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MATHEMATICAL SCIENCES IN AUSTRALIA: LOOKING FOR A FUTURE

By

Jan Thomas

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LOOKING FOR A FUTURE

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Acronyms

ARC	Australian Research Council
AMSC	Australian Mathematical Sciences Council
AustMS	Australian Mathematical Society Inc.
CMIS	CSIRO Mathematical and Information Sciences
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DETYA	Department of Education, Training and Youth Affairs
HECS	Higher Education Contribution Scheme
ISIG	Innovation Summit Implementation Group
IT	Information Technology
MERGA	Mathematics Education Research Group of Australasia
SET	Science, Engineering and Technology
SMEs	Small to medium enterprises
STAP	Science and Technology Awareness Program
TAFE	Technical and Further Education
VIEPS	Victorian Institute of Earth and Planetary Sciences

Definition

Mathematical sciences is used as an inclusive term for all areas related to teaching, learning and research in mathematical disciplines.

Acknowledgments

The paper draws on many sources. Some cannot be identified because of the sensitive positions they hold in the universities or government agencies. I therefore thank them all, collectively and unreservedly, and not individually. However, without the support of the Australian Mathematical Society and the Heads of Mathematical Sciences Departments in the universities, this paper could not have been written and their pivotal role must be acknowledged.

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Australian Mathematical Sciences Council

http://matilda.vu.edu.au/~amsc/

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Executive Summary

The brain drain from the universities, exemplified by the data from the mathematical sciences documented as part of this study, represents the kind of loss of intellectual capital no nation that aspires to be a leader in science and technology can afford. Significantly much of this loss has been in areas such as statistics which underpin other areas where Australia aspires to be a world leader such as financial services and biotechnology.

Further, in terms of young peoples' life chances, English and mathematics remain the access subjects. However, the economic divide in access to mathematics is now firmly entrenched in our schools system, and will become progressively worse unless something is done urgently about teacher supply. Remote rural schools and 'hard to staff' inner urban schools will be left deprived of the essential resource they need—well qualified mathematics teachers—to offer the more advanced courses and a quality mathematics education for all students.

In the long term, solving the supply of mathematics teachers is intimately connected to the number of students studying advanced level mathematics in schools and strong mathematical sciences in the universities. However, both of these have shrunk—when they should have been expanding—so Australia now suffers a crisis throughout the mathematical sciences.

For these reasons the sense of optimism engendered in the science community by the Chief Scientist's Discussion Paper *The Chance to Change*[1], and the report of the Innovation Summit Implementation Group (ISIG) *Innovation—Unlocking the Future*[2], is more muted in the mathematical sciences. In the words of one mathematician, "…neither increased ARC funding nor post docs will help much the diminished role of mathematics and statistics departments in universities"[3]. This echoes the fear in the mathematical sciences that even if the recommendations of these two reports are implemented—which they should be—the implementation will fall far short of what is needed to restore the health of this fundamental discipline. In 2000 the mathematical sciences in Australia face a perilous future.

Summary of Principal Findings and Priorities for Action

This report has three main findings and priorities for investment in the mathematical sciences. These are the areas that need immediate action but to re-build the mathematical sciences in Australia a long term, coordinated strategy is needed that addresses the multi-faceted weaknesses that are now inherent across the discipline. The priority areas are:

- improving the number of students in advanced mathematical courses in schools and universities,
- ensuring that all students are taught mathematics by teachers with appropriate content knowledge and teaching skills and,
- addressing the problems in university mathematics by reversing the excessive staff and student losses.

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[1] Batterham, R. (2000). www.isr.gov.au/science/review

[2] Miles, D. (2000). www.isr.gov.au/industry/summit/

[3] Personal communication

Participation of students in advanced level mathematics courses

The finding: The number of year 12 students studying advanced mathematical courses continues to decline, a consistent trend since 1990.
Solution: A national campaign to promote awareness of the benefits of continuing the study of mathematics at the highest levels for as long as possible and which highlights the benefits to long term career prospects.

Teacher supply

The finding: Few mathematics graduates are choosing teaching as a career at a time when many experienced and well-qualified mathematics teachers are retiring. Many primary teachers need further studies in mathematics and it is estimated that about 40% of junior secondary students are taught mathematics by a teacher who has little or no background in mathematics and no studies in the teaching of mathematics.
Solution: Greatly improved incentives must be found to attract mathematics graduates to teaching and also students into mathematics and thence to teaching. Secondary teachers teaching out of field should be given study leave to develop appropriate mathematical knowledge and skills. Professional development for primary teachers should be enhanced to include more opportunities for improvement in content knowledge. Teacher education for primary teachers should be re-examined to ensure that sufficient and appropriate mathematical content is taught and learnt

Mathematics in the universities

The finding: A decline of some 25% in staff since 1995, a brain drain of both experienced and new researchers, marginalised or restructured departments, fewer applications for research grants, few if any new appointments, difficulties in making appointments in key areas such as financial mathematics and statistics, and some universities no longer offering a three year degree majoring in mathematics or statistics.
Solution: Implementation of the Chief Scientist's and ISIG reports with special attention to be paid to the mathematical sciences as the world-wide demand for excellent mathematical scientists far outstrips supply. Greater support for existing research and teaching in the mathematical sciences in the universities, disincentives for collaborative teaching to be removed and the visibility of the mathematical sciences to be enhanced. A national centre with adjunct state centres, possibly on the lines of the Canadian Fields Institute[4], should be established.

[4] The author visited the Fields Institute this year and holds a copy of the 1999 report. See also www.fields.utoronto.ca and Chapter 8 in National Committee for Mathematics (1996). *Mathematical sciences: Adding to Australia.* Canberra: Australian Government Publishing Service, pp. 99-107.

Introduction

> "We could indeed think of modern industrialised society as being based on a Mathematico-technological culture"[5]

> "…modern mathematical science, is in its own right a supreme creation of the human intellect; it is also critical for economic competitiveness, and the basis for investigations in many fields"[6]

> "The mathematical sciences now reach far beyond the physical sciences and engineering; they reach into medicine, commerce, industry, the life sciences, the social sciences, and every other application that needs quantitative analysis"[7]

> "The mathematical sciences are vital for economic competitiveness. They are a critical, generic, enabling technology"[8]

> "A society can base its production for survival on primitive farming or on the use of high technology. What is considered to be important knowledge in a society in not independent of the way people live their lives…Language education is probably the most important in subject in this respect. It is my conviction, however, that mathematics education can be as important"[9]

Mathematical sciences are more than a technological tool and their importance extends beyond economic considerations. All cultures have developed mathematics in response to the demands of their environment. Within-cultural developments, and cross-cultural interactions, have produced the powerful international discipline[10]. As societies have become more technologically advanced, the importance of mathematical knowledge has increased and, if individuals are denied access to this knowledge, they are denied access to part of their culture as well as many other opportunities within that society.

Recent government initiatives both here and overseas have stressed the need for literacy and mathematics. There are societal expectations that all young people will achieve appropriate literacy skills and this is seen as both achievable and necessary. Within Australia, failure to develop appropriate mathematical skills for a technological society for all young people has been give much lesser priority, both by current and previous governments. The current emphasis on 'numeracy'[11], particularly in primary schools, is welcome but the numeracy benchmarks are very low level indeed. There has been little emphasis on improving the level of participation and achievement across all levels of schooling.

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[5] Bishop, A. (1988). *Mathematical Enculturation.* Dordrecht: Kluwer Academic Publishing, p. 59.

[6] National Committee for Mathematics (1996). *Mathematical sciences: Adding to Australia.* Canberra: Australian Government Publishing Service, p. ix.

[7] ibid

[8] ibid, p. 44, quoting Glimm (1991)

[9] Mellin-Olsen, S. (1987). *The Politics of Mathematics Education.* Dordrecht: Kluwer Academic Publishing, p. 15.

[10] Bishop. A. (1988). Op cit.

[11] The use of the term 'numeracy' is limited to Australia and the UK. Its definition is rather confused. See DETYA (2000). *Numeracy, A priority for all: Challenges for Australian Schools.*

Mathematical scientists believe in a high-tech, high wage society but cannot conceive of such a society in Australia unless the mathematical sciences are strong. So all young people need an excellent mathematics education with clear reasons for why it important. This calls for excellent and knowledgable teachers. In turn this calls for excellence in the mathematical sciences in the tertiary sector, not just in the universities but with leadership and role models from business and industry and in government scientific organisations such as CSIRO. These parts are inter-related and interdependent.

For example, Bill Gates understands the importance of mathematics in innovation. That is why *Microsoft* supports a team of some of the world's best mathematicians to do research. World leaders, Clinton in particular, frequently talk of the importance of mathematics. A major new report to the Secretary of Education in the USA is quite unequivocal that it is about ***mathematics*** and ***science*** education and suggests that if its recommendations are ignored "our nation will pay the high price that always accompanies apathy"[12].

Apathy seems a very apt word to describe the deafening silence about mathematics in Australia. This is a very Australian phenomenon. Australia alone seems to bury mathematics within science or science, engineering and technology (SET) and 'numeracy' and consequently render it invisible..

Yet the review of advanced mathematical sciences in Australia completed in 1995[13], highlighted the pervasiveness of mathematics, not just in science and technology, but in business, industry, design, information systems and many other aspects of work and society. It clearly demonstrated that if Australia was to have a high technology future, then mathematics needed to be fostered and many more young people needed high level mathematics. They needed mathematics not just so they could become research mathematicians but also to become financial planners, environmental scientists, medical researchers or a host of other careers. This pervasiveness of mathematics surprised even the mathematicians.

