Teachers in touch

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There are two reasons why it might not be wise to talk of the difficulties in the education system in Australia as a crisis:

(1) As the Minister, Dr Nelson, has said, voters may not regard the kinds of problems that we have as a crisis. If this is true, calling the problems a crisis may alienate the electorate at a time when solutions of the problems will require at the very least acquiescence in changes of government policy and;

(2) Using emotive terms like “crisis” may prevent careful explanation of the exact nature of the problems, thereby preventing a reasonable and thorough discussion of possible solutions.

Reason 2 is for me the strongest one to move on from just proclaiming there is a crisis in university education. It is to be earnestly hoped that if we move from describing the problems as a crisis, the Government will maintain its commitment to seriously and consistently address the concrete problems that are raised.

Some years ago there was a national outcry when our medal tally at the Olympic Games fell below what was regarded as a respectable level. The Government at the time, to its credit, decided on a whole programme of action, involving commitment of large amounts of new public money for the Australian Institute of Sport as well as other reforms. The outcomes of the combined initiatives were clear to see at the last Olympic Games. It is a severe contrast to see, therefore, that the one outcome of the current review of higher education that seems to have been ruled out from the start is the investment of more public money.

The term investment is used carefully and in a broad sense: money that is sensibly invested in science and mathematics higher education will clearly yield strong economic returns for the country. Money that is invested in higher education in the humanities is argued to yield strong social returns for the country. The justification for the latter is not one that I will pursue, but I think the clearest justification for the former is the direct relationship between heavy investment in higher education in the US, Singapore, Ireland, Switzerland and Finland and subsequent startling economic returns in these countries from industries which rely heavily on innovation in science, mathematics and technology.

I think the message left by Rupert Murdoch and the Governor of the Reserve Bank for the Government is clear, and adding more to it by me is unlikely to change anything. Let me then, for the rest of the talk, largely leave behind the questions of funding that are dominating the debate in the press so far, and talk about some problems which *can* be resolved, even without more public or indeed private monetary investment.

Here then are some concrete problems:

(1) The percentage of students studying “enabling” sciences (physics, chemistry and biology) at Year 12 has declined across the nation. This has been clearly documented in the report Trends in Science Education from the Australian Council of Deans of Science. More recent data from the Victorian Board of Studies shows that the percentage of students doing the compulsory Year 12 English who also study physics in Year 12 has declined from about 19% in 1992 to 16% in 2001. In biology it has gone from about 28% to 23% and in Chemistry from about 20% to 17%. Since study of these is necessary to complete the traditional rigorous and fast moving science degree, it is little wonder that there has been downward pressure on numbers studying science at University. This is most clearly evident in the ENTER or UAI necessary to gain entry to courses: in 2002, it was easier to get into science at the University of Melbourne than primary teaching.

(2) There has been a worrying simultaneous trend to change the content and assessment practices in courses in fundamental sciences and mathematics.

At the beginning of the 90’s, the Mathematics courses in Victoria at Year 12 were changed in such a way that it became impossible for students to study in depth across the broad spectrum of mathematics that is necessary for study in Engineering and many Sciences at University. Additionally, assessment was changed so that a substantial proportion of the final mark was determined by completion of work at home in unsupervised conditions over a period of several weeks. Marks were determined by reference to criteria, despite the fact that it was clear that there was no way to ensure uniform adherence to the criteria across schools and even more across subjects. In 1992, only 30% of the Victorian community had faith in Year 12 and a survey conducted as part of a study by Sam Ball (later Chief Executive Office of the Board of Studies) and me showed that 57% of students at a leading Melbourne school admitted that they had obtained “undue assistance” in completing there take-home assessment. Many painful years of reform in Victoria have brought about a system now where the majority of these problems have been solved. However, a study by E. Catchpole and B. Anderson from the Australian Defence Academy[1], where students from NSW and Victoria mix, has questioned whether the standards in the top mathematics subjects achieved by students with equal entry scores are the same in the two states.

More worrying is that there are elements of the newly revised HSC in NSW which appear to replicate some of the problems in curriculum that were evident in Victoria ten years

[1] Catchpole, E.A. & Anderson, B.A. (1998). Comparing the performance of NSW and Victorian students in a first-year mathematics course (with discussion). *Austr. & N.Z. J. Stats.*, **40**, 901-918.

ago in the introduction of the VCE. Let me illustrate this in some detail with reference to Physics.

A colleague tells me that his son, a student talented in the top level of Mathematics, dropped Physics at Year 12 last year because the subject was not primarily about Physics, but was more about writing essays, admittedly related to Physics, but centred on history and social issues. The deciding factors for the Physics dropout were the following assessment tasks:

- (exam question at school) Write an essay about the benefits to society of fibre optics.
- (project at school) Think of a physicist and makeup a board game or a web page about his/her life.

This was not just a teething mistake by the school since the examination in Physics in NSW at the end of 2001 contained the following questions:

- Describe ONE way in which an understanding of crystal structure has impacted on science

- Discuss the effects of the development of electrical generators on society and the environment

- The Manhattan Project is the codename given to the development of atomic (nuclear fission) bombs during World War II. Discuss the significance of this project for society.

Some argue that society suffers because scientists don't learn enough about the effects of science on society. For example, Hurd(1984)[2] argues "the discipline-based science courses as they are now organised promote scientific illiteracy; students are unable to identify and reasonably interpret a science/technology-based personal or social problem".

