GROUP OF EIGHT

Review of Education in Mathematics, Data Science and Quantitative Disciplines

Report to the Group of Eight Universities

Professor Gavin Brown *AO, FAA, Corr FRSE*

December 2009

The University of Western Australia | Monash University | The Australian National University | The University of Adelaide | The University of Melbourne | The University of New South Wales | The University of Queensland | The University of Sydney

The Group of Eight
Level 2, Group of Eight House
101 Northbourne Avenue
Turner ACT 2612
www.go8.edu.au

Introduction

The Reference Committee firmly shares the view that the state of the mathematical sciences and related quantitative disciplines in Australia has deteriorated to a dangerous level, and continues to deteriorate. Accordingly we decided to structure this Report around a small number of recommendations, some long term and others to address immediate problems.

In the last five years there have been many reviews analysing the mathematical sciences in Australia and elsewhere. See Appendix A for a list of eleven Australian sources, two major studies from the United States and reports from the United Kingdom and Ireland.

Australia has gone backwards over the last 20 years in terms of the quality and quantity of students completing Year 12 mathematics. This is despite considerable effort put into improving the situation, including Government funding. This deterioration hasn't been the case in every country.

This report does not attempt a comprehensive overview of the mathematical sciences, but rather, on the basis of these sources, stakeholder consultations and material provided by individual universities, attempts a concise justification for our view expressed in the opening sentence.

All is not gloom. The sense of potential crisis, which was evident from the stakeholders and the Reference Committee itself, has created a willingness for constructive cooperative activity. Discussions have been remarkably free of internal 'tribal' bickering within or between the broad quantitative disciplines and there is a commitment to mutual self-help. The Government recognises the importance of supporting the mathematical sciences, most recently (13 October 2009) providing $2m centred on an Australian Mathematical Sciences Institute (AMSI) project, Improving Mathematics Education in Schools, which began with the BlueScope Steel Illawarra Outreach Program encouraging and resourcing students of low socio-economic background. Obviously much more needs to be done and that requires the formulation of sound advice.

Broad picture

Primary

Attitudes are formed from when a student first enters school and, although entry scores for high school students undertaking Go8 courses in Primary education are reasonably high, there is normally no mathematics requirement. Indeed many of those intending teachers drop mathematics in order to maximise their tertiary entry rank. We were told by Professor Jacqui Ramagge, who has extensive experience of working with primary teachers and trainees in Newcastle, Wollongong and Vermont, that mathematics phobia is surprisingly common in these groups and, presumably, it transfers to the school students.

What is at stake here is not merely the acquisition of a specific skills set but the first steps to a disciplined appreciation of data and of quantification. Every citizen in a technology based society needs such capacity to make informed individual choices and to vote effectively. It is also a prerequisite for enjoying quantitative disciplines (or even disciplines where quantitative skills are not considered highly relevant but would deliver an advantage) sufficiently to consider a career therein.

One thing that is essential is making mathematics (and statistics) fun to school students. Some just love the conceptual beauty of calculus and algebra, and the challenges they provide. These children are relatively small in number. Whilst these children are important, there is a much broader target audience. Most children become much more interested when they can see the applications of mathematics and statistics and why these topics are important in real life. Teaching has to have this applied emphasis to make mathematics interesting and relevant.

Such a wide sense of early development of quantitative appreciation requires parental and community support and it is encouraging that there is investment in coordinating science awareness initiatives for the broader community. So far as we are aware, however, the mathematicians, scientists, engineers and economists have very little input to the training of primary teachers possibly because they have not sought it. This seems particularly true of the Go8 universities. The University of Newcastle has a compulsory mathematics content subject, taught by the Mathematics Department, in its primary teacher training and the University of Wollongong is introducing two such subjects. It is claimed that students in the practicum at Newcastle now demonstrate a better mastery of, and a greater willingness to engage with the mathematics.

It is difficult to find sharp evidence of how these issues affect attainment in primary schools but it seems dangerous to ignore the first links of the supply chain. (A related secondary study is reported in *Maths? Why Not?* and will be discussed later.)

International benchmarks

Australia participates in two well-regarded international benchmarking tests, PISA and TIMSS.

