hand, statistics, biometrics, psychometrics and econometrics and on the other hand applied mathematics and parts of engineering. Communication among these groups seems to be minimal even though (for example) directions in econometrics should be informing some research in statistics (and vice versa).

A2 To identify areas of current and anticipated strength and weakness in research in the mathematical sciences in Australia, in light of Australia's strategic needs.

Historically Australia has had a number of internationally recognised mathematicians who have had a focus on particular application areas. For example Fellows of the Royal Society include Bullen (seismology), Phillip (Agriculture) and Moran (applications of stochastic processes) and this suggests a strategy around multidisciplinary research could be successful. Research published by Genest[1] shows that in the 80's and 90's Australian statistics (on a population basis) was particularly strong internationally. While there remain areas of strength, that position has weakened considerably and will be further eroded with the continuing lack of production of strong future researchers.

A4 To evaluate benefits and challenges arising from interdisciplinary research involving the mathematical sciences.

There are benefits to mathematics and also to the community from interdisciplinary research. For mathematics, interdisciplinary research creates new research problems and whole new areas of research opportunity. Notable current examples include biotechnology, nanotechnology and material science, For the community the benefits are better products and solutions to environmental and social problems. From CSIRO's recent history we can give a number of examples.

(i) Working with the Australian Greenhouse Office, CSIRO mathematicians have developed the National Carbon Accounting Scheme which gives a national estimate of the total amount of carbon captured in vegetation. This enables an on-going assessment of Australia's performance against the Kyoto protocols. A benefit cost study by the Centre for International Economics identified quantifiable national benefits of the mathematical contributions of the order of $100M.

(ii) CSIRO fishery biologists and mathematicians have been estimating fish populations in commercial fisheries (for prawns and Southern BlueFin Tuna, for example) and have been able to identify populations under threat where management action has been needed (and undertaken, based on the mathematical advice) to ensure that the population is sustainable.

(iii) CSIRO work in Image Analysis has led to the development of a world first device for recognising melanomas (with PolarTechnics) and a device for measuring, in real time at 100 km per hour, cracks in a road.

[1] Genest and Guay (2002). Worldwide research output in Probability and Statistics. Canadian J of Statist.

(iv) Lens design software developed by CSIRO has allowed SOLA to improve there progressive lenses so that they now give clearer, more comfortable vision to millions of people

(v) Using expertise in mathematical optimization, CSIRO has helped to overcome scheduling challenges for THL a company specialising in the rental of recreational vehicles. The CSIRO software is a critical component to THL Rentals success

(vi) CS IRO has developed a suite of modelling technologies for simulating fluid and granular flows interacting with complex geometry and involving complex multi-physics processes

(vii) CSIRO mathematical modelling of metal rolling has reduced defects and increased productivity through waste reduction

(viii) CSIRO has produced robust and accurate FX option pricing technology that is now available as a plug-in for FENIX® FX

.

A5 To identify any factors which impinge on the quantity and quality of research in the mathematical sciences.

In CSIRO, the quantity of mathematical publications is increasing though there is a greater proportion of publication occurring through Conference proceedings rather than journals and books. There is also a trend for more of these publications to be in 'applications' journals rather than in the core discipline journals. This reflects Government policy for greater involvement of researchers with end users (notably industry and government) and the response of CSIRO, CMIS and individuals to that policy.

Some data (Table 1 below) on CSIRO publications by mathematicians with more than 50 citations drawn together for a history of statistics in CSIRO shows that the numbers of very highly cited papers has decreased and has shifted from methodology to applications.

	Methodology in Core Journals	**Methodology in Subject Journals**	**Applications**
Before 1974	13	4	2
1974 – 1987	7	8	5
1988 – 2000	3	5	4
Total	**23**	**17**	**11**

Table 1: Distribution of highly cited publications

In the 1980's, CSIRO's publication record according to the Genest[2] analysis was particularly strong. This was the outcome of a mix of:

[2] Genest, C (1997) Statistics on statistics: measuring research productivity by journal publications between 1985 and 1995. Canad. J. Statist., **25** 441-457

(a) an excellent cohort of researchers;
(b) strong involvement in multidisciplinary research; and
(c) the ability to consolidate the multidisciplinary research into mathematical and statistical research.