The comprehensive report "The Status and Quality of Teaching and Learning of Science in Australian Schools"[3] says:

"Fundamental to the ideal picture is the belief that scientific literacy is a high priority for all citizens, helping them to be interested in, and understand the world around them, to engage in the discourses of and about science, to be sceptical and questioning of claims made by others about scientific matters, to be able to identify questions and draw evidence-based conclusions, and to make informed decisions about the environment and their own health and well-being. The ideal picture is described in nine themes:

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[2] Hurd, P. deH. (1984). Science education: The search for a new vision. *Educational Leadership, 4*1(4), 20-22.

[3]Goodrum, Hackling and Rennie (2001) The Status and Quality of Teaching and Learning of Science in Australian Schools, Research Report, DETYA No. 6623DRED00A

(1) The science curriculum is relevant to the needs, concerns and personal experiences of students.
(2) Teaching and learning of science is centred on inquiry. Students investigate, construct and test ideas and explanations about the natural world."

The disturbing aspect of this is that to some extent the report and its antecedents in the UK and US draw a distinction between science literacy and science. Points (1) and (2) above are the only parts of the "ideal picture" of science education which deal with science itself; the rest concern assessment, the teaching-learning environment, teachers, facilities, class sizes and the value placed on science and science education by the community.

Furthermore, the report says "There should be no conflict between the preparation of future scientists and the science education of all young people. In making science more relevant for young people it is reasonable to assume that it will also become more interesting for those who wish to pursue a career in science. It might be expected that more students would consider a science or technological career as the result of exciting and interesting science studies at school." By contrast and in my view more realistically, the report says "In his seminal essay of 1985, Fensham[4] provided an international analysis of the state of science education in the context of the contemporary slogan "Science for All". Simply, science education did not cater for all students because of the overwhelming focus on its role in providing training for the 20% of an age cohort from whom future scientists and science-related professionals would be drawn. Fensham (1985) acknowledged that the changes of the 1960s/1970s gave this group much better curricula. However, the other 80%, for whom society demanded a science education that would prepare "a more scientifically literate citizenry" (p. 417), were less well served. In fact, Fensham argued that these two demands on science education are conflicting rather than complementary. This tension remains in most countries in the world. The problem is that upper level science courses were designed to select and prepare students for further science study and have a heavy, discipline-based focus on science content. Fensham describes these courses as involving large amounts of content and abstract scientific principles with limited attention to their significance in a social sense. This approach frequently cascades down to lower secondary school, resulting in irrelevant, content-laden curricula which lack meaning and relevance to most of the students who study them. This apparent conflict can be resolved by maintaining a focus on scientific literacy during the compulsory years of schooling and providing a diversity of science courses to cater for the different needs of different students in the post-compulsory years."

However, in seeking to overcome problems of the connection of science, society and the educational needs of the vast majority of students, diversity in science courses at the end of school is essential. Students who are preparing for tertiary courses in Science and Engineering do need a "heavy discipline-based focus on science content", as Fensham states.

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[4] Fensham, P. J. (1985). Science for all: A reflective essay. *Journal of Curriculum Studies, 17,* 415-435.

At the same time, those with more general interests should have the opportunity to pursue courses which have a scientific focus but also link science to more general science considerations. It is pleasing to see in this connection that NSW HSC has a a very interesting subject called Earth and Environment which looks just at such issues, as well as arguably doing as much science as there is in the new Physics course.

However, it is not a good idea to solve the problems of the 80% by ensuring no-one learns physics adequately. Teachers from a leading Sydney school uniformly report that it consumes much time having to train students to give answers which will score high marks to the above questions in the NSW Physics examinations, and this time comes at the high cost that it is no longer possible to adequately teach physics (in their view). And by adequately, I mean not the much higher standards that are demanded in A-levels of Singapore or the International Baccalaureate higher level physics, but just at the standard that has been traditional in Australian Year 12 physics.

Anecdotally, another motivation for including the social issues was to increase participation in physics at Year 12. This is risky because students talented in science and mathematics will not be studying the subjects where their talent lies, and students talented in humanities may prefer to stick with subjects like history rather than switch to a humanities oriented physics course.

Worrying again is that the introduction of criterion referenced assessment in NSW HSC has caused problems for schools and students in ensuring comparability of standards, albeit not of the magnitude experienced in Victoria.

(3) The products of the kind of education I have just talked about are less ready to tackle rigorous mathematics and fundamental sciences at University. This is a big problem because the economy of this century, especially in biotechnology, will require many people able to understand mathematics, physics, computer science, molecular biology, chemistry, biochemistry, zoology and botany at a high level. Furthermore, successful countries in the new economy will require many people able to contribute solutions to real problems using these and many other disciplines.

An emerging subject where this is already evident is bioinformatics. Bioinformatics will be a key contributor to biotechnology as it uses statistical methodology, computer science, biochemistry and molecular biology to unravel practically useful information from the vast databases of low-level information about genomes of humans and other species. Only a few practitioners in bioinformatics will have a good understanding of all the disciplines involved in the subject, but all will need some University level acquaintance with their application in bioinformatics and all will need a specialised, often postgraduate level, understanding of at least one. Furthermore, such scientists and those associated with them in the rapidly emerging companies, will need the ability to communicate scientifically, that is they will need a level of familiarity with science and mathematics that makes the acquisition of new knowledge straightforward.