The review noted that over time "the mathematical sciences have developed a rich and intrinsic culture that feeds back into the natural sciences and technology, often in unexpected ways"[14]. Mathematical sciences underpin the financial models that our superannuation and insurance policies depend upon, the SET that builds bridges and tunnels, the IT that grows increasingly more complex, the biotechnology that leads to new medical treatments, the environmental studies that monitor climate change and pollution and many other aspects of our lives.

In 2000 there is much rhetoric concerning a prosperous Australia built on science and technology. The Chief Scientist's and ISIG reports highlight the need for investment in SET and both give some support and encouragement to the mathematical sciences[15]. However neither of these reports at the federal level, nor recent actions or policies of state governments, appear to recognise the depth of the problems in the mathematical sciences in Australia. Our political leaders have failed

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[12] Glenn, J. (Chair) (2000). *Before It's Too Late: A report to the Nation from The National Commission on Mathematics and Science Teaching for the 21st Century*, p. 2.
(see www.ed.gov/americacounts/glenn)

[13] National Committee for Mathematics (1996). Op cit

[14] ibid, p. ix

[15] www.isr.gov.au/science/review & www.isr.gov.au/industry/summit/

to talk-up mathematics and have helped to render it invisible. University administrators must also shoulder some of the blame. Even in times of financial restraint there is no excuse for the way the mathematical sciences have been allowed to be marginalised in many of the universities. The following case study is not atypical[16].

> The group of statisticians at my University has long been considered by outsiders and recent foreign published rankings as one of the top 2 or 3 most productive groups in the country. We have 5 current members only, and hold a large ARC grant, an NHMRC grant, a National Institute of Health grant from the USA and an IREX grant for 2001 to bring an outstanding European statistician to work with us. Nevertheless, we are in danger of marginalisation. In the last five years:
>
> • We lost two of our best teachers and brightest young researchers, both senior lecturers, to nearby Asian universities where they more than doubled their salaries and halved their teaching loads.
>
> • We lost an excellent researcher and consultant to the Medical School of a British University. This person worked one day a week at a local hospital (for which they paid half her senior lecturer salary) … Even though she held this dual position for 6 years…there were no funds to continue her position. She reluctantly left and is now being considered for a Readership.
>
> • We lost the Professor of our Department to a research position elsewhere in Australia; this position remains unfilled…We have received no salary savings to hire temporary teaching assistance in the meantime.
>
> • We lost our only tutor to another Faculty because they could offer her a better position.
>
> In return for these losses, we have now been allowed to advertise for one continuing position at the lowest level, Associate Lecturer. A prime candidate who is both a good researcher and teacher, and who was interested in such a position, has since found that she can obtain a much larger salary in a city bank, and is thus lost to the profession, at least for now.

It has become all too common for universities to be announcing major new initiatives in biological and information technologies at the same time as they were losing their best statisticians and mathematicians. There is at least one documented case of a position being declined at one of these sites because there was no longer adequate statistical support within the university to support the research that was to be undertaken[17].

In part this seems to relate to some misunderstanding of the role of mathematics in SET and emerging beliefs that being computer 'literate' somehow does away with the need for mathematics. It may also relate to a lack of appreciation of the role of highly skilled mathematical scientists in areas other than SET, especially the financial sector and medically related fields. Thus recently announced initiatives to attract financial services to Victoria[18] may well fail unless the underlying mathematical skills shortages in that state can be addressed.

The mathematical sciences in Australia are in crisis. There is no other word that

[16] Personal communication

[17] Personal communication.

[18] See for example, *The Age* (editorial) September 26, 2000

adequately describes the situation across all sectors—an acute shortage of appropriately qualified teachers across schools, falling enrolments in advanced level mathematics courses both in schools and universities, the collapse of university mathematics and statistics, inadequate support for mathematics education research and a brain drain of many of Australia's best mathematical scientists especially, but not exclusively, to the USA.

The mathematical sciences need long-term planning and bipartisan support, not ad hoc decisions for short-term political gain. They need the support of State and Federal governments, business and industry. The solutions to the multiple challenges lie with the mathematical sciences community in Australia, not with outside experts or further reviews, but support for that community is needed now while there is still some residual energy and hope remaining.

In particular the mathematical sciences need the support of the community. The solutions will not come without considerable financial investment and that will only come if the people of Australia make known that they consider this investment is justified. This paper puts the case for that support. It identifies three priority areas:

- improving the number of students in advanced mathematical courses,
- ensuring that all students are taught mathematics by teachers with appropriate content and teaching skills and,
- addressing the problems in university mathematics by reversing the excessive staff and student losses.

It would be a mistake to view each of the above as isolated or the only weaknesses in the mathematical sciences and, while these are identified as the priority areas for action, other areas include:

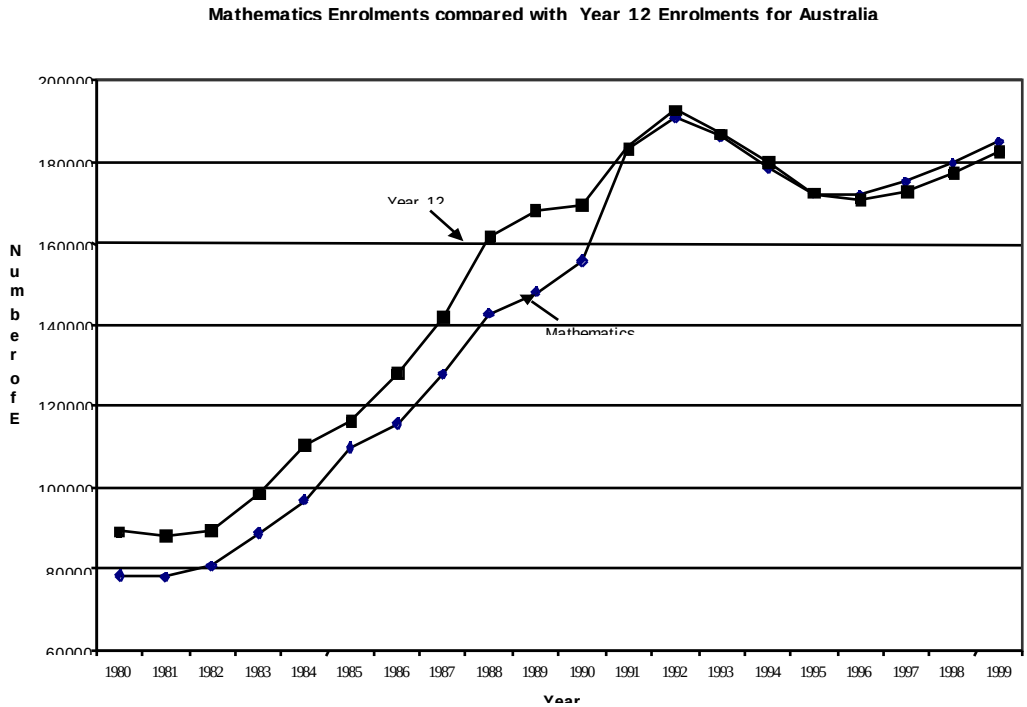
- mathematical services,
- mathematics education teaching and research, and
- the TAFE sector

In the following sections each of these, as well as the priority areas, are discussed in more detail. The priority areas need immediate action but to re-build the mathematical sciences in Australia a long term, coordinated strategy is needed that addresses the multi-faceted weaknesses that are now inherent across the discipline. Some of the problems not addressed, or only touched on here, include the range of problems relating to low teacher expectations of far too many students in primary and early secondary years, and the variety of mathematical sciences needs of other disciplines and faculties within the universities. This is a particular problem in the light of increasingly disparate student backgrounds and increasingly diverse industry and business needs in a technological world.

Participation of students in advanced level mathematics courses

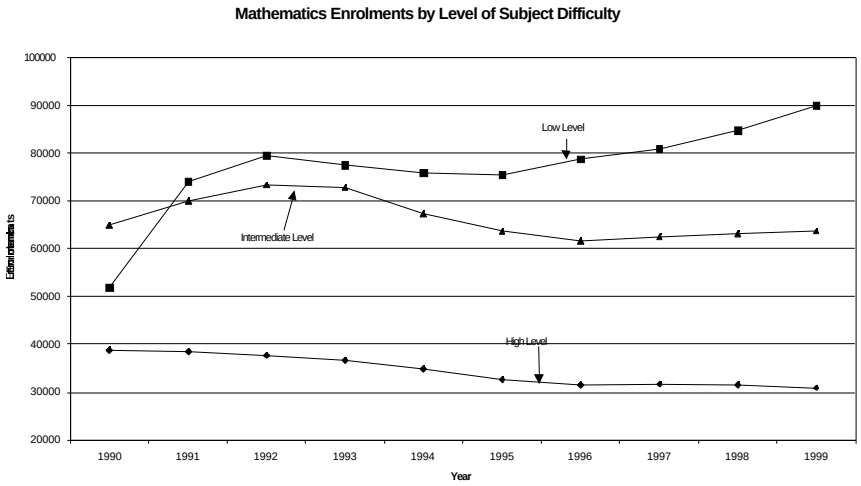
The Paradox of Year 12 Enrolments in Mathematics

The following diagram has been extracted from two unpublished reports that cover enrolment trends for science, mathematics and computing for the period 1980 – 1999[19]. The total mathematics enrolments are slightly higher than the total Year 12 school enrolment reflecting an apparent healthy state with most students doing some mathematics and some doing two subjects.