PISA (Program for International Student Assessment) is operated by the OECD to measure applied learning and problem-solving ability in 15 years olds. The latest results (2006) can be regarded as tolerably good for Australia. In mathematics we come 8th equal out of 30 and, in science, 6th out of 30. Remarkably the United States comes 25th and 24th respectively and the United Kingdom, 18th equal and 17th. On the other hand New Zealand is ahead of Australia on both. The two countries which stand out clearly above all others are Korea and Finland.

TIMSS (Trends in Mathematics and Science Study) is discussed on the ABS website, 4102.0 *Australian Social Trends 2009*, where the latest results (those for 2007) are described. This evaluates mathematics and science at Year 4 and at Year 8. Thirty-six countries took part at the Year 4 and 49 at the Year 8 level. The

Australian component is conducted by the Australian Council for Educational Research and surveyed 229 primary schools and 228 secondary schools, with a total of approximately 4000 students participating at each year level.

At first reading Australia performed commendably, being above or not significantly below the international average in all categories. Moreover Australian students achieved rankings of 14th for Years 4 and 8 mathematics and 13th for Years 4 and 8 science.

There are, however, some worrying features. We are outperformed by England and the United States and very heavily outperformed by most Asian countries, most prominent among which are Singapore, Chinese Taipei, Hong Kong and Korea.

We have results at four year intervals from 1995 to 2007. For Year 8 mathematics there is the following trend:

1995	Australia statistically higher than the United States and England, who are not statistically different from each other
1999	Australia statistically higher than the United States and England, who are not statistically different from each other
2003	Australia not statistically different from the United States or England
2007	Australia statistically below both the United States and England

Perhaps the most alarming finding concerns student attitudes. For Year 4 mathematics 66 per cent of Australian students declared a positive attitude, an outcome similar to the international average. For Year 8 mathematics only about 33 per cent of Australian students retained a positive attitude compared with an international average of 54 per cent. This may be suggestive of mathematics teachers who themselves were not adequately trained in mathematics.

Secondary

We have, of course, entered junior secondary with our discussion of international benchmarks. It is subject choice at senior secondary which frightens us all. In material provided to the document, *A National Strategy for Mathematical Sciences in Australia* (2009), Frank Barrington of the University of Melbourne provides alarming statistics.

Using percentages of the Year 12 cohort (not including International Baccalaureate students) he shows that the proportion of students whose highest level mathematics course is Elementary has increased by almost 30 per cent from 1995 to 2007. Over the same period the proportion whose highest level is Intermediate has declined by 22 per cent and the proportion taking Advanced has dropped by 27 per cent.

In this context it should be noted that Advanced Mathematics is *not* an esoteric excursion into the higher realms of pure mathematics. It is widely regarded as necessary background for a first year Engineering student in a Go8 university.

Nevertheless an Australian Council for Educational Research (ACER) study on patterns of subject participation based on gender, ethnicity, socio-economic background, school location and related factors (Fullarton, Walker, Ainley and Hillman, 2003) has raised issues about the attractiveness of Advanced Mathematics to students of different socio-economic and cultural backgrounds, even in schools where the option is available. There appears to be a widespread perception that the effort and time for this subject is comparatively so great that only the most talented can be confident of net benefit.

As noted above, enrolment patterns are not solely a matter of student choice because very many schools, even in metropolitan locations, do not have the resources to offer Advanced Mathematics. A major problem is, of course, the availability of teachers with a sufficiently strong mathematics background. We have found it difficult to access current data on teacher qualifications but the ACER report, *Participation in Science, Mathematics and Technology in Australian Education, 2008* states that, in 2007, 40 per cent of senior mathematics teachers in Australia did not have three years of university study in mathematics (compared with 30 per cent in 1999).

On the other hand, some states (in particular, New South Wales) require a major in mathematics as a prerequisite for training as a secondary school mathematics teacher. This considerable lack of commonality in expertise and training of mathematics teachers calls into question the appropriateness of a national curriculum without national standards for teacher training.

Australia therefore faces the twin related problems that students are migrating to easier options from senior mathematics courses and that there is a severe shortage of mathematics teachers (with no doubt a biased geographic spread). This means that in the short to medium term, universities will be required to provided enabling (i.e. remedial) courses.