Degrading the level of mathematics and fundamental science at Year 12 is going in the opposite direction to that needed for a country which wants to participate and succeed in the new economies of the twenty-first century.

(4) In the United States there has been a radical movement of prominent mathematicians at University to try to arrest problems similar problems. These are not entirely new problems – that wonderful comic and former professional mathematician Tom Lehrer wrote in his song New Math in 1965:

"So you've got thirteen
And you take away seven,
And that leaves five...
...Well, six actually
But the idea is the important thing"

A lot of the controversy is summarised well in the Wall Street Journal[5] :

"… many folks in the education world are hawking yet another reform. It is known by names like "Connected Math," or "Everyday Math … it focuses on concepts and theory, scorning textbooks and pencil-and-paper computation as "rote drill." … Eight of the 10 curriculums recently recommended for nationwide use by an influential Education Department panel teach the New New Math. …

Consider MathLand, which won a "promising" rating from the panel. Its literature says it focuses on "attention to conceptual understanding, communication, reasoning and problem solving." This sounds harmless, but consider: MathLand does not teach standard arithmetic operations. No carrying and borrowing at the blackboard here. Instead, children are supposed to meet in small groups and invent their own ways to add, subtract, multiply and divide. This detour is necessary, the handbook informs, to spare youngsters the awful subjugation of "teacher-imposed rules."

Next comes Connected Math, another panel favorite. It too skips or glosses over crucial skills. Example: The division of fractions, an immutable prerequisite for algebra, is absent from its middle-school curriculum. In shutting the door to algebra, David Klein of Cal State Northridge points out, "Connected Math also closes doors to careers in engineering and science for its graduates."

Finally there is Everyday Math. No textbooks here, either. Everyday Math ensures juvenile dependency to calculators by endorsing their use from kindergarten. Rather than teach long division, the program devotes substantial time to that important area of math study, self-esteem. A Grade 5 worksheet asks students to fill in the blanks on the questions below:

A. If math were a color, it would be_____, because____.

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[5] Wall Street Journal, Editorial, January 4 2000:

B. If it were a food, it would_______, because_____.

C. If it were weather, it would be_______, because, ______.

We'll allow a pause here for primal screams. ..."

And then move on to the main question: Why? The reason for the New New Math, as for many other curriculum reforms, is that teachers, school administrators and their unions are tired of being blamed for statistical declines and poor student performances. …"

Curricula and assessment in the United States have been subject to quite local control at school. Mutually aggressive controversy (the common name for the controversy is the "math wars") has developed between teachers and academics about appropriate curricula and assessment methods with varying results across the country.

In California, prominent mathematicians, including H-H Wu, of the University of California, Berkeley, have become deeply involved in attempts to reform the mathematics curriculum and assessment and particularly the preparation of teachers. In a paper[6] from last year Wu says "the most urgent need of mathematics teachers (in California) was content knowledge rather than new pedagogical techniques or clever classroom projects. Teachers needed systematic exposition on the basic topics of whole number algorithms, fractions, and area and volume formulas". Fortunately, the math wars have lead for people like Wu to a deep involvement in mathematical education at primary and secondary levels and such involvement is the seed for resolving the conflicts to the mutual benefit of students, teachers, mathematicians and society at large.

What is needed therefore in Australia is cooperation between teachers and those who understand the subjects they teach very deeply. Deep understanding is mostly achieved as a result of active research in a discipline or allied disciplines. It thus falls to those who are or have been active researchers to participate actively in the development of curricula and assessment practices, just as it falls to teachers and those in Education Faculties to be receptive to the active involvement of those who understand the disciplines very deeply.

A related major problem is the widespread perception in Australia that you can teach without having a major in the discipline. Many of those teaching Science and Mathematics in Year 12 have done degrees in Education rather than having a Science degree followed by a teaching qualification. Thus some teachers, and some of those that are involved in their training in Education Faculties or Education Departments, are actively hostile to Wu's notion that curriculum content is at least as important techniques in teaching. Indeed, some have actively supported curricula, such as that in NSW Physics, which seem determined to have as little of the content of discipline as is possible. Such notions are antithetical to the ideas of exciting students to study so that

[6] http://math.berkeley.edu/~wu/pspd4a.pdf

they can be involved in creating and using new knowledge to advance Australia socially and economically in the 21st century.

(5) As a result of the problems described in (4), many teachers in Australia are not familiar with the rapid advances in science and mathematics. For example, in the best case, a teacher might have a first class honours degree in mathematics from the 1970s and now be the Head of mathematics in a major school. When that teacher studied mathematical statistics as part of second or third year, electronic calculators had just been introduced. They had two memories. Calculating the standard deviation of a set of numbers was a major exercise, and contemplating tasks that Excel would do in the flash of an eye was daunting or impossible. The impact of computers on mathematics has thus been profound.

Interestingly, statistics is an area of mathematics that is greatly favoured by proponents of the New New Math in the United States and in many recent curricula in Australia. Unfortunately, however, there are virtually no teachers who have had recent exposure to the way in which computing has changed the nature of statistical methodology in the last twenty years. Such exposure would not change the basic and rigorous work on probability theory that our first class honours graduate of the 1970s would lay proper emphasis on for her students in Years 11 and 12. The exposure would however enormously expand the range and relationships to reality of the problems that students can be expected to solve, as well as the computational methods for obtaining exact or approximate numbers as answers. There are matters of balance in introduction of the old and the new, but those without recent experience of developments in their disciplines run the danger that their emphasis is outdated and their ability to excite students limited.