However, when mathematics enrolments are broken down by subject difficulty as in the next diagram, the relatively small number of students taking advanced level courses emerges. Not only has the number dropped since the 1992 peak but it is continuing to fall. Dekkers, Malone and De Laeter explain that many of the trends are connected with the increasing retention of females to Year 12 which now sees a greater percentage than ever doing mathematics. Thus overall, the levels of mathematics enrolments would be lower than they are now had it not been for the increases in female enrolments in these areas. The current enrolment patterns indicate that the many programs to improve girls' participation in mathematics have been successful. They also indicate all young people should now be targeted in a new campaign.

[19] Personal Communication from Dekkers, J., Malone, J., & De Laeter, J. (2000). Data from two unpublished reports which are being incorporated in a forthcoming book



Given this decline in the number of students taking advanced level mathematics courses in schools, it is not surprising that there was a decline of 23% Australia wide in enrolments in mathematics as a percentage of total university enrolments in the period 1991-97[20]. Comparing these figures with enrolments in tertiary courses where it would be expected that students have a solid background in mathematics such as science, engineering, IT and economics, it becomes apparent that many students are taking these courses without sufficient of this fundamental building block[21]. This is supported by a recent summary of fields of study which showed many more campuses teaching sciences, computing and IT than mathematics[22]. It would appear that many students are studying degrees without building a solid foundation in an enabling subject that may give them flexible career options in the future

The situation is being exacerbated by universities dropping, or weakening, pre-requisites so that the importance of a strong mathematics background in many discipline areas is often not recognised by students, many teachers or their families. This tends to lead to frustration with the courses and unnecessary failure. The creation of boutique courses requiring little or no mathematics which lead to short term careers but lack of flexibility to labour market changes also short changes students..

Mathematics must be promoted to students, teachers and parents. Much has been done already by the mathematical sciences community but it has been fragmented and reached only a small percentage of the target audience. For example, 2000 is World Mathematical Year, launched by the International Mathematical Union and supported by UNESCO. At a conference celebrating this[23] Adam Spencer from the ABC described mathematics as "staggeringly beautiful". At the same event, Keith Devlin from America who has done much to bring mathematical ideas to the public through his television series *Life by the Numbers* and in other ways, spoke of mathematics as the "light at the end of the tunnel" helping you to see what's at the end. Two of the eminent mathematicians at this event spoke of "failing mathematics" at some time

[20] Goldsworthy, A. (2000). *Future Australia* (BHERT News), pp. 144-145.

[21] For enrolment details see Dobson, I.R., & Calderon, A.J. (1999). *Trends in Science Education: Learning, Teaching and Outcomes 1989-1997.* Monash University: Australian Council of Deans of Science.

[22] *Education Age*, 2/8/00, adapted from a table published in *The Good Universities Guide.*

[23] *Mathematics 2000 Festival.* The University of Melbourne, January 2000.

during their schooling. These ideas—mathematics is important, it's beautiful, and you can fail some tests sometimes and be still be a mathematician—need to be conveyed to young people.

The professional societies, the Heads of Mathematical Sciences departments, the Australian Mathematics Trust, many individuals and groups have generously supported with both time and money a wealth of activities, events, posters, brochures, internet resources, media stories and much more. Support from government has been limited to a few small grants through the Science and Technology Awareness Program (STAP). Business and industry seem to have taken a message from governments that supporting mathematics is 'unfashionable'. As a result dissemination and access to these activities is fragmented and is limited to small audiences instead of all young people. The STAP program has been a dismal failure for mathematics with one comment after the last round suggesting that perhaps a proposal to throw boomerangs in the shape of integral signs in the desert might get funded.

To date applications to raise awareness of mathematics have tended not to receive STAP support. Examples of successful mathematical sciences activities that have also not received STAP support include cutting edge enrichment and extension programs, activities with senior school students involving young mathematical graduates, and proposals to develop materials for regional and remote schools.

Currently the AustMS, in conjunction with the Institution of Engineers Australia and the Institute of Actuaries of Australia, has an ambitious but well-developed proposal for a repeat of the highly successful *Maths Multiplies Your Choices* campaign which was conducted in Victoria in the 1980s[24]. At that time the target was improving girls' participation and a key feature was catchy television slots at prime family viewing time. It was backed by other media and telephone hot-lines and was remarkably successful[25].

As a nation we currently fail dismally to give young people reasons for persevering with mathematics. As a community we accept that it is something that a few can do but is too hard for most, a view which is at odds with that in countries like Japan and Singapore where many more students achieve much higher levels. The same high expectations need to be developed for Australian students but young people cannot be expected to persevere with something that many of them will struggle with at some time—often in classes being taught by a reluctant, under-qualified teacher—unless they are given reasons for doing so.

The current year 12 enrolment figures show this clearly. 'Study the minimum level mathematics necessary to get into a course' needs to be turned into 'do the hardest mathematics courses I can manage so I can do my course well and have real career options at the end of it'.

[24] STAP proposal to initiate this in 2001 was unsuccessful.

[25] McAnalley, K. (1991). Encouraging parents to stop pigeon-holing their daughters: The "*Maths Multiplies Your Choices"* campaign. V.I.E.R. Bulletin no. 66.

Teacher supply

> "A study by London University's Institute of Education has claimed that the growing shortage of qualified maths teachers could ultimately lead to a whole generation being innumerate"[26]

> "Subtraction, with or without regrouping is a very early topic anyway. Is a deep understanding of mathematics necessary to teach it? Does such a simple topic even involve a deep understanding of mathematics? Would a teachers' subject matter knowledge make any difference in his or her teaching, and eventually contribute to students' learning? There is only one answer to all these questions: Yes. Even with such an elementary mathematical topic, the teachers displayed a wide range of subject matter knowledge, which suggests their students had a corresponding range of learning opportunities"[27]

The success of mathematics teaching in schools depends on students' opportunities to learn. Ma clearly demonstrates, in her research quoted above, that teachers with a deep understanding of what they are teaching are better teachers. This is supported by American data which has shown that students taught by teachers with degrees in mathematics or mathematics education perform better in national tests[28]. This research should not be taken to imply that primary or adult basic education teachers should have degrees in mathematics. However, what it does say is that teachers need to really know and understand the mathematics they are teaching and that students who are taught by teachers with this knowledge have more opportunities to learn.

In Ma's study the American primary teachers—with very similar backgrounds to Australian primary teachers—were clearly shown to have poorer content knowledge than their Chinese counterparts. There have been ongoing concerns about the content knowledge of Australian primary teachers for years and these need to be addressed if current attempts to improve primary mathematics education are to be successful.

In secondary schools teacher shortages affect the other important aspect of opportunity to learn which is time in the curriculum. Historically, one of the reasons for girls' under-achievement was related to them studying subjects like home economics while the boys did additional mathematics. In the USA, black schools had fewer resources and also operated for less days. In Australia, reduction in time for mathematics in the secondary curriculum came initially as a way of dealing with an inadequate teacher supply, and this was followed by a demand for more time for other subjects especially following the National Statements and Profiles[29]. It is likely that the recent poor mathematics results reported for students, especially boys, in Melbourne's poorer suburbs can be partly attributed to lack of time in the curriculum. These are also 'hard to staff' schools so increasing the time for mathematics is especially difficult when there is a shortage of mathematics teachers.

There is considerable anecdotal evidence accumulating around Australia that some remote rural schools and other 'hard to staff' schools are not offering the more advanced mathematics subjects because they cannot find the staff to teach them. However no principal is likely to publicise this when the school's reputation is at

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[26] Smithers, R. (13 September, 2000). UK teacher 'crisis', *Education Age*, p. 11

[27] Ma, L. (1999). *Knowing and teaching elementary mathematics.* New Jersey: Lawrence Erlbaum, p. 2

[28] ibid. p. 32

[29] These divided the curriculum into eight key learning areas with an expectation that all areas would be timetabled for all students every week.

stake and the universities have reduced pre-requisites so there is less pressure to publicise the problem.

Thus mathematics teacher supply problems in Australia at the present time are a complex mix of primary teachers with inadequate content knowledge and, in secondary schools:

- normal replacement needs due to retirement and other factors,
- teachers teaching out of field or with inadequate qualifications, and
- the need for more time and curriculum offerings.

In regard to 'other factors' for example, it is being suggested that recent changes to staffing conditions in Victorian secondary schools could require 1000 new teachers. About 250 of these would need to be mathematics and science and this alone would probably absorb every mathematics teacher graduating in Victoria in 2000[30]. There is a mathematics teacher shortage and it has existed for a long time. What has changed is the depth and intractability of the problem although the extent of this is also problematic as very little is known about who is teaching mathematics in Australia nor future demands.

For example, in 1987 a Working Group on the Quality and Quantity of Mathematics and Science Teachers in Victoria found that it could not identify the number of qualified mathematics and science teachers in schools. Its first recommendation was the establishment of a reliable data base to be used as a framework for future planning and to assist in establishing the retraining needs within the existing teaching force[31]. In 2000 this data base has still to be established in Victoria and there is little evidence that any other state has the kind of comprehensive data base that is needed for labour force planning[32].

So while it is now accepted that there is a shortage of properly qualified mathematics teachers, there is no proper data. Further a certain complacency exists in parts of Australia because the number in mathematics methods classes seems to have increased. This is probably the same kind of statistical blip that occurred in England when it became apparent how easy it had become to get a teaching position. As a result, mature age people who have wanted to become teachers are now prepared to make the sacrifice of a year's study knowing they will have a choice of positions at the end of it. Based on what has happened in England, this pool tends to dry up very quickly[33] and very few new mathematics graduates are becoming teachers at a time when there are fewer of them and they have many other options.