The situation looks worse when we consider demand for graduates. Both CSIRO and the ABS expressed grave concern over being able to recruit graduates simply to cover retirement replacement let alone growth. Official government estimates have predicted an annual growth rate of 3.5 per cent in demand for mathematics and statistics graduates between 2006 and 2013. (The annual demand between 1998 and 2005 was a growth of 5.4 per cent.)

Engineering has a dismal outlook. Material gathered by Engineers Australia in 2008 quotes a DEST audit (2006) which predicted a shortfall of 20,000 scientists and engineers by 2011. It predicts a need for 70,000 more workers in the minerals industry by 2015 and a professional skills gap in the urban water industry of more than 80 per cent by 2017. Meanwhile the number of BE graduates in Australia fell from 5268 in 2001 to 5044 in 2006.

In South Australia where major new resource developments are underway the number of BE graduates dropped from 343 in 2001 to 223 in 2006.

It could be argued that those comments stray from the secondary sector to the tertiary, but the massive drift from senior mathematics in high schools must be addressed if the universities are to be able to produce anything approaching the required number of graduates in quantitative disciplines.

Moreover, mathematical skills are universally needed for the study of science. Mathematics is an important enabling science. The community perception is that this relates mostly to the physical sciences. However, it is an enabling science for a much broader range of disciplines, including environmental sciences, meteorology, psychology, health sciences, geography, economics, finance, business, and many others. For example, an article in the journal *Science* in 2007 (vol. 317, pp. 457–458) observed that taking extra mathematics at high school gave students an advantage across all science subjects, "including college biology, a discipline not traditionally associated with strong mathematics preparation". The study went on to conclude that "the two pillars supporting college science appear to be study in the same science subject and more advanced study of mathematics in high school". There are few disciplines which do not benefit from a good foundation in the concepts and skills developed in mathematics and data sciences. University remedial courses are a second best option for students to gain such skills.

That drift was examined in *Maths? Why Not?* mainly by means of online surveys of mathematics teachers and "career professionals", the latter being the authors' chosen descriptor of those in schools with responsibilities for career and course advice. The most significant influences on student choice can be listed as follows:

- Students' experience of junior secondary mathematics
- Appeal of less demanding subjects
- Advice by mathematics teachers
- Student perceptions of their own mathematics ability
- Parental expectations and aspirations
- Understanding career pathways

The authors of *Maths? Why Not?* note that students often complain that mathematics is not "useful", but are careful to say that more understanding of what students mean by this is necessary.

Do they, for example, mean that, unless they are outstanding, it is not useful for maximising tertiary entrance scores?

Do they mean that the extra work is not useful compared with sport or music or other activities?

Do they mean that it is not obvious that it will enhance their career options or gain approval from parents or peers?

Do they mean that they have performed meaningless exercises without gaining a feeling for the intrinsic enabling power of mathematics? We believe that there is little value in telling students of the practical power of mathematical modelling without relating this to the mathematics that they already understand.

The quality of teachers is clearly of crucial importance. It appears that, despite a number of initiatives, there are not enough appropriately qualified maths teachers. This needs persistence. It is not something that can be solved overnight but it is key to addressing the long term problems of mathematics in schools. The situation in Finland provides insights. One of the major reasons given for the success of Finland in mathematics and other disciplines is the quality of the teachers. They are well qualified, well paid and teachers are regarded by the general population as a very important occupation group. Schools are a fundamental part of local communities. We have to keep working in this direction.

In the context of the severe problems already identified it may seem idealistic to raise the issue of functional quantitative skills for all students. In a science and technology based society, however, even those students who have opted for different specialisations should gain some appreciation for data and its presentation in order to be engaged citizens. There is a need for defensive skills when data is presented with distorted scales or in other misleading ways and we have been able to identify very little which will help the general student. The ABS provides a useful module on how a census works and how data can be presented responsibly.

Tertiary

The universities cannot ignore the downward change in mathematics preparedness affecting entering students. In the short term there appear to be only two conceivable responses: the provision of enabling (i.e. remedial) programs and the lowering of standards. As regards the latter, professional accrediting bodies for engineering and business maintain external pressure for effective quantitative skills development within each degree program. The employer base for science and mathematics is more diffuse so that external influences are less clear-cut except where universities organise employer consultative groups. There are several programs offering degrees in Advanced Mathematics of Advanced Science for high achievers and this device offers the possibility of maintaining a standard program at a realistic level. This requires delicate judgement and has equity problems. There must exist effective pathways for talented students who, for economic or geographical reasons, enter university under-prepared.