(6) Content in recent curricula and assessment in Australia is often not ideal given the problems mentioned in sections (4) and (5). The old saying “a little knowledge is a dangerous thing” has a great deal of force.

An anecdote illustrates this. A question on a Year 5 state-wide test in mathematics in Victoria said that a coin was tossed 5 times and each time came up heads. Students were asked if the coin was tossed again whether it was:

A. more likely than not to be heads
B. less likely than not to be heads or
C. equally likely to be heads or tails.

The Year 5 students were not told whether or not there was bias towards heads or tails in the coin or in the way the coin was being thrown.

The setters of the question expected the answer C because they assumed that all coins and coin-throwers are exactly fair, and that coins and coin-throwers have no memory of the past at the stage that the chance of heads on the next is assessed.

Unfortunately, however, the science of statistics, on which this question was nominally based, has one absolutely fundamental premise and that is "Everything *varies*!!!". So the idea, albeit an interesting mathematical special case, that all coins and all throwers of coins will produce a chance of heads of exactly $\frac{1}{2}$, regardless of the past, is not one that has a relationship to the science of statistics.

To make matters worse, if we allow for the idea that coins and coin-throwers *vary* in the chance of heads, albeit around an *average* chance of heads of $\frac{1}{2}$, but still assume that coins and coin-throwers have no memory of the past at the stage that the chance of heads on the next throw is assessed, Appendix A rigorously demonstrates that answer A is actually the correct answer, save in the exceptional and unrealistic world where all coins and all coin-throwers on all occasions throw with a chance of heads of exactly $\frac{1}{2}$!

This fact is a particularly acute irony. Proponents of answer C think that in marking answer A wrong they are *correcting* the naïve idea that "The more you get heads the more likely you are to get in the future". The opposite is true. The quoted argument is actually much more correct than is answer C, in that applies to many more models than does answer C.

Proponents of this question and of answer C would argue that it is important to educate very young students about chance and its consequences in the world. Posing questions like this one is actually doing the opposite: it gives students bad ideas about chance, bad ideas about the essentials of statistical models, bad ideas about mathematical modelling in general and, worst of all, it leads later to resistance against learning about better ways of thinking. This resistance has been observed repeatedly by me in first year university students who have been educated at school to think that probability is a subject where all that is required is to write down the answer.

The demonstration that A is almost always the correct answer – perhaps in accord with "common" sense – is not a simple matter. It involves sophisticated ideas from probability theory and the use of mathematical proof: see Appendix A.

(7) Appendix A is included to illustrate the power of rigour in mathematics for solving real-world problems. Some in Australia argue that this power is too difficult for any school students in Australia today. This power, however, is a mark of the internationally-competitive education for talented students that countries like Singapore produce. The reasoning in Singapore is that the hard edge of information technology still uses precisely this kind of logic and power to produce economically-competitive products. Furthermore, Appendix A is also *intended* to illustrate that, far from being a mass of symbols and equations, good communication of mathematics requires many more words and minimises symbols.

Another anecdote illustrates the difference between Singapore and Australia. A colleague went to Singapore to work on academic exchange for 3 months. His daughter was in

Year 10, but was sufficiently talented in mathematics that she had completed Year 11 mathematics in Victoria before going to Singapore. She scored at the top in Year 11 mathematics in her school, not only of those doing Year 11 mathematics in Year 10, but also those doing it in Year 11. However, because of timetabling difficulties to do with Year 10 examinations in Singapore, the daughter was placed in Year 9 in Singapore. In her first mathematics lesson, there was a test and the daughter returned home in tears, saying that she could not do the first question on the test. The first question on the test required students to prove a statement in algebra and then to use this statement and logic to deduce statements about the solutions to an algebraic equation as the highest power in the equation varied. Such a question would be outlawed as too difficult for any students in Australia, but 90% of the Singapore class were able to complete the question. Rightly so in the case of Australia, because on checking back with the teachers of the former Year 11 mathematics student of an exclusive private school, the colleague found that none of the teachers could do the first question on the Singapore year 9 mathematics either. No quick fix will make Australia internationally-competitive in this economically vital way.

On the other hand, Australia does very well in the International Mathematical Olympiad and also does very well in the International Science Olympiads. These Olympiads require high degrees of content knowledge in science and mathematics, as well as an extraordinary ability to reason in the rigorous way that the Singapore Year 9 test demanded in question 1 above. The resolution to this apparent conflict is that Australia has a very good system for identifying those who might be competitive in the top 100 students in the world, and provides for this tiny group of students, on a voluntary basis by university staff, a curriculum and training that produces amazingly competitive students.

However, there are worrying signs that we will shortly be unable to compete in this arena of stars either. The *top* student in one state in the qualifying test to enter the training for one science's Olympiad team came 78th in the nation, indicating that all students in this state were way behind the national, let alone international, standard (this state is, however, argued to be a model for "scientific literacy"). What is much more worrying for the education system in this science in this state is that this student DID NOT study this science in this state, realising that it would be much better to take the international recommended textbook and study from this by herself.