One aspect of teacher shortages that is not well understood is the depth of the existing shortfall. Hence reports can talk about anticipated shortages and the need for 375 new mathematics teachers by 2002[34]. This figure was apparently arrived at by

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[30] Approximately 25% of time in the curriculum is mathematics and science, commonly about 200 minutes a week for mathematics and about 150 for science.

[31] Victorian Ministry of Education Portfolio Policy Coordination Division (1987*). Report of the Working Group on the Quality and Quantity of Mathematics and Science Teachers*

[32] The Ministerial Advisory Committee for the Teaching and Learning of Mathematics in South Australia (1999) reached a similar conclusion.

[33] Graduates in England this year in areas of shortfall will get the equivalent of about $A25 000 for doing their teaching qualification but even this has failed to attract enough applicants.

[34] *Forecasting Teacher Demand by Subject 2000.* Reported in *The Age* , Aug 19, 2000 (Employment Section)

asking principals their anticipated needs and probably assumed a steady state which failed to take account of existing hidden shortages of teachers teaching out of field. Figures from the USA indicate that only 72% of their year 7 and 8 teachers are certified[35]. Estimates in Australia for the early years of high school tend to be even higher[36],[37].

There appears to be little or no data on the age profile of mathematics teachers and some evidence that those who are retiring have better qualifications than those replacing them. Canada predicts that half the mathematics teachers in Ontario schools will retire in the next ten years. The USA expects to replace two-thirds of its teachers in the next decade. It seems likely that Australia faces similar challenges.

Even if the current number of mathematics teachers could be maintained, the effect of quite small increases in time on demand could be dramatic. In the 1987 Victorian report it was found that time on mathematics in years 7-10 had dropped below 200 minutes a week and that to take it back to 200 would require 56 new teachers. To take it back to 240 minutes, which was about the norm in 1981, would have required about 440 new teachers. This was for government schools only[38].

Finally the depth of the teacher supply problem was also demonstrated by data from the Third International Mathematics and Science Study where it was found that in excess of 50% of year 8 Australian mathematics and science teachers indicated they would change to a different career if they had the chance[39]. The implications of this for innovation, enterprise and SET are obvious.

'Solutions' that won't work

Past experiments to solve teacher shortages have included retraining primary teachers for secondary schools and overseas recruitment. The first only diminishes a scarce resource in primary schools by taking the people most likely to provide leadership and support for mathematics and science curriculum out of that sector. There is also a shortage of primary teachers emerging.

The second assumes teachers could be recruited from overseas which is debatable. Further, in 1987 the Victorian Government was actively recruiting from overseas. By mid-year, 17 teachers had been placed in schools or were in the process of immigrating and 16 of these were to teach physics, chemistry or mathematics to year 12. Many of them were from Asia but they also came from Britain, Ireland and other countries. All of those who had been placed had been sent to country schools—Portland, Traralgon, Morwell (2), Echuca, Seymour, Orbost, Maryborough, Eaglehawk and Robinvale[40]. Not only does this highlight the way in which rural schools bear the brunt of teacher shortages, but it raises issues about the expectations

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[35] Dossey, J. & Usiskin, Z. (2000). Mathematics education in the United States 2000. Reston, Va.: National Council of Teachers of Mathematics, p.31.

[36] For early secondary it is thought to be about 40%. The Mathematical Association of Victoria is currently collecting data which may clarify this.

[37] Brinkworth, P. et al reviewed senior mathematics subjects in South Australia and also found reduced time in the curriculum and 60% of teachers in junior secondary teaching less than 20% of their time in mathematics. Teaching mathematics was not their main activity.

[38] Note that this is new mathematics teachers, not an increase in the total number of teachers.

[39] Lokan, J. et al. (1996). *Maths and Science on theLine.* Melbourne: ACER, p. 209.

[40] Overseas Recruitment Scheme: Update 22/6/87

of immigrant teachers to adjust to living in communities very different from their origins.

Solutions that might work

There is compelling evidence that there is a teacher shortage and it is going to get worse. Ultimately the solution to an adequate supply of secondary mathematics teachers lies with more graduates from the universities. In the short term that is not going to happen so other solutions must be found. These should include:

- retraining existing teachers,
- additional incentives for graduates to enter teaching, especially mature age people looking for a career change, and
- special programs to support non-English speaking background immigrant graduates, especially those with some prior teaching experience, into teaching.

Many of the teachers who are teaching out of field would like the opportunity to obtain proper qualifications but expecting them to do it at their own cost and in their own time is unrealistic and unfair. Similarly mature-age people have financial commitments that mean that they need proper financial support while doing additional studies. The immigrant graduates often have excellent content knowledge but their special language needs, and difficulties with the culture of Australian schools, cause problems for both schools of education and supervising teachers in schools.

The actions above need to be taken immediately. At the same time there needs to be opportunities for existing primary teachers to improve their content knowledge and a re-examination of primary teacher education in mathematics. Not only was the review that examined this in 1989 never implemented properly but much more is now known about the content knowledge and teaching skills needed to teach mathematics well in the primary years.

Further, a structure needs to be put in place so that there is a proper data base on teachers' specialisation and there can be long term planning. A recent DETYA project brief stated: "While the Department's annual higher education student statistical collection is useful for data analysis in the broad context of teacher education nationally, it does not provide the details of completing student numbers in terms of specialisation"[41]. This is fiddling at the edges of what is a much bigger problem of lack of knowledge about who is teaching what, and with what qualifications, in our schools. It is not even obvious that DETYA acknowledges the existing shortfalls. A word search of a recent publication, *Teachers for the 21st Century - Making the Difference*[42], failed to find 'shortage', 'shortfall', or 'number of teachers'. Again, the failure to even acknowledge that this is a problem is a very Australian phenomenon.

Currently Monash University is hosting a project with the aim to offer certification to mathematics teachers identified as 'excellent'[43]. This would appear to be the third stage of what should have two preliminary stages. The first of these is some form of registration of teachers which states they meet certain minimum requirements to teach and at what levels. The second is basic certification to teach mathematics and to what level. This should require certain content standards and

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[41] Brief obtained when it was circulated electronically.

[42] www.detya.gov.au/schools/publications/reports/t21/t21.htm

[43] Morony, W. (1999). Excellence in the teaching of mathematics. *Australian Mathematics Teacher*, 55(3), pp. 42-44

specific methods studies for primary, middle years, and senior secondary. As there are differences in State curricula, this should be addressed at a state level within broad national guidelines. It would require collaboration between teachers of mathematics, university mathematics educators and discipline specialists as well as the employing authorities.

Until there is some form of certification in place the widespread shortage will remain hidden. Parents will continue to lack even basic information on the mathematical qualifications of those teaching their children and labour market planning in education will continue to be ad hoc guess work.

Mathematics in the universities

> "… there is a crisis of confidence amongst junior staff. We're facing three colliding tidal waves, any one of which is deeply disturbing: (1) our best new graduates are leaving and staying away (2) our most prominent senior researchers are leaving (3) a large fraction of our current university mathematicians are approaching retirement. Put together these add up to looming catastrophe"[44]

> "…my own department has lost approximately a third of its teaching staff in the last few years, with more losses to come…"[45]

> "The loss to Australia of these top academics in my field alone is not easily measured, but even if each of them had only mentored one replacement with the same capabilities and productivity, the nation would have benefited immensely. There is almost no chance of luring these people back to academia with the current demeaning funding models. The solution is not recruiting a few high flyers and paying them twice what the rest of the lecturers and professors get. A cultural shift is required"[46]

It has been claimed that Australia has had a net gain in science-based immigration[47]. But Minister Kemp claimed that Labor party policy would not fundamentally change the problem of a brain drain from Australia and hence explicitly acknowledged its existence[48].

Data collected for this report and documented in the final section shows an irrefutable and unsustainable brain drain in the mathematical sciences. No discipline can afford this kind of haemorrhaging and remain vibrant, creative and innovative. The national loss cannot be counted in simple dollar terms as such expertise and talent is irreplaceable. Neither can the loss of morale among those who have chosen to remain, many of whom will retire within the next few years and are in despair about a discipline area they saw grow in international reputation and which is now seen as having little or no future.

The young academic

Professor Terry Tao completed a masters degree at Flinders University at age sixteen and then a PhD at Princeton. At the end of 1999, while on a visit to UNSW, he received four spectacular honours. At age 24 he was promoted to Full Professor at UCLA. He was also awarded an Alfred Sloan Fellowship, a prestigious award to outstanding young researchers, a Packard Fellowship to further his research, worth $1M (Aus) and a Clay Foundation Fellowship worth $2M for his research and salary over the next 5 years. Professor Tao has made several visits to the UNSW in recent years where his mentor and teacher from age 12, Professor Garth Gaudry, is now Head of School. Professor Tao's contribution to research and teaching at UNSW has been much appreciated.

[44] Personal communication

[45] Monro, G. (2000). Mathematics service teaching in 2010. The Australian Mathematical Society Gazette, 27(2), p. 46

[46] Personal communication

[47] Senator Minchin, Minister for Science, reported in Campus Review of July 19-25, p. 2

[48] Dr David Kemp, Minister for Education, reported in Campus Review, August 9-15, p. 1

The young entrepreneur:

Andrew Conway completed his PhD in Mathematics at the University of Melbourne in 1992, working on a project in Mathematical Physics and Combinatorics. He then went to Stanford University, where he completed a PhD in Electrical Engineering in 1995. Following this he undertook postdoctoral studies in Bordeaux (France) in the area of Combinatorics, and then applied his combinatorial and programming skills to biochemistry, taking up a post-doctoral position in the Dept. of Biochemistry at Stanford University. After about a year there, he decided to start his own business supplying specialist computer programs for gene sequencing and related activities. The name of his company is Silicon Genetics, and details of what it does can be found on www.sigenetics.com. In two years it has grown from a 1 man to a 21 person business, and has been profitable from day 1. Start-up grants and continuation grants were instrumental in growing and developing the business.