The Reference Committee believes that enabling programs are essential and require systematic organisation. This is not merely a matter of careful syllabus design but requires new funding initiatives. At present there is a fixed pool of government support and universities may apply for enabling load (funded at a level below normal load) with the ongoing possibility that the pool may be severely diminished or exhausted after the university's commitment has been made.

These issues are discussed in a context where, in 2003, the percentage of Australian students graduating with a major in mathematics or statistics was 0.4 per cent compared with an OECD average of 1 per cent. In the period 2001 to 2007 the number of mathematics major enrolments in Australian universities declined by approximately 15 per cent. From 2002 to 2006 the number of applicants to mathematics degrees in the

United Kingdom (not, of course, a directly comparable statistic) increased by two-thirds!

The decline in Australian mathematics majors has been matched by a loss of staff numbers in mathematics departments. Several are now unable to offer mathematics majors and an external review of another (not Go8 but research committed and successful in many disciplines) states that the mathematics staff is now so small and so over-worked that it cannot offer an externally credible mathematics major without substantial new investment. (As this was provided confidentially to the Chair, the Review does not name the university.)

Some of these difficulties can be traced to the overall funding model, but it should be noted that the Government tried to be helpful by increasing base funding to mathematics and relieving the HECS burden. This strategy needs to be re-evaluated in the light of experience (including some of the technical rules that apply to graduates moving to mathematics teaching). Where mathematics departments are weathering the storm is where there is a healthy culture of service teaching and where a university administration and several disciplines have cooperated to find alternative internal models. This may have depended in large measure on the willingness of mathematicians to be realistic and cooperative. In one discussion of a troubled case it was stated, "Too often we heard that the School took an authoritarian view in determining the subjects covered and the manner and rigor with which they were treated". As noted earlier, there is certainly now a palpable spirit of self-help and the time is ripe for further leadership in this area.

Shrinking mathematics departments put at risk critical mass for research and the Go8 is not immune. Several young Australian mathematicians are now making their mark overseas, especially in the US, but we can find it difficult to attract them back, even for extended research visits, when our local clusters are weakened. Despite some jokes about their social graces, mathematicians need to be interactive to be productive. It would be tragic to generate a culture within which individuals boarded planes from time to time to visit their research colleagues while the less fortunate and prominent maintained a teaching effort in Australia. The Reference Committee believes that more research networking within Australia needs to be encouraged and that the Go8 has a leadership obligation.

The Reference Committee spent considerable time on probability and statistics. There is an increasing need for students in many quantitative disciplines to be able to use statistical tools. If this amounts to applying a "black box" without understanding then it can be negatively productive. On the other hand a traditional introduction through a long study of theoretical probability can frustrate these students and increase anxiety. An apparently successful package developed by the University of Auckland was brought to our attention as well as related initiatives at the University of Western Australia. It was noted further that students with little or no mathematical background might suddenly need to apply statistics at postgraduate level and that there is a further and different challenge here.

At the same time researchers in many disciplines now require the advice of statistical consultants on specific projects, although this is rarely mandated by Australian research bodies (unlike the National Institutes of Health (NIH) in the United States).

All these demands are additional to the need to prepare graduates with a major in statistics and to maintain Australia as a player in research in probability and statistics. With respect to the latter Australia did have considerable strength some years ago, but, with the exception of some outstanding individuals, is now regarded as having slipped back badly. In fact the preeminent research facility in statistics in the western Pacific and Asia is, in the opinion of leading US statisticians, the Institute of Statistical Science of the Academia Sinica, Taiwan. It has 37 full time researchers, has made giant strides in the last five years and competes favourably with any statistics grouping in the world. The populations of Australia and Taiwan are comparable in size, being 22 and 23 million respectively.

Examples like this have a practical aspect. International companies locate their R&D where there is a conducive climate of innovation and a steady supply of high-quality PhD graduates. It is worth recalling at this point that *BIO 2010*, a 2003 US NRC report, gave eight recommendations, of which four urged increased involvement with the mathematical, physical and information sciences.