The performance of our second, third, fourth, … level athletes does not worry the Australian public as much as our ability to get medals at the Olympic Games – of course, the existence of the medallists indicates that the second, third, fourth level work is going well. However, in science and mathematics the situation is different – more Nobel laureates in Australia would be a great thing for the nation, but it is the scientific entrepreneurs who will make the real difference in the country's economic future.

Contrary to many views in Australia, creative scientific entrepeneurs people do need to be more than adequate in science as well as creative entrepreneurs. Bill Gates was a very talented student before he became the creator of the Microsoft Empire. The performance of our second, third, fourth, … students in science and mathematics *should* worry the

Australian public a great deal because our economic future is bound up with the international competitiveness of the skills and knowledge of some people in this group. It is this group that is being excluded in current debate at the expense of the 80% to whom Fensham referred. Providing properly for the top 5% or 10% in science and mathematics is surely economically affordable because, as nations like Singapore have already proved, the returns from special education for this group will be thousands of percent on modest investments.

If you are concerned about the elitist tendencies in the statements above, consider the following:

(1) No-one in Australia seems concerned about elitism in relation to sport.
(2) Elitism in relation to the tiny, tiny minority participating in Mathematics and Science Olympiads raises no questions – why should this group raise no problems, when catering for a slightly larger one will contribute greatly to the economic and educational health of the whole country in the future.

(8) In Australia, there is a distressing tendency to say that some areas or approaches are too hard for students.

A prime example of this was the disappearance of Euclidean geometry from all mathematics syllabi in Australia from the 60's to today. This disappearance was universally "justified" by the fact that a relatively small proportion (say 5% or 10%) of students became comfortable and proficient in this subject. On the other hand, Euclidean geometry is an outstanding introduction to the power of modern mathematics because, from a very modest set of axioms, the 5% or 10% of students can see hard work in logic producing an enormous array of practically applicable results. Moreover, Euclidean geometry and the Lemma in the Appendix A share a vital common feature: they both use the power of construction to simplify and explain otherwise mathematically obscure ideas.

Many in the professional mathematical community would argue that the disappearance of proofs, construction and rigour in mathematics will produce quantifiable economic loss in the country. Whilst Bill Gates may not have completed the University mathematics degree he started at the time that he was producing the first version of MSDOS, he had just finished enjoying and learning from the kind of secondary and lower-tertiary mathematics education from which we are excluding Australian students today.

This problem is not unique to Australia. The Wall Street Journal[7] discusses the corresponding problems in the US and says "New Mathie and federal panel member Steven Leinwand explains: "It's time to recognize that, for many students, real mathematical power, on the one hand, and facility with multidigit, pencil-and-paper computational algorithms, on the other, are mutually exclusive." Or, as Professor Klein translates: "Underlying their

[7] Wall Street Journal, Editorial, January 4 2000

programs is an assumption that minorities and women are too dumb to learn real mathematics." …"

As an extreme example of this kind of "dumbing-down", a New South Wales draft of a revised curriculum has declared that it is too difficult for mathematics students in Year 10 to understand that squares are a special kind of rectangle in which the sides all have equal length. Instead, it is apparently pedagogically more acceptable for students to learn that squares and rectangles are mutually exclusive shapes the latter being quadrilaterals that have the property that all included angles are right-angles but in which adjacent sides have different lengths. Interestingly, the same colleague that went to Singapore reported that his *two* year old daughter understands exactly the idea that a square is a particular kind of rectangle in which the length of all sides is the same.

(9) Another worrying trend in science and mathematics is the exodus of the very best tertiary level staff to other countries. Salaries in the US, Britain and Europe are typically several times the salaries in Australia. Even more worrying is that gross salaries achieved by the best researchers here when they relocate to leading Asian centres like Hong Kong and Singapore are typically 3 to 5 times those in Australia and even larger multiple when our relatively high tax is taken into account. Data on the exodus on many of the very best of our tertiary mathematics staff is contained in the FASTS report by Jan Thomas (this report is just being revised and updated so look on the web site for the most recent version).[8]

The common theme of the apparently diverse problems raised is an unfortunate, possibly unintended, side-consequence of high-participation rate in education in Australia in Years 11 and 12 (the participation being over 70% in Victoria for example). This new larger group in Years 11 and 12 has lead to new syllabi in science and mathematics which are argued to cater for this larger group (and not just at Years 11 and 12 but also lower in secondary schools), but do so sometimes at the expense of maintaining the traditional levels of deep content knowledge and rigour.

Many regard the diminution of knowledge and rigour as inevitable. They do this because teachers and schools can be wrongly blamed for poor performance of students when those students are unable to cope with a strongly academically oriented curriculum. To quote the New Wall Street Journal further[9]: "The reason for the New New Math, as for many other curriculum reforms, is that teachers, school administrators and their unions are tired of being blamed for statistical declines and poor student performances. …"

(10) Australian higher education has had 38 percent more enrolments in undergraduate degrees from 1990 to 2001[10]. This was on top of a 48 percent increase in total enrolments from 1980 to 1990.[11] The years from 1980 to 2001 have seen higher education move from

[8] http://www.fasts.org/site/policy/occasionalpapers/Lookingfor_future.pdf

[9] Wall Street Journal, Editorial, January 4 2000

[10] Higher Education at the Crossroads, Department of Education Science and Training, Table

[11] Education, Training and Employment Programs, 1970-2001: Funding and Participation, National Board of Employment, Education and Training, 1992, Commissioned Report No. 11, p. 36

catering for a small proportion of each age group to a large percentage. As far as preparation of undergraduates in the most rigorous science and mathematics, at best this has meant that an equivalent standard has been maintained at the same time that class sizes have grown dramatically. At worst, standards of degrees may have changed to accommodate this much larger cohort with a much larger range of academic achievements and aspirations.