From one university:

• Dr. Gek Lim (PhD 1995, departed 1996), took up a post doctoral fellowship at U of Southern Florida, then did two years at Bell Labs (Lucent Technologies) and recently took up a position with a Silicon Valley high tech company. She is working in algorithms for medical image analysis.

• Dr Robert Mclaughlin (PhD 1999, departed 1999) is doing postdoctoral work at the Robotics lab, Oxford on medical imaging.

• Mr Jason Hutchens (enrolled PhD, still to complete his thesis) is working in a senior position in an Israeli start-up company on natural language acquisition modelling. Left in 1999.

The case of Jason above is another reason for concern in the mathematical sciences. Current plans for research funding include rewarding universities for students completing research degrees[49]. Indications are that on these criteria mathematics at Stanford would fare very badly as many of their students are attracted to Silicon Valley well before completion. It would also appear many young mathematicians are being attracted to the high salaries of—especially—IT and the finance industry before they even start a higher degree.

At the conclusion of the review of advanced mathematical sciences at the end of 1995 it was considered that, in general, Australia had a sound research base but that it was fragile and that there were areas of particular weakness which included operations research and financial mathematics. In the preceding years universities had taken in 20% more students with no increase in academic staff. This may have been sustainable but the subsequent loss of staff is not. Nor is the fact that young people of the calibre above are not coming back to replace them as in the majority of cases they are not being replaced.

Data from the Heads of Mathematical Sciences Departments shows that about

[49] Kemp, D. (1999). *Knowledge and Innovation.* Canberra: Commonwealth of Australia.

26% of staff were lost between 1995-9 but that the overall teaching load stayed about the same. Further, while a few universities have had an increase in third year numbers, in general third year numbers are down. The discipline is losing its identity as departments of mathematical sciences are constantly being reviewed, restructured, renamed or re-organised. This creates tension for staff and confusion for students.

The review took a very optimistic view of post-graduate numbers, predicting steady increases in all areas. It appears that the most recent figures that were available to the review represented a high in enrolments and the trends have been all downwards since. In particular, the number of Honours graduates peaked at about 250 in 1992 but had fallen to less than 150 by 1995[50]. From Heads of Department data it would appear that they have been around that figure since.

Contrary to popular belief about the teaching of mathematics at universities, a recent summary of fields of study showed mathematics graduates happy with the teaching quality. The same summary showed many more campuses teaching sciences and Computing and IT than mathematics[51]. The tendency for service teaching to be done within other departments rather than by mathematics departments is usually for financial rather than educational reasons. It weakens mathematical sciences departments in the university and ultimately weakens the quality of mathematics courses for students. It also appears that many students are studying degrees with little or no mathematics. These weaknesses will also soon become apparent to employers and ultimately to the students.

Like most nations, Australia is not producing enough graduates in the mathematical sciences even though starting salaries are only exceeded by a few other areas[52]. Further, enrolments in mathematics and science based courses can be quite sensitive to immigration patterns. Research conducted on students enrolled in first-year mathematics in Victorian universities in 1993-4 showed one or two ethnic groups who had been born overseas greatly over-represented[53]. It would appear that the number of PhDs in mathematics at the current time is boosted by a number of recent, in particular, Russian immigrants[54]. The effect of reduced immigration or changing patterns of immigration could be profound. At the same time there are difficulties in the already stretched tertiary sector in dealing with overseas recruits with poor English skills, particularly those doing research degrees.

Compounding Australia's and the rest of the world's mathematical skills shortage is the fact there was a 6% decline in bachelor degrees in mathematics in America between 1990-5 with reports of a further 8% in 1995-7[55]. This is bad news for the rest of the world as the booming USA economy means continuing loss of talent to the USA. The USA Congress has just backed another big increase in the number of visas for skilled workers in a move summed up by one Representative as 'We either import workers or export jobs and industries'[56].

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[50] Personal communication. Data collected by Peter Petocz, UTS, Sydney.

[51] *Education Age*, 2/8/00, adapted from a table published in *The Good Universities Guide.*

[52] Ibid.

[53] Thomas, J. (1995). Mathematics and bilingual students. Proceedings of the 18th MERGA Conference.

[54] Israel is recruiting many of its new teachers from Russian immigrants (personal communication)

[55] Dossey, J. & Usiskin, Z. (2000). Mathematics education in the United States 2000. Reston, Va.: National Council of Teachers of Mathematics, p. 17.

[56] *The New York Times*, October 4, 2000

Clearly the mathematical sciences have been caught up in the same malaise affecting the rest of the university sector and if recent reports are implemented and the issue of university salaries is addressed, the brain drain may be arrested. Australia has the advantage of being a very nice place to live but there must be satisfying careers. There is little chance of career satisfaction in the current system where heavy teaching loads, lack of support staff, loss of the best Australian students to overseas universities who can offer them more support, the additional workload associated with often weak full-fee paying students and inadequate research funding combine to disillusion remaining staff. In the last round of ARC grants there was a 15% reduction in the number of applications to the physical sciences panel which includes advanced mathematical sciences[57].

Some specific problems also emerge. It is clear that in some key areas, including financial mathematics, statistics, and all the mathematical areas that support and partner IT, university salaries are quite uncompetitive. This is often compounded by the high cost of housing in some areas, especially but not exclusively, Sydney. Further, although cutting edge IT desperately needs mathematically-able people trained in both mathematics and IT, the current IT skills shortage is making it very hard for students to resist IT overtures offering top salaries without the mathematical underpinning. This increases pressure on universities to reduce the mathematical prerequisites for, and requirements within, IT degrees to the detriment of both cutting edge IT and the mathematical sciences.

Not only do the issues in universities need attention but the visibility of mathematics must be enhanced. Canada, for example, has three national centres for mathematics. Australia has none. Without some direction and incentives from government, industry and the community, university administrators will continue to neglect the mathematical sciences. Further, the disincentives for collaborative teaching must be removed. The Victorian Institute of Earth and Planetary Sciences model has potential for national and state centres, as does the Canadian Fields Institute. Any national or state institutes must involve new money—on no account should any action be taken to further weaken existing research and teaching in the universities.

[57] Letter from Prof Vicki Sara, Chair ARC to Prof Garth Gaudry as Chair of Heads of Department Group, 29 March, 2000.

Mathematical services

> "…the mathematical situation in CSIRO is unacceptable in the short term and unsustainable in the long term. Compared to international research organisations, CSIRO is inefficient and overly bureaucratic"[58]

Central to mathematical services in Australia are the mathematical sciences in the CSIRO. The Review made several complimentary comments about CSIRO Division of Mathematics and Statistics[59]. It summarised its views in Recommendation 6d: *"CSIRO is encouraged to continue its funding support for the activities of CSIRO Division of Mathematics and Statistics. This Division should continue to operate on a disciplinary basis"*

Shortly after the Review was completed, CSIRO Division of Mathematics and Statistics was merged with three other CSIRO groups to form CSIRO Mathematical and Information Sciences (CMIS). There are about 20 research groups in CMIS, with a total of nearly 200 professional scientists[60]. The main problem in the past 5 years is perceived to have come from the CSIRO corporate structure. When the Review was under way, CSIRO had a typical hierarchical structure, with Institutes and Divisions. There was justifiable criticism with this, especially:

- competition and duplication between Institutes and Divisions, with attendant
- poor mechanisms for establishing research priorities, and
- insufficiently strong connections to the needs of the Australian customers

However, that structure worked well for CSIRO Division of Mathematics and Statistics.

Around 1996-97, CSIRO commenced a major internal restructuring process and there was general acclaim for the changes. However the restructure made life very difficult for those Divisions with generically applicable science. Before the Sector process, CMIS operated in 18 of the 22 Sectors but this was reduced to 7 major and 4 minor Sectors. The mathematical needs of the other Sectors are either not being met, or met by mathematicians employed in other Divisions sub-optimally. CMIS has found it exceptionally difficult to obtain funding, in that it needs to bid for its budget from 11 separate committees. The general perception is that CMIS was cut into many small pieces, with relatively little power in most of them. Returning to recommendation 6d, it becomes apparent that the mathematical sciences in CSIRO have suffered a similar loss of identity as is happening in the universities.

This lack of identity exacerbates the difficulties of small to medium enterprises (SMEs), in particular, accessing mathematical services. The annual Mathematics in Industry Study Group meeting demonstrates the value of mathematical services to industry problems. The problems associated with the invisibility of mathematical services in the universities and CSIRO, and the lack of mechanisms for short courses and coursework degrees that meet specific industry needs, highlight the need for new structures. In particular, the current rules of the CRC program exclude the possibility of a CRC concentrating on generic mathematical technology and CRC participation for the mathematicians is on a piecemeal basis.

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[58] Personal communication.

[59] Op cit. - see pp. 53-56.

[60] See www.cmis.csiro.au

Mathematics education teaching and research

Like mathematical science departments, education faculties have shrunk and fewer mathematics educators now teach many more students. Additional stresses have arisen with the demise or reduction of consultancy and curriculum specialists in state ministries. This has considerably reduced the number of people available for specialist curriculum work and professional development and also eliminated an opportunity for excellent teachers to be more involved with teacher education, ministries and schools.