The factors impinging on quality and quantity include
(a) Expectations that researchers are involved with end-users (in industry or multi-disciplinary research) rather than undertaking research driven by colleagues in the same discipline. This has the effect of increasing the probability that research results will be useful and thus cited.
(b) Increasing dependence of researchers on contracts rather than block grants for research funding leading to a short-term focus.
(c) Contracts generally support research on the application but do not support the consolidation of research ideas into 'polished' mathematical research, thus reducing the total impact of the research.
(d) There seems to be an increasing expectation that a senior researcher will accomplish research through graduate students and post-doctoral fellows, but the average quality of students going into the mathematical sciences appears to have declined and so research conducted by them is likely to be of lesser quality.

The priority given to mathematics by policymakers, funders and students depends on its relevance to contemporary issues. Mathematics in Australia has been too slow to engage with and demonstrate its value in areas such as biotechnology, information technology, and engineering. From outside the education system it seems that too much effort is expended on dispute among the sub disciplines on the distribution of the current, diminishing, slice of pie, based on subjective comparisons of merit rather than looking at how to increase the impact of the mathematical sciences and the return on the resource allocated to them.

It is noteworthy that in the current roadmapping document for the national collaborative research infrastructure scheme (NCRIS) http://www.dest.gov.au/NR/rdonlyres/E2001074-CDA2-4CEA-A1B4-775B4882A5F5/9519/NCRISStrategicRoadmap.pdf there is mention of the need to develop capability in computer science but not mathematics. Yet many of the areas where infrastructure is proposed to be purchased will have a great need for innovative mathematical and statistical modelling.

Action is required to ensure that mathematical sciences are recognised as contributing to such areas and are funded accordingly.

B Provision of Advanced Mathematical Services

B1 To examine how advanced services in the mathematical sciences contribute to other fields of endeavour, and to assess the benefits of the nation's investment in the mathematical sciences.

B2 To determine the areas of the mathematical sciences most used by business, industry, government, and other organisations, and identify those most likely to be needed in the next decade.

We have chosen to work in biotechnology and health, environment and decision tools for minerals, manufacturing and service industries. These are the application areas where we anticipate the biggest realisable opportunities. We believe that the areas needed in the coming decade include computational modelling, simulation and optimisation, bioinformatics, imaging, risk quantification, the analysis of streaming data and the integrated mathematical and statistical modelling of systems (rather than components).

B3 To identify strengths and weaknesses in the provision of advanced services in the mathematical sciences in Australia.

There are undoubtedly many highly capable people delivering advanced services in the mathematical sciences in Australia. The weaknesses are that

1. There is low recognition of the value of the mathematical sciences in industry and so finding customers and industrial collaborators is difficult for researchers, particularly if working alone or in very small groups as is often the case so that there is little strategy or co-ordination
2. The delivery is often opportunistic, ad hoc and unprofessional. This is ultimately damaging to the discipline. The approach is often to deliver a short-term answer to a specific question, rather than to develop a broader approach of greater long-term value.
3. Some research grants require commercialisation or commercial returns and the requirement is simplistically interpreted as a need to undertake consulting work. While that is part of the solution mathematics is an underpinning technology and can have far greater impact if a long-term rather than short-term approach is taken.

B5 To recommend policy and funding changes that will

(a) enable the mathematical sciences community to offer better services to business, industry and government and other organisations;
(b) facilitate the update of advanced services in the mathematical sciences by organisations that may benefit from the use of these; and
(c) improve communication and mobility between the academic mathematical sciences community and business, industry and government.