There are four major efforts that are needed to address the problems identified:

(A) We need to give students appropriate encouragement to specialize more, not less, in universities. This way more talented students may obtain a rigorous scientific education that will equip them not only to contribute to jobs of many descriptions right now, but will give them the background so that as knowledge, skills and concepts change they will easily be able to adapt. Australia seems to be on the end of the spectrum in assuming that those with degrees in Commerce or Law and Arts are equipped to contribute across a broad range of jobs, but those with degrees in Science are technical nerds – implicit is the idea, perhaps unknown outside Australia, that knowledge gets in the way of making important decisions. This is not to say that those with specialist knowledge in Science are superior to all those without that knowledge, but rather to argue that *some* of those with specialist knowledge in Science should be those charged with *a significant role in* important decisions in society. Sometimes an argument appears that disciplinary background is unimportant except that those with backgrounds in Science are too narrow to be useful.

Such an argument is not one that receives acceptance outside Australia, but this notion appears all too often from those in positions of power who do not have knowledge in Science. also to ensure that all science and mathematics teachers at upper secondary *all* get elements of their university education which expose them to rigour in patterns of thought and the latest developments in knowledge and techniques for problem solution in science and mathematics. The experience of Wu[12] and many others in the US suggests that we will solve the problems of enabling students to succeed in science and mathematics, regardless of the varied backgrounds from which they come, only when all students are exposed to teachers who enthuse in primary school about science and mathematics and understand these subjects at a deep level.

The growing trend for high-achieving students to study degrees or combined degrees that involve 4 or more years study means that fewer of them are taking general degrees followed by an honours year. Many of these students are attracted to the combined degree programs by their status which in turn hinges on the difficulty of entry – the latter is demonstrated by James, Baldwin and McInnis[13] who say "course entry scores, and by implication 'university scores', serve as a proxy for quality in prospective students' eyes".

[12] http://math.berkeley.edu/~wu/pspd3d.pdf

[13] Which University? The Factors Influencing the Choices of Prospective Undergraduates, Report No. 99/3, Evaluations and Investigations Programme Higher Education, Division Department of Education, Training and Youth Affairs, 1999, Executive Summary.

On the other hand, James, Baldwin and McInnis[4] also report "Science applicants are characterised by the emphasis they attach to an institution's research reputation and the opportunities for higher degree study".

Scientists and mathematicians in universities around the country need to exercise their best skills in creative imagination to make science and mathematics as alluring as are combined degrees. Somehow they must leap from a vicious cycle of entry standards declining leading to reduced demand because of perceived lower quality and attractiveness leading to further declining entry standards … to a virtuous cycle in which entry standards are raised so the students are better able to cope with more challenging and interesting material so students have a better experience so demand rises so entry standards can rise again … . It is remarkable the effect that this virtuous cycle has had on courses in Law and Medicine, especially when graduates will often say how poor careers in Law and Medicine *can* actually be (GPs appear to occupy much air time saying that it is impossible to make a reasonable living as a GP and there are more people doing Law degrees than there are practising Law).

(B) Fundamental to improvement for science and mathematics education at tertiary and secondary level is a new spirit of cooperation between tertiary academics in science and mathematics, tertiary academics in science and mathematics education and secondary teachers. Academics need to devote time to this[14]; teachers must drop prejudice.

(C) A healthy and educated society, leading in advanced scientific and technological economy, demands a good supply of high-achieving PhD graduates. These graduates are in the best position both to make the breakthroughs that change the economy or society and to ensure transmission of knowledge, skills and understanding to the next generation. Economically and socially advanced societies around the world recognise this. They invest not only in PhD degrees but also in the preparation of students for their PhD research - in the United States, PhD candidates spend several years in advanced coursework before they commence their research projects.

Completing a PhD requires a "substantial original contribution to knowledge in the form of new knowledge or significant and original adaptation, application and interpretation of existing knowledge."[15] Knowledge is becoming more fragmented in its rapid evolution. Original contributions increasingly involve combinations of several disciplines. Coming to the leading-edge of knowledge in each discipline is becoming more time-consuming and difficult. Hence, the cognitive and creative requirements to complete an outstanding PhD thesis are increasing rather than decreasing.

It is in Australia's interests to ensure that a healthy proportion of the most outstanding school leavers is attracted to courses which will prepare them optimally should they choose

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[14] http://math.berkeley.edu/~wu/reform3.pdf

[15] Australian Qualifications Framework: Implementation Handbook, 3rd Edition, Australian Qualifications Advisory Board, 2002, p. 9.

to undertake a PhD. Although absolute numbers of PhD students have increased in Australia, it is not clear that as many of the outstanding school leavers are being attracted to the degree and it is even less clear that undergraduate degrees are meeting the necessary increased requirements for cognitive and creative development.