As a result there is a shortage of people with a background in mathematics education teaching and research which is being exacerbated by governments tendering out much work that used to be done in ministries. Much of this is woefully inefficient and very frustrating for those trying to ensure that a good product emerges. Many aspects of education such as course and curriculum development take time and special expertise. This expertise has been lost from ministries at an alarming rate and there are few people left who could mentor and assist new people assume these roles.

This is exacerbating a huge gap in professional development delivery and availability. Coursework post-graduate studies were attractive to teachers but not on a full-fee paying basis, especially when completion of further studies has seldom been recognised financially. The state mathematics teachers' professional associations, university mathematics education staff and a few private consultants struggle to provide professional development for schools and individual teacher groups but no other industry group would treat the ongoing professional development of staff in the way it is treated for teachers.

Australian mathematics education research has a very good reputation in the international arena and Australians are well represented in international committees and editorial boards. However many of these researchers are now tied to government tenders and some of the research may never be published. There is also some concern about research being funded by groups such as calculator companies with an interest in particular outcomes.

There are other challenges in mathematics teacher education itself. Issues specific to mathematics can be lost in faculties of education where there are often other priorities and mathematics educators a minority. Current issues include the need to fundamentally change expectations in regard to content for primary teachers and to re-examine the preparation of mathematics teachers for the early years of secondary[61].

School mathematics

There are a wealth of issues in school mathematics that need ongoing research. In recent years there has been a tendency to address issues in schools via outcomes based curriculum linked to testing. This is a global phenomenon and there is limited evidence for its effectiveness. One of the problems with an outcomes based curriculum is that underqualified teachers teach to outcomes and tests and the view of mathematics that is conveyed to students is fragmented. Until the problem of

[61] For more detailed description of recent issues in mathematics education research see Owens, K & Mousley, J. (eds) (2000). *Research in Mathematics Education in Australasia 1996-99*. University of Western Sydney: MERGA

underqualified teachers is addressed, improving the textbooks used in schools would probably produce better results.

Unlike the USA, Australia has had in place high quality year 12 courses which have tended to focus schools on preparing students for them. The integrity of these courses needs to be maintained. The move to more and more testing in the USA has come in response to a situation peculiar to that country and is now beginning to encounter considerable community backlash as parents become increasingly concerned about the amount of time spent on preparing for, and taking, tests.

Similarly, nearly 12 years of national curriculum and testing in the UK has not produced any indication that these kinds of regimes are particularly successful. The reluctance of people to pursue teaching as a career in the UK at present should be a salutary reminder to governments everywhere that professionals like some control of their professional lives. The rigid control of teacher education, teachers and schools—and the apparently unbridled power of the inspectors—appears to have contributed to a situation where even very considerable financial rewards for pursuing teaching qualifications have largely failed[62].

Provision for talented students

If Australian mathematical sciences are to have a future then talented young mathematicians must have opportunities to develop those talents. Many young people with an interest and talent in mathematics do not need accelerated programs or early entry into university. The Australian Mathematics Trust with its network of overseas contacts has considerable expertise in the kind of extension problems and projects that can supplement the normal curriculum for such students.

However, a major problem in making provision for talented young mathematicians is the lessening of the content knowledge base of mathematics teachers. Further, the occasional exceptionally gifted student does emerge. Fostering and nurturing such students has usually been done by mathematicians in the universities[63]. Mathematicians in the universities have also been very much involved in the Mathematics Olympiad and other enrichment activities. Such activities, in the current climate in universities, are not seen as core work and are unlikely to be valued because they do not bring in monetary reward to the university. Increasingly academics, who take on such work at the expense of research, are jeopardising their future careers. This could be remedied by monetary recognition by the federal government which has created the situation and could reward this kind of activity within funding mechanisms[64].

[62] These personal observations, based on a visit to the UK, were supported by an Australian representative of TimePlan, who were managing the financial incentives scheme.

[63] For example Professors Cheryl Praeger of the University of WA and Garth Gaudry of UNSW

[64] For example, mentoring a talent student or assisting with the Mathematics Olympiad for a year could be equated with one refereed paper

The TAFE sector

> "With any given numeracy problem, I have 'a' (that's one single, solo, isolated) strategy, and if that doesn't work, I'm sunk—and then I get that cosy glow that results from having confused a student more deeply and confirmed their belief that they're dumb!"[65]

Mathematics has little status in the TAFE and community education sector. Permanent positions have tended to be associated with specific diplomas and certificates rather than 'service' subjects such as mathematics. As a result, mathematics has increasingly been taught by sessional and contract staff. There appears to be little data on who is teaching mathematics and with what qualifications. Data collected in Victoria in 1987 showed all the problems of secondary schools identified earlier in this report and called for programs of appropriate mathematics and teaching methods[66].

The diversity of needs from basic numeracy to tertiary level mathematics means that there needs to be a focus on developing a sense of community among those teaching mathematics in the TAFE sector. The TAFE sector must be able to both support good mathematics teaching within its own courses but should also be a second chance for some young people and adults whose schooling has failed them. There needs to be much wider recognition that adults can learn mathematics.

All of the above imply that there must be qualified staff who have ongoing positions and who need a variety of teaching skills, not all requiring advanced level mathematics. Given the weaknesses elsewhere in the system, TAFE mathematics teaching and mathematics teachers need to be given special attention by the Australian National Training Authority. In particular, the shortage of mathematics teachers in the secondary sector has implications for TAFE. This should be addressed by the TAFE sector taking more responsibility for the education of its teachers.

TAFE and community education teachers of mathematics would benefit by recognition as teachers of mathematics within a special setting and development of their own professional body. This is unlikely to happen with a largely sessional and contract staff. Neither are the structures and courses necessary to ensure adults who are not in the university sector have access to appropriate mathematics for vocational education and training, as well as articulation to other courses, likely to be in place.

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[65] Adult literacy and numeracy teacher in *Fine Print*, Winter 2000, 23(2), p. 26

[66] A copy is held by the author

Funding a Future

This paper has identified a number of priorities if the mathematical sciences are to have a future in Australia. The weaknesses in the mathematical sciences are clearly related to other issues addressed in the Chief Scientist's and ISIG reports. However, it is difficult to see how those reports can successfully be implemented if the weaknesses apparent in the key enabling technology—mathematical sciences—are not addressed.

The mathematical sciences do occupy a unique position and the problems are deeply entrenched. In particular, the recognition of the importance of mathematical scientists in the rest of the world means that they are attracting high salaries and much better support for research elsewhere. Reversing the brain drain is not going to be easy and the longer it is allowed to persist, the harder it is going to get. This threatens not only SET in Australia but also others areas of vital important such as financial services.

In Australia the mathematical sciences and their importance have been allowed to become invisible. In part this seems to have arisen by a uniquely Australian phenomenon of embedding mathematics in SET. In schools this has translated into programs that address science teaching while ignoring the much deeper problems associated with mathematics teaching, including more teachers teaching out of field[67]. Mathematical sciences must be put back on the agenda and the woeful failure of science and technology awareness programs to cater for them must be addressed. However, if more young people are to be attracted to mathematics in schools and universities, there must be the teachers and the courses to make this both possible and attractive.

Funding and Implementation

In the following table some suggestions for what needs to be done, funding sources and major participants in the implementation are summarised.

ACTION	FUNDING	IMPLEMENTATION
Public campaign to improve participation in mathematics	Some state and federal, most from industry	Discipline societies with assistance from MERGA and mathematics teachers associations
Improving teacher supply and quality	State and federal governments and other employers	State ministries of education in conjunction with university education and mathematics departments. Some national coordination through Fields type institute
Improving support for advanced level mathematical sciences and services	State and federal governments and industry, including finance, IT, engineering, manufacturing and biotechnology. Access to CRC program through revised guidelines	Establish Fields type institute. Key partners to be university mathematical science departments and mathematics educators, CMIS, industry users

[67] For example, Victoria has a *Science in Schools Program* which is upgrading junior secondary science teachers physics skills and employing support people in the regions. No such program exists for mathematics.

A campaign to improve participation in mathematics of the kind envisaged should involved a mix of funding and the initial investment would be substantial but once-only. In particular, this is one area where the financial services and media and communications industries, who are major beneficiaries of a strong mathematical sciences base, could make a substantial contribution. The professional societies have many of the core materials, ideas and personal resources to support this program. The major cost is a one-off media campaign and the development of the support materials to back this. The professional societies believe that if these can be developed and distributed nationally, they have the resources to keep them up-to-date.

The major area of government responsibility is in improving teacher supply and quality. Fixing it is going to require a very considerable ongoing investment and the longer the problem is largely ignored the more expensive and difficult it is going to be to fix. For example, student teachers have to be placed in schools for teaching practice rounds. City schools are reaching saturation point but more students could possibly be placed in remote and country schools if there was funding to support them and the supervising universities. Ultimately the number of placements available may limit the number of students in pre-service courses and this needs to be recognised.

Actions taken by the federal government need to include:

- addressing the dramatic decline in education in the universities and the apparent lack of places for some appropriately qualified graduates wanting to do graduate diplomas
- redressing the HECS inequities, and
- providing HECS based and HECS free places for teachers completing additional post-graduate qualifications.

The state governments need to invest much more in the way of incentives but as the principal employing group must also take responsibility for ensuring that teachers stay in teaching. If the federal government funds the places so teachers can re-train, the state governments need to provide the study-leave and other support this will require.