The attrition of mathematics departments is still less than that of statistics departments. We accept that the multiple demands for statistical expertise leads to a distributed model but there is an urgent need to train the next generation of statisticians and to have critical mass for research activity. Accordingly we believe that the balance between centralisation and distribution needs to be investigated further.

Recommendations

1. **The Go8 should encourage dialogue between Faculties of Education and Mathematics Departments with a view to introducing a component in the primary training program giving mathematical confidence and resources to future teachers. This would be taught by the Mathematics Department or School.**

   Comment: Much can be learned from the Universities of Newcastle and Wollongong including the need to choose appropriate lecturers. This needs to be recognised by the university as important work.

2. **The Go8 should support the raising of mathematics and science awareness in the community, covering all years of high school. This includes extra-curricular resource provision**

   Comment: There are initiatives in this area by CSIRO and RiAus, and the ABS. The universities can contribute by encouraging staff to participate in existing and new programs. It is essential that teachers, career advisers and parents become more aware of the importance of mathematics skills across a wide range of other disciplines.

3. **Each Go8 vice-chancellor should review service teaching arrangements especially the internal funding model which drives them. Insight should be shared.**

   Comment: In universities where Mathematics, Science and Engineering sit within the same "super faculty" arrangements appear to have been easier. There are other quantitative disciplines which are stakeholders. It is possible that some modification of the government funding formula should be sought. At present there is some incentive for attributing each course to the highest funded discipline involved.

4. **The Go8, sharing expertise already gained, should develop a systematic structure of enabling programs to counter the drop in students entering with low mathematics experience.**

   Comment: This has a strong social equity dimension and should include careful lobbying for government support. This recommendation is additional to addressing the problems of low mathematics experience and skills acquisition in schools, before students reach university.

5. **The Go8 should encourage research networking within Australia, not confined to its own universities. One specific proposal is that AMSI should be invited to organise research programs of six months or a year on specific topics with international visitors. The Go8 by contributing $10K each annually could, in sequence, second a program leader on sabbatical. Other costs could be sourced from research agencies and philanthropic organisations.**

   Comment: The "equivalent" of AMSI in the United States or United Kingdom is funded to provide such research infrastructure. This proposal demonstrates pre-emptive self-help.

6. **The Go8 should pay particular attention to Statistics, the ongoing consulting needs within the universities, the training of the next generation and the recovery of a strong research culture.**

   Comment: It seems timely to review the structural deployment of statisticians within each university. There is likely to be strong high level cooperation with Go8 from CSIRO, ABS and employer groups for the purposes of graduate training.

Appendix A

Many reviews have been conducted over the last five years:

2005	Review of Statistics
2006	National Strategic Review of Mathematical Sciences in Australia
2006	Australian Council of Deans Science Study
2007	Productivity Review of Public Support for Science and Innovation
2008	ACER Research Monograph, Participation in Science, Mathematics and Technology in Australian Education
2008	Maths? Why Not? Report to DWEER
2008	Mathematics Education for 21st Century Engineering Students, AMSI
2006-08	A series of reviews, surveys and reports at www.workplace.gov.au—on employment, stakeholder needs, student pathways in Science, Engineering and Technology, SET awareness raising
2009	A National Strategy for Mathematical Sciences in Australia, National Committee for Mathematics
2009	Engaging Science and Mathematics Education—A Five Year Strategy for South Australia, Premier's Science and Research Council
2009	School Mathematics for the 21st Century—AAMT Discussion Paper

From the US:

2009	The Economic Impact of the Achievement Gap in America's Schools, McKinsey
2009	The Opportunity Equation—Transforming Mathematics and Science Education for Citizenship and the Global Economy, Carnegie Corporation of New York and IAS, Princeton

From the UK:

2004	An International Review of UK Research in Mathematics

From the Republic of Ireland:

2005	Review of Mathematics in Post-Primary Education
2005	International Trends In Post-Primary Mathematics Education

Appendix B

Go8 Review of Education in Mathematics, Data Science and Quantitative Disciplines