As mentioned above, James, Baldwin and McInnis[4] report “Science applicants are characterised by the emphasis they attach to an institution’s research reputation and the opportunities for higher degree study”. There is thus an opportunity to fill a gap in Science by introducing a new degree which is much more specifically designed to provide excellent preparation for research. Such a degree needs at the same time to give graduates all of the standard skills in Science as well as the standard generic skills, such as those in oral and written communication, teamwork and problem solving. Such a degree should naturally lead its graduates to PhD programs if they want to pursue them.

The Australian National University Act specifies that the University is to “encourage, and provide facilities, for post-graduate research and study, both generally and in relation to subjects of national importance”. There is thus a particular requirement for the University to provide a focussed preparation for post-graduate research in a new undergraduate degree. The Education Committee at the ANU has decided to approve a new Bachelor of Philosophy (Honours) as a further step for the University in fulfilling this requirement. The presence of the Institute of Advanced Studies and the Faculties means that the Australian National University is best able in Australia to undertake the ambitious task of introducing such a research focussed undergraduate degree.

Given that most Australians study in their home region (which for only about 1% of them is close to the ANU) many of the extremely able students choose to study at institutions other than the Australian National University. The situation is now changing with many gifted students prepared to travel from their home states (not all of them with scholarships) and a number of institutions (for example Monash, UNSW and Sydney) already offer advanced science degrees (with national entry scores being required to be in the 90s).

The title of the degree, Bachelor of Philosophy (Honours) has been chosen because the word philosophy comes from Greek roots literally meaning a liking of wisdom and equally because the Oxford English dictionary gives one of its meanings as “advanced learning in general”. To ensure that there is no confusion with study of the discipline of Philosophy, each degree will have the name of the Honours discipline or the name of the Faculty recorded on the student’s transcript. A big advantage of the name of the degree is that it will emphasise the connection with the PhD and the abbreviation of the degree to PhB(Hons.) will further emphasise the connection.

In the PhB(Hons.), every student will have an individual academic supervisor from the beginning, and every student will complete three-quarters of a year of advanced studies courses during the equivalent of the first three years. It is perhaps impossible for any other university in Australia to provide a degree with such intensive individual attention as is the centrepiece of the PhB(Hons.) – natural comparator degrees overseas are at Oxford and Cambridge where students receive attention in small groups from leading researchers. Indeed, students in this programme may be as likely to receive individual tuition from a

Fellow of the Royal Society (the leading honour for a scientist in the UK) as would an undergraduate at Cambridge or Oxford since there are 35 such Fellows at the ANU. There will be a strict quota in this program whereas at Oxford or Cambridge there is an intake of thousands.

The three-quarters of a year of advanced studies are described as follows:

"These courses are taken under the direction of the academic supervisor of a student in the PhB(Hons.), but may involve teaching and learning from a very wide variety of sources. The program of study and/or research is approved by the relevant Head of Department or School on the recommendation of the academic supervisor of the student. The sources include but are not limited to:

- Involvement in current research at the University or CSIRO
- Special research projects from both the Faculties and the Research Schools of the ANU
- Special lecture courses
- Reading courses/ literature surveys
- Specially designed courses of field work or laboratory work
- Development of problems for competitions like the Australian Mathematics Competition
- A programme designed in conjunction with one of the organisations for Australia's teams in the Science and Mathematics Olympiads
- A programme of mentoring for other students, for example in a college, provided that the program involves both production, for example on the web, and delivery of teaching materials
- Talks to Year 12 and other students in the University
- Web page development
- Seminars to staff and students

Assessment:
Written details of the assessment are approved by the Head of Department or School on the recommendation of the academic supervisor and given in writing to the student at the start of the period of study for the course.

Duration and timing:
Advanced studies courses are available at any time of year, as agreed with the academic supervisor, and will last for a time which is agreed with the academic supervisor."

(D) The Faculty of Science, in collaboration with science-based Research Schools, at the Australian National University proposes to establish a degree program at Masters level aimed at practising science teachers in high schools and colleges, and others in the field of science education. This program was prepared by the Deputy Dean in the Faculty of

Science and I quote from the document prepared by him “The objectives of this program would be to attract such people back into the university environment to:

- refresh and increase their knowledge base in their own and cognate discipline areas through on-line learning experiences designed to present state-of-the-art progress in the several disciplines of science; and
- expose them to the rapid evolution of scientific discover by providing them with the opportunity of becoming actively engaged, if only in a time-limited fashion, with cutting-edge research either within the Faculty or other parts of the University.

We plan for the program to:

- be modularised to ensure the best fit between student needs and the availability of discipline-based course material, and to allow the program to be taken over a flexible time span;
- be taken on-line, so far as possible, to further facilitate flexibility and provide learning opportunities for students outside the ACT; and
- effectively integrate the research and teaching strengths both of the Faculty and the University’s science-based Research Schools, and in doing this, to ensure that students come face to face with the most up to date science possible.

As a final outcome for science teachers and others undertaking the program, the Faculty of Science would aim to significantly enhance levels of contemporary knowledge in their immediate or cognate discipline areas, present this material in a way which can be easily translated to science teaching in high schools and colleges, and renew and enhance enthusiasm for science through close interaction with scientists at the ANU who are creating that knowledge.