Governments have a number of existing revenue sources available including the monies within the numeracy strategy. An additional source of revenue could be a levy on resource rich private schools and the TAFE sector[68]. Teachers are the most important resource a school has. Finding the additional resources that are needed for initial teacher education courses and re-training in the next decade is going to be an enormously costly exercise. All sectors are going to have to contribute.

The other source of funding for both teacher education and injecting extra funding to the universities is the money that is currently being collected through the HECS scheme and contributing to the government surplus instead of improving the education of the current generation of students. Reviving the mathematical sciences is in part tied to improving university funding[69]. However, that alone will not be sufficient. A framework is needed that provides a focus of activity and addresses the inherent problems in a demoralised and depleted discipline.

The Canadian *Fields Institute for the Mathematical Sciences,* funded by the

[68] Both the private school and the TAFE sector have, in the past, taken greater responsibility for the education of their teaching staff

[69] See *Returns to Investment in Higher Education* (2000)at www.econ.unimelb.edu.au/iaesrww/pdf/rihe.pdf

equivalent of state government, ARC and university sources, and industry partners provides one initiative that should be considered for Australia. Such an Institute should:

- provide a focus for mathematical services, including development of short courses to meet industry needs and visibility for SMEs wishing to access mathematical services
- through its scientific program, run year long programs in specific areas and provide greater depth and variety to post-graduate courses.
- provide for collaborative work in mathematics education, including issues arising in regard to the development of courses for retraining existing teachers, professional development and others.

A major attraction of the Fields model is the multi-disciplinary work it is doing and that an Australian centre could be supported by linked state institutes.

There has been some discussion within the mathematics community of possible sites for the national headquarters of a multi-sited National Institute. Because of their strong industry bases, it is generally considered that Sydney or Melbourne are the most realistic possibilities. Sydney has the stronger mathematics base especially as it can draw more easily on the mathematical expertise in Canberra. Melbourne has cheaper accommodation and a state government with better policy and commitment to science but which has, however, shown little interest in the mathematical sciences so far. The President of AMSC considers that “Such institutes MUST be linked with business, industry, government, education, other professions—that's what Australia really needs—a more coherent, encompassing, in-your-face approach to mathematical sciences”.

The discussion has considered that the multi-sited model will strengthen the mathematical sciences in all states, allowing as it does for excellence to flourish in any state based on state needs and expertise. Existing structures for Institutes and Centres have failed the mathematical sciences. Canada has three and the Fields Institute for the Mathematical Sciences with its close proximity to the Ontario Institute for Studies in Education provides a model that could well be emulated.

A state-based model that has much to recommend it, and could link to a National Institute, is the Victorian Institute of Earth and Planetary Sciences (VIEPS) which was established with substantial funding from the former Victoria Education Foundation. The continued existence of VIEPS has meant that post-graduate students in earth sciences in Victoria have continued to have access to a wide range of courses even if enrolled in institutions that had been forced to reduce offerings. Such an institute structure is needed if the small number of honours mathematical sciences students are to have a suitable range of courses and there can be effective short-course development for specific industry needs.

The Final Chapter?

On Tuesday, 23 January 1996, at the Australian Academy of Science, Sir Gustav Nossal launched *Mathematical Sciences: Adding to Australia,* the discipline review of advanced mathematical sciences in Australia. It was a happy occasion. The review had highlighted the importance of the mathematical sciences to Australian life. They were found to face some challenges and have a rather fragile base but they were basically in good shape. The review was acknowledged as being realistic and implementation of the recommendations did not require a major injection of new money.

Much can happen in a few years as the data in this final section shows. No discipline can afford to lose the wealth of intellectual capital that is documented here. Not everyone listed below who has gone overseas has an international reputation but many do. Each one represents an Australian investment lost to another nation. This would not matter if they were being replaced by the same number of people of equal calibre from overseas but the flood from Australia is countered by an incoming trickle.

Significantly, many of the people listed are statisticians of international repute. While money for medical research was being doubled, at the same time much of the key mathematical sciences expertise needed for medical and biotechnology research was being lost. The data presented here is a monument to ad hoc science policy in general and under-funding of the enabling disciplines in particular.

These are not definitive lists—I asked for data post 1995 and it has been through several iterations for additions and corrections through an e-mail list that covers all university mathematical sciences departments. There will still be errors and omissions.

The data makes me angry. I knew the mathematical sciences were being damaged because I knew the numbers of academic staff losses for the same period. But I was not prepared for the story that is told below. Not all of that story is revealed—many of the e-mail messages I received that I would like to share cannot be reproduced because they contained sensitive information about specific institutions or individuals. I have reproduced some of the comments I received because they help to tell the story. These have not been edited and they are often personal, reflecting a special sense of loss for named people.

Here then is the story. For Australia's sake, I hope it is not the final chapter but this trend is unsustainable. It has to be stopped now.

Experienced Researchers to Other Countries

Name	**Destination**
Prof Lee White	Carnegie-Mellon
Prof Walter Neumann	Columbia
Dr Danny Ralph (Senior Lecturer)	Cambridge
Dr Marcelo Laca (Senior Research Associate)	U of Muenster (Germany)
Dr Neil Fowler (lecturer B, originally recruited from USA)	USA
Prof Alan Welsh	Southampton
Dr Matthew Wand	Harvard

*Prof Roger Grimshaw FAA	Loughborough
Dr JimWright	Edinburgh
Professor Richard Brent	Oxford
Dr David Stewart (Research Fellow)	Iowa
Dr A. Dimca	France
Dr A Parusinski	France
Dr V.Zheligovsky	Russia
Dr Gita Mishra, (Australian PhD)	Cambridge
Dr Russell Rimmer (reader)	Scotland.
Prof Roger Hosking	University of Brunei
Prof Peter Kloeden	Frankfurt
Dr Maciej Kocan (Research Fellow)	Frankfurt
Prof Kewei Zhang (Research Fellow)	Sussex
Dr Jeff Hogan (Research Fellow/lecturer)	Arkansas
Dr Owen Jones	Southampton
Dr Marek Musiela (Sen Lecturer - declined Chair in Aust)	Paribas London
Dr Bob Griffiths (Reader)	Oxford (Chair)
Prof Warren Ewens FRS, FAA	University of Pennsylvania
Prof Peter Brockwell	Colorado State
*Prof K.L. Teo	Chair at HK Poly U
A/Prof CJ Goh	Private business, 1998
Dr X. Zhou	HK Poly U
Prof Murray Aitkin (ARC Senior Research Fellow)	Chair, Newcastle UK
Dr X.Q. Yang (ARC res fellow, 50+ papers!, young)	HK Poly U
Dr Anthony Kuk (Senior Lecturer)	University of Singapore
Dr Grace Chan (Lecturer)	University of Iowa
**Prof William Dunsmuir	University of Minnesota
Dr David Broutman	Naval Res Lab., Wash DC
*Assoc. Prof. Liqun Qi	HK Poly U
Dr X. Chen (ARC Research Fellow)	Japan
Dr Massoud Bazargan-Lari	Embry-Riddle Aeronautical U
Dr Malcolm Anderson	Uni of Brunei
Dr D. Andrew Barry (maths PhD)	Chair /Civil Eng. at Edinburgh
Dr Song Chen (senior lecturer)	Singapore
Dr Gary Davis (reader)	Southampton, U.K.
Dr Murray Elder	University of Texas, USA
Dr Anthony Brockwell	Harvard University
Dr Lisa Carbone (Assistant Prof)	Harvard
Dr Kevin McAvaney	Oman
Dr Matthew Emerton	University of Michigan, USA
Dr Ian Wanless	Oxford University, UK
*Dr Tao Qian	Macau
Dr Jeff Hogan	University of Arkansas, USA
Prof Graham Wood	Massey NZ
Dr Peter Miller	USA
Dr Glenn Fulford	AgResearch, New Zealand
Dr Genkai Zhang (Research Associate)	Chalmers Inst of Tech Sweden
Prof Ray Chambers	Southampton
Dr David Scott	Auckland
Dr M. Faddy.	Birmingham Uni, UK

Dr P. Burton	Dubia, Arab Emirates
Dr Dawei Huang (Senior Lecturer	Beijing, Lucent Technologies
Dr Nicolai Leonenko (Research Fellow)	Cardiff
Dr Rod Gover (QEII Fellow)	Auckland
Dr Kim Anh Do (medical statistician)	USA

* Leave without pay or other long term leave - may return
** Leave of absence 2001 - may return

Comments added:

• *We have replaced none of our retiring or retrenched staff.*

• *The first two caused us considerable problems as they were the best researchers of our younger mathematicians at the time.*

• *One aspect of the brain drain, which is difficult to capture, is the number applying for positions overseas-- from what I hear there are many in this category.*

• *Please emphasise that in particular Griffiths, Ewens and Brockwell are absolutely top-flight people who left Oz because of the unsatisfactory state of academia here.*

• *Alan Welsh won the Moran medal awarded by the Australian Academy of Science in 1990 …. He is a great loss.*

• *… there is a fair bit of head hunting going on. In the last year I have had serious approaches for three jobs in the UK. They were better paid and in a better research or professional environment- one paid 100,000 pounds, i.e. more than A$250,000. I didn't pursue them because I actually like living here and I didn't want to disrupt my children's education*

• *White, Neumann, Ralph, Elder, Brockwell (jnr), Wanless all left Melbourne in the last few years – not only two of our biggest stars in White and Neumann, but Ralph, Elder, Brockwell and Wanless are all really enormously talented young people. In either case, is this anything but a big loss for the country.*

• *Australia used to have world-class strength in Statistical Science. Almost a whole generation of Australian talent has emigrated in the last 5-10 years. Recently expatriate Australians occupied the editorial (Editor-in-Chief) positions in* ***all*** *of the top 5 international journals in mathematical statistics.*