While government, industry and university administrations can make changes to enhance the future of the mathematical sciences, early steps should be taken by the mathematical community to demonstrate its importance and establish its "right to grow". It seems that the community spends too much effort bemoaning its treatment by "them" or celebrating minor successes over peers, and too little in developing and achieving joint goals for the future.

The mathematical sciences in Australia need to work together to develop a broad marketing approach to explain to industry, government and the community the real value that the mathematical sciences can deliver. This may also involve the mathematical sciences discovering what those real benefits are. While the circumstances are certainly different, Australian astronomy has a decadal plan and Australian mathematics has nothing comparable.

Graduates in the mathematical sciences are often not as good as graduates from other disciplines such as engineering or information technology in formulating problems, working in teams and delivering services to industry. This should be explicitly addressed in courses through some combination of major projects and industrial experience (either through sandwich courses or through vacation employment). Setting up this industrial experience would require all University teachers interacting with industry and this would have the spin-off benefit of improving communication and mobility.

It may also be that there are potential mathematicians who are not currently attracted by current courses. Many of the courses match descriptions from 20 years ago. Others give the impression of aiming to provide all possible options rather than training students in problem formulation and mathematical thinking. A degree course in computation and mathematical and statistical modelling could address several issues identified here.

C. Infrastructure

C1 To assess the flow of high quality students into training and research in the mathematical sciences and areas utilising the mathematical sciences.

It has become quite difficult for us to recruit suitable staff. As indicated in Figure 1, CMIS has been unable to fill a substantial number of the positions that have been advertised. Figure 2, shows the senior appointments in CMIS. A lack of suitable senior appointees has hampered our growth opportunities with industry and is seriously inhibiting further investment by CSIRO. The difficulty in recruiting appropriate staff is due, at least in part, to the decreasing number of high quality graduates and postgraduates from Australian universities over the last couple of decades.