In determining the specific nature and content of discipline based units the Faculty will look both to the breadth and strength of scientific activity within the University and to recent government decisions on national research funding priorities. Most importantly, however, we would want to be closely guided by the needs of potential consumers of the program. We would intend, therefore, to actively seek consultations with education departments in the ACT and elsewhere, to look at existing curriculum structures along with both immediate and projected needs, and to talk with science teachers themselves. A recent summer school for science teachers hosted by the ANU highlighted enthusiasm for a program such as the one proposed and raised areas of particular interest which might be among those covered in the program (astronomy and astrophysics, genetics - perhaps spurred by the human genome project, and photonics and optics all rated highly).”

I remain an optimist. Australia has a proud record of contributing to Science and Mathematics worldwide at a level way above our population size[16]. However, the problems indicated here with curricula, assessment and expectations of students, as well as trends for students to study in areas other than Science and Mathematics are serious ones. Australia's scientists and mathematicians will need to devote more attention to these problems to assist in the solution – and they must do this in collaboration with educators both at secondary and tertiary level.

[16] "Measured against accepted international standards, Australia's research activity displays many significant strengths. Its share of world knowledge production, as a proportion of world output of scientific publications over the period 1993-97, is some 2.7 per cent[22]—an impressive achievement, relative to a share of world trade of about 1 per cent.[23] The research output of Australia's universities specifically is also well regarded internationally,[24] despite some recent indication of a decline in citations of Australian scientific research.[25] A recent evaluation study found that 61 per cent of research funded under the Commonwealth's Large Grants Scheme—the principal source of competitive funding for university research—is considered to be at the forefront of international research in its field. A further 24 per cent was found to produce outcomes of high quality which are likely to exert an influence internationally."
http://www.dest.gov.au/archive/highered/otherpub/greenpaper/chapt1.htm, Section 1.32

Appendix A - A statewide Year 5 test question

A coin was tossed 5 times and each time came up heads. Students were asked if the coin was tossed again whether it was:

D. more likely than not to be Heads
E. less likely than not to be Heads or
F. equally likely to be Heads or Tails.

Lemma. If f and g are either both strictly increasing or both strictly decreasing functions from reals to reals and p is an integrable random variable, then

$$E\big(f(p)g(p)\big) \geq E\big(f(p)\big)E\big(g(p)\big) \tag{1}$$

with equality if, and only if, p is deterministic.

Proof. Let r be an independent random variable with the same distribution as p (such a random variable can always be constructed, if necessary by enlarging the probability space[17]). Because f and g are both strictly increasing or both strictly decreasing, the signs of both terms in the product on the left of (2) are the same (for each outcome in the probability space) and so

$$\big(f(p)-f(r)\big)\times\big(g(p)-g(r)\big) \geq 0 \tag{2}$$

and equality occurs if, and only if, p = r. Now p = r with probability one if, and only if, p is deterministic[18]. Hence

$$E\Big(\big(f(p)-f(r)\big)\times\big(g(p)-g(r)\big)\Big) \geq 0 \qquad (3),$$

with equality if, and only if, p is deterministic[19]. But[20]

$$E\Big(\big(f(p)-f(r)\big)\times\big(g(p)-g(r)\big)\Big) = 2\Big(E\big(f(p)g(p)\big)-E\big(f(p)\big)E\big(g(p)\big)\Big). \tag{4}$$

The result follows by combining equations combining equation (4) with inequality (3) and the condition for equality after it.

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[17] Billingsley, P.(1979) *Probability and Measure* John Wiley and Sons, 2nd Edition, p.228

[18] Suppose X is non-deterministic and B is a Borel set with $0 < P(X \in B) < 1$. Then
$P(X=Y) \leq P(X \in B \cap Y \in B) + P(X \in B^c \cap Y \in B^c) = P(X \in B)P(Y \in B) + P(X \in B^c)P(Y \in B^c) < 1.$

[19] The condition for equality follows from the previous two sentences and Billingsley, P.(1979) *Probability and Measure* John Wiley and Sons, 2nd Edition, Theorem 15.2, p.174.

[20] Billingsley, P.(1979) *Probability and Measure* John Wiley and Sons, 2nd Edition, p.177 and p.241.

To apply the Lemma to the coin tossing example, let $f(x) = x$ and $g(x) = x^5$ and let p be the random variable giving the probability of heads for the particular coin and coin-thrower (assumed to be random selections from all possible coins and throwers). The combination of lack of a concrete statement in the question about bias of the coin and the history of coin-tossing documented, for example in Feller[21], leads to the requirement that $E(p) = \frac{1}{2}$.

Furthermore, problems in the practicality of controlling the chance of heads from one toss to another lead to the reasonable model that, given p, each coin should land heads with probability p independently of all other coins. Using the definition of conditional probability, using a fundamental property of conditioning[22], invoking conditional independence of the results of successive tosses and applying the Lemma at the inequality step, we obtain

$$\begin{aligned}
&P(\text{heads on 6th toss} \mid \text{heads on first five tosses}) \\
&= \frac{P(6\,\text{heads in a row})}{P(5\,\text{heads in a row})} \\
&= \frac{E(P(6\,\text{heads in a row} \mid p))}{E(P(5\,\text{heads in a row} \mid p))} \\
&= \frac{E(p^6)}{E(p^5)} \\
&\geq E(p) = \frac{1}{2},
\end{aligned}$$

with the inequality being equality if, and only if, p is deterministically $\frac{1}{2}$.

[21] Feller, W.
[22] Billingsley, P.(1979) *Probability and Measure* John Wiley and Sons, 2nd Edition, p.177 and p.241.