• *It is also worth noting that over the last couple of years, 6 full-time positions (including the Professorial position) have not been filled after relocation, retirement and people moving into other career paths.*

• *I know there are many other senior people who have only stayed for family reasons.*

• *I should like to point out that many talented mathematicians also live in physics or other departments. I know of one, Dr Bill Spence, who left MU theoretical Physics to go to IC in London. Such people may be missed out from your survey.*

Experienced Researchers from Other Countries

Name	From
Prof Lynn Batten	Canada
Dr Paddy McCrudden, (Research Fellow)	McGill
Dr Ken Palmer (ex-Australian)	Miami U.S.A.
Dr Martin Hazelton	Imperial College
Prof Sever Dragomir	Timisora Romania & Transkei, South Africa
Dr Estate Khmaladze (Senior Lecturer	Georgian Academy of Sciences
Dr Leigh Brookshaw (ex-Australian)	Los Alamos
Dr Victor Korotkich	Russia
Dr Mark Nelson	Leeds, UK
Dr Oleg Derjo	Russia

Comments *added:*

• We have a letter on file from a senior professor in statistics in the US stating that Australian salaries provide no attraction for even junior staff to come from the USA to a position here.
• I approached an outstanding Australian for the Chair in Mathematics of Finance. He replied that his salary in the US is $184K Aus. and that he can add to that as much consulting as he wants to do. We are uncompetitive.

New Researchers to Other Countries

Name	Destination
Dr Mathai Varghese (AustMS Medal 2000)	MIT
Dr Siye Wu (QE II)	San Diego
Dr David Adams (ARC postdoc)	Taiwan
Dr Justin Sawon (honours in Aust/PhD overseas)	Oxford
Dr May Nilsen (Australian PhD)	Texas A&M
Dr Astrid an Heuf (honours in Aust/PhD overseas)	University of Denver
Dr Philip Charlton (Australian PhD)	California Institute of Tech
Dr Johnathan Kress (Australian PhD)	University of Waikato
Adam Piggot (Uni medallist)	Oxford - scholarship
Gaurav Raina (Hons I)	Cambridge
Ha Viet Hoang, (Uni medallist)	Cambridge
Dong Vu To (4 year degree in 3 years)	PhD at Buffalo
Dr Peter Tritscher, (PhD and post doc)	University of Brunei
Dr Andrew Rechnitzer. (Post-doc)	Canada
Dr Denis Labutin , (ARC Res.Assoc, Aust PhD)	ETH, Zurich
Michael Giudici	Queen Mary & Westfield Phd study
Akshay Venkatesh	Princeton PhD study
Dr Yanqun Liu (recent PhD/ postdoc)	HK Poly U
Dr Gek Lim (PhD)	Silicon Valley high tech company
Dr Robert Mclaughlin	Robotics lab, Oxford
Mr Jason Hutchens (still to complete PhD)	Senior position Israeli start-up company
Dr Paul Armsworth (Aust PhD - originally UK)	Stanford

Dr Danny Arrigo (post doc)	Univ of Central Arkansas
Dr J. Grotowski (BSc hon Aust/PhD New York U	Germany, Uni of Freiburg (?)
Dr M. Simon (PhD Aust)	University of Freiburg, Germany
Dr Andrew van Deth (PhD)	University of Waterloo, Canada
Paul Hannah (PhD Aust - to be submitted)	Manchester (post-doc type work)
Brett Parker (PhD studies)	Stanford
Selena Ng (PhD studies)	Cambridge
Dr J.Crisp (Aust Ph D)	France
Dr Danny Calegari (postdoc)	Harvard
Frank Calegari (PhD studies)	Berkeley
Emma Carberry (PhD studies)	Princeton
Dr S. McCue	U Nottingham UK
Dr A. Koerber	U Nottingham UK
Dr B. Maen Hautt	Open Uni UK
Dr B. Chan	ABN AMRO Bank Hong Kong
Dr Andrew George (PhD)	Edinburgh
Dr Monica Hurdal (PhD)	Florida
Dr Sarah Ratcliffe (Aust PhD)	Pennsylvania State
Dr James Murray (postdoc)	Leicester Uni, UK
Dr Jarrod Hurley (PhD in UK, now postdoc)	USA
Dr Robin Humble (postdoc)	CITA, Toronto
David Wong (PhD studies)	Uni of Texas
Dr Dorota Doherty	Houston

Comments added:

• We have sent our top honours undergraduates overseas to do a PhD almost every year now for ages. None have returned.

• We have also lost two exceptionally talented young researchers, not to other countries, but to industrial positions offering very much higher salaries, share options and significantly more positive prospects for the future than we can possibly offer them in Universities.

Australian Born New Researchers returning from Other Countries

Name	**From**
Dr Catherine Greenhill (ARC post-doc)	PhD and post-doc in UK
Dr Ben Andrews (ARC PDF)	Postdoc at Stanford
Dr Andrew Hassell, (ARC PDF)	PhD at MIT
Dr Gary Froyland	Postdoc in Germany
Dr Sarah Maddison	France
Dr Morwenna Griffiths	Reading UK
Dr Simon Clarke	London
Dr Duncan Farrow (post-doc)	Norwich
Dr Ross Taplin (PhD studies)	Washington

Comments added:

• The main problem is staff losses through "encouraged" retirement and not being given permission to recruit to replace them. Hence very limited opportunities in the university system for good young researchers or attracting expat Aussies back here. Our research students get good jobs in the finance sector, but are lost to the national research effort.

• In fact this is a great weakness of the Chief Scientists proposals - universities have destroyed a lot of the base of science … so it is pretty unlikely that having either more ARC funds or more post docs would attract such people back here.

New Researchers from Other Countries

Name	**From**
Janny Lindiarni (PhD study)	Indonesia
Dr Alankar Karol (Came as PhD student)	India— casual employment 2000
Mr Markus Voege (PhD study)	Germany
Mr Henry Wong (PhD study)	New Zealand
Dr Iwan Jensen (Post-Doc/ ARC Fellowship)	Denmark
Dr Christoph Richard (post-doc))	Germany, largely funded by Germany
Dr Ole Warnaaar (ARC Fellow)	Holland
William Joyce (Research Ass)	Univ. Canterbury
Tian Khoon Lim (PhD study)	Singapore
Sanming Zhou (PhD study, now post-doc)	PR China
Dr Sergey Suslov (new PhD graduate	Uni of Notre Dame, USA
Mr Kazimir Kolossovski (PhD study)	Russia
Mr Vladimir Gubernov (PhD study)	Russia
Mr Isaac Towers (PhD study)	New Zealand

Comments added:

*• We are still getting some overseas PhD students, notably from Russi*a.

• Our fee and university structure make it very difficult for us to attract the best people from overseas as research students. We cannot compete with the support available in the USA through their waiving of fees and the availability of Teaching Associate positions. I have repeatedly seen the best students from Asia, South Africa, and Europe RECRUITED to do PhD's in America. Providing high-level research training to overseas students should not be seen as way to raise revenue, but rather as a powerful device for establish strong links between Australia and the future leaders of business, industry and government in foreign countries. This is certainly how the United States has used it, and very effectively.

Concluding note

> "That these intellectual resources are now operating in an environment which is below world standards is beyond dispute: the entire scientific community is united behind the findings of this report that lay bare the dwindling investment in these national intellectual assets"[70]

> "The truly wonderful thing about the Olympic Games is that one can see that countries with dedication and strong leadership can achieve results far above expectations on the basis of wealth or population. Australia is a good example, with strong performances across the board, especially swimming. Other good examples include the Russian gymnasts, the Turkish weightlifters, the French cyclists and the Japanese judo wrestlers. These excellent efforts are achieved by building the culture of the activity, and supporting that with investment over the long term. We can do these things in sport, but we do them poorly in innovation and business. We are not doing enough with education and R&D. The positive results are evident in the Olympics, the negative results are evident in the long-term slide of the Australian dollar"[71]

There is something seriously amiss in a country when many of its best teachers and researchers in disciplines as important as the mathematical sciences are demoralised, disillusioned and depressed. This has many causes but to an insider the principal cause is fear for the discipline itself. No discipline will grow and prosper with the kind of loss of intellectual capital that is represented by the mathematical brain drain that has been documented here. Nor can Australia prosper while the mathematics education of its young is in the hands of an increasingly under-qualified cohort of teachers.

These issues should be of national concern—and addressed immediately—not after the next discussion paper, review, budget, election or the host of other excuses used in the last few years. This paper suggest some ways forward. Above all there needs to be a cohesive, collaborative approach to the inter-related difficulties that have to be faced. All universities need to be able to teach a three year sequence of mathematics well and all students at all levels deserve properly qualified teachers. There are a number of possible ways of approaching other areas but competition within Australia for scarce resources would be counterproductive.

The Australian Institute of Sport provides one useful model. This was established after Australia's poor performance at the Montreal Olympics and the investment in this has shown that when Australians put their minds to something they can achieve well above their weight. The notion of a flagship site with supporting centres of excellence has much to recommend it in other areas. This is essentially what the Australian Fields model is. If the ARC funding is doubled, the CRC guidelines relaxed and the federal and state governments put some money into mathematical awareness and the Australian Fields, industry will get the message and invest in the mathematical sciences. The big ticket item remains teacher supply and that is governments' responsibility.

Sport wins the hearts and minds of the Australian public. In 2000 we need a cultural change to valuing intellectual capital.

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[70] FASTS response to Chief Scientist's Report

[71] Personal communication