Terms of Reference

1. Investigate and report on the present state of mathematics and data sciences teaching and research in Go8 universities, including the quantitative competency of students.
2. Investigate and report on other disciplines with substantial mathematical, data science and other quantitative elements.
3. Investigate and make recommendations on primary and secondary school teaching of mathematics and related disciplines as it impacts upon the number and competency of students seeking to undertake university courses in mathematics, data sciences or other disciplines requiring mathematical skills, and measures to address the present deficits.
4. Report on the future demand for qualified mathematicians and data sciences graduates in Australia, and the capacity of mathematics departments in Go8 universities to substantially meet that demand. This aspect is to cover both pure and applied mathematics, statistics and the range of disciplines which require substantial university-level mathematics.
5. Recommend options for initiatives to equip and encourage more students to develop high order mathematical and data skills.
6. Identify options for Commonwealth and State government action to support strengthening of education in mathematics and quantitative disciplines in Australia.
7. Identify existing barriers and ways of retaining mathematics educators at secondary and university level, and attracting both qualified Australians engaged in other activities and qualified immigrants, to strengthen Australian secondary and tertiary mathematics education.

The Review will seek input from the Commonwealth and State levels of government, and industry, as well as the various sectors of the education system.

The review will report towards the end of 2009, in time for input to the May 2010 Commonwealth Budget.

Reference Committee

The Review was undertaken by Professor Gavin Brown AO, FAA Corr FRSE.

The members of the Reference Committee to support this Review were:

- Professor Philip Broadbrige, Director, Australian Mathematical Sciences Institute
- Associate Professor Jim Denier, Head, School of Mathematical Sciences, The University of Adelaide
- Professor Peter Dowd FREng, FRSA, FTSE, Executive Dean Faculty of Engineering, Computer and Mathematical Sciences, The University of Adelaide
- Professor William Dunsmuir, Department of Statistics, The University of New South Wales (nominee and President of the Statistical Society of Australia)
- Professor Peter Hall FAA, FRS, CorrFRSE FAustMS, Department of Mathematics and Statistics, The University of Melbourne
- Professor Nalini Joshi FAA, Professor of Applied Mathematics, The University of Sydney (nominee and incoming President of the Australian Mathematical Society)
- Professor Max King FASSA, Sir John Monash Distinguished Professor and Pro Vice-Chancellor (Research & Research Training), Monash University
- Professor Cheryl Praeger AM, FAA, FAustMS, FTICA, Winthrop Professor, School of Mathematics and Statistics, The University of Western Australia
- Professor J Hyam Rubinstein FAA, FAustMS, Department of Mathematics and Statistics, The University of Melbourne
- Mr Dennis Trewin AO, FASSA, Australian Statistician 2000–2007, Australian Electoral Commissioner 2002–2007

Meetings of the Reference Committee

The Reference Committee met by teleconference to discuss various issues relevant to the Review on four occasions—18 March, 6 May, 2 July and 14 August 2009. Professors Brown and Peter Hall met on 8 May.

Consultations

Professor Brown and/or Mr Alan Mackay (Go8 Director, Information Strategy) met with the following:

Department of Innovation, Industry, Science and Research:

- Ms Stella Morahan, General Manager, Cooperative Research Centres Branch
- Dr Gillian Treloar, Assistant Manager, Research Performance and Analysis

Department of Education, Employment and Workplace Relations:

- Mr Jason Coutts, Branch Manager, Equity Performance and Indigenous Branch, Higher Education Group
- Ms Suzanne Northcott, Branch Manager, National Curriculum Branch, National Curriculum Assessment and Reporting Group
- Mr Scott Lambert, Director, Science and Maths Education Team, National Curriculum Branch
- Mr Mike Teece, Analysis Unit, Equity Performance and Indigenous Branch

Australian Bureau of Statistics:

- Mr Brian Pink, Australian Statistician
- Mr Geoff Lee, First Assistant Statistician, Methodology and Data Management Division

National Health and Medical Research Council:

- Professor Warwick Anderson, Chief Executive Officer
- Ms Hilary Russell, Deputy Head and General Manager
- Mr Marcus Nicol, Director, Evaluation and Reporting, Program Management Branch

CSIRO

- Dr Louise Ryan, Chief, CSIRO Mathematical and Information Sciences

University of Wollongong:

- Associate Professor Jacqui Ramagge, School of Mathematics and Applied Statistics

GROUP OF EIGHT

The Group of Eight
Level 2, Group of Eight House
101 Northbourne Avenue
Turner ACT 2612
www.go8.edu.au