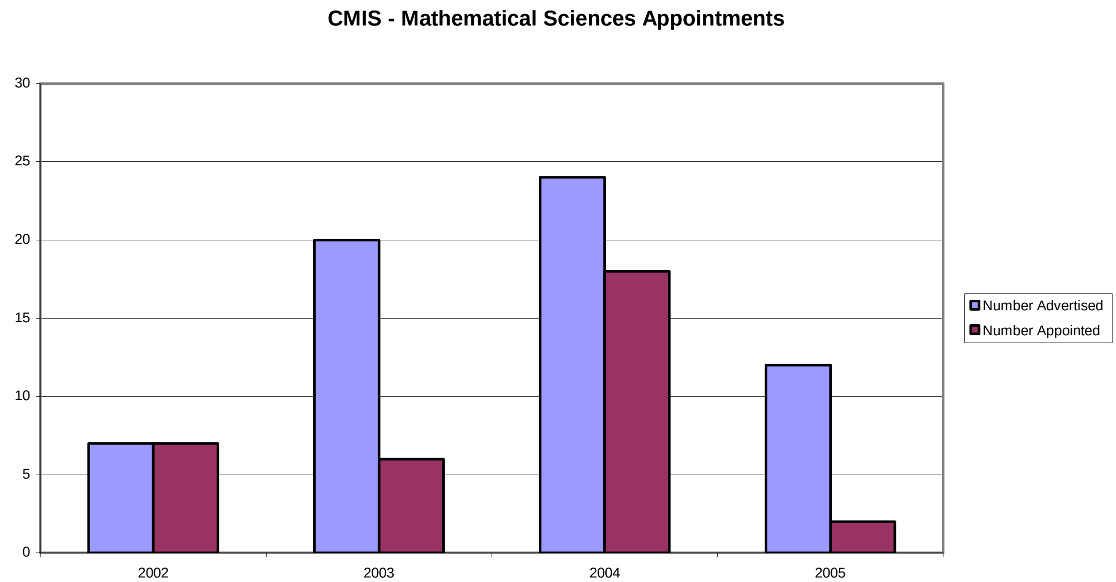

Figure 1: CMIS Advertised and Filled Positions in Mathematical Sciences

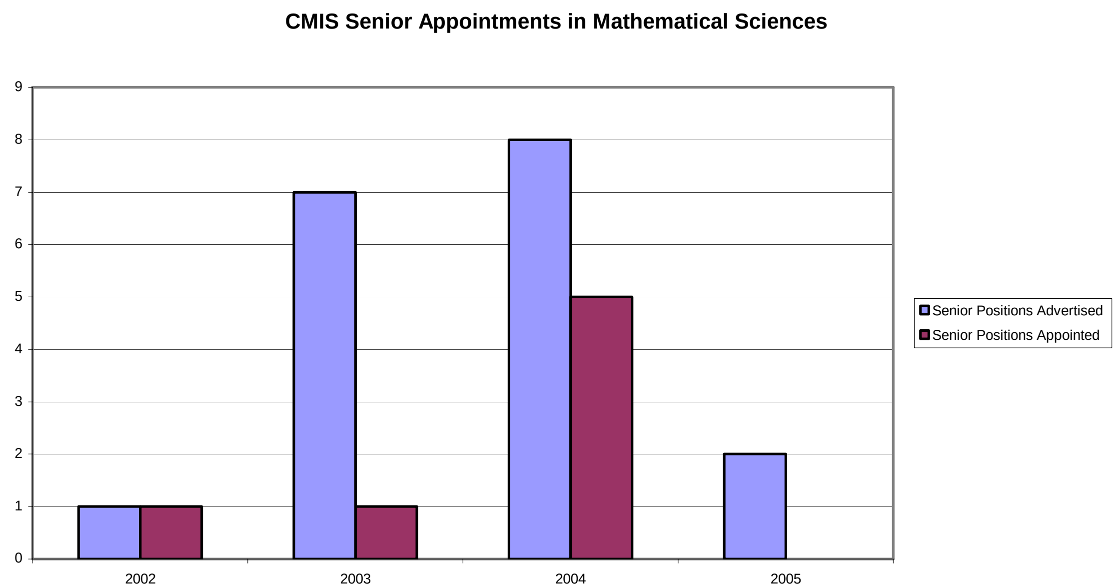

Figure 2: CMIS Advertised and Filled senior Positions in Mathematical Sciences

The observation of CSIRO is that over the last five or more years it has become increasingly difficult to appoint high-quality mathematicians to research position.

C2 To investigate human resource issues associated with mathematical, statistical and interdisciplinary research and the provision of advanced services in the mathematical sciences.

Speed[3] (1988) commented that "few honours graduates and even fewer PhD graduates in statistics have the appropriate education and training for work in [CMIS]". This remains true. In the last 4 years, 1/3 of our "statistics" and ½ our "applied mathematics" vacancies have been filled by graduates from engineering and computer science departments. Some employers have commented (for example in the recent review of statistics in universities) that mathematically trained graduates tend to try to apply prepackaged solutions rather than creating a solution from first principles. This should be investigated further and if true, remedial action taken.

C5 To examine current government support for research and for the provision of advanced services in the mathematical sciences.

Government support for the mathematical sciences is through grants for research through the ARC and support to CSIRO. Other government funding mechanisms seem to focus on industry outcomes and view mathematics as an underpinning science rather than a core contribute contributor. Consequently, it is difficult to develop critical mass in the mathematical sciences although some Cooperative Research Centres have had a significant mathematical component.

C6 To identify any other infrastructural factors which impinge on the quality and quantity of research and the provision of and demand for advanced services in the mathematical sciences.

The approach to mathematical sciences research in Australia has not been strategic but rather has involved small groups reacting to local opportunities. This reduces the opportunity for critical mass in research and also does not create sufficient basis for explaining the benefits of new mathematical directions to industry.

[3] Speed, T.P. (1988) The Role of Statisticians in CSIRO. Austral J Statist 30 15-34