Points for Consideration by National Strategic Review

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1. First, a point of methodology for the panel to consider. An economist friend once made the point that economists explain observed behaviour in terms of incentives explicit or implicit in existing structures. Therefore if the panel is considering strategies to change behaviours (e.g. encourage interactions with other disciplines), it might consider why that isn't occuring now and what incentives would need to be in place to make it happen.

2. While at DSTO I have sat on many recruitment panels and I currently chair the panel responsible for that component of DSTO's postgraduate education program with the greatest mathematical content. This experience has given me a strong interest in the quality of post-graduate degrees in mathematics, and also in the extent that graduates in related disciplines (in particular electrical engineering) are receiving essential mathematical training as part of their higher degrees.

    a. The existing structure of the mathematics PhD in Australia has several major deficiencies

        i. In the face of rapid and inexorable expansion in the knowledge base, the PhD structure has stayed unchanged for almost a century. Three years are now no longer enough for a candidate to both do serious innovative research while at the same time getting a solid grounding in the range of existing material (e.g. numerical techniques) that needs to be known to conduct such research effectively.

        ii. The current structure makes no provision for organised coursework as in the US model, nor does the community provide it. This is a particularly pressing problem in light of the steady decline in the size and breadth of final year honours courses, the traditional source of such training. In my view the maths community <u>must</u> collaborate on a national basis to set up summer schools or similar mechanisms to provide such training: if this is not done, Australian PhD's will decline into irrelevance.[1]

        iii. Centred as it is on a student and supervisor, the current structure does not encourage cross-disciplinary interactions or large projects. As a result, mathematicians are not used to working in anything but small, loose collaborations: in my experience mathematics graduates arriving in DSTO are woefully under-prepared for conducting research within a large organization. In contrast the applied disciplines often group their graduate

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[1] In a recent visit Rodney Brooks, professor of robotics at MIT and originally a graduate of Flinders, made remarks to the effect that Australian PhD's were no longer considered to be on a par with US ones: MIT would hire fresh US PhD's, but would not consider hiring an Australian PhD until he or she had a few years further post-doctoral experience.

students into teams during their graduate degrees, giving students some experience in these issues.

3. In general the mathematics community in Australia has not reached a consensus on how to provide related disciplines with essential mathematics courses, especially at post-graduate level. Mathematics is the language of discourse for any quantitative discipline, yet in my experience PhD candidates in these areas often spend significant amounts of time re-inventing well-known mathematical wheels.[2] Moreover they come on to the job market in the dangerous situation of being nominally qualified researchers who not only don't know what they should know, but don't even know they need to know it.

    a. It is a sad comment on our inability to learn at the community level that, after almost half a century of modern university structures, mathematics and engineering departments are still to agree on the best way of providing mathematics education to engineers.

4. The Masters of Signal and Information Processing (MSIP), set up by the (unfortunately now defunct) Cooperative Research Centre for Sensor Signal and Information Processing (CSSIP), has shown it is possible to set up a cross-disciplinary graduate coursework program with a significant mathematics component. Maintaining it has proven to be a tougher call, however, even with the privileged access it has enjoyed to a pool of DSTO staff interested in receiving this training.

    a. In contrast to US graduate programs, in Australia, no single location provides a large enough pool of eligible students to support a substantial graduate coursework program, nor is any single department large enough to run one. Even DSTO Adelaide, with perhaps the largest single concentration of hard scientists in the country, cannot provide enough students to support the graduate level course work programs it needs on its own. Likewise DSTO has found it very difficult to identify individual faculties of sufficient size to provide the breadth and depth of courses it is looking for.

    b. A solution is coursework programs run by the relevant research communities (e.g. mathematics and related disciplines) at a national level. Unfortunately this requires both national coordination and national resourcing; the record here is patchy. CSSIP did make a major effort in this area, with Bill Moran in particular ensuring the necessary mathematics was included in the education program; AMSI has made a commitment to national educational issues, but I am not in a position to judge its impact; NICTA has so far failed to rise to the occasion.

    c. This challenge could be viewed as an opportunity: the inability to maintain multiple graduate programs within individual institutions as in the American model could spur the development of new ways of distributed development and delivery of courses. Again MSIP with its on-line courses has been a trail blazer in this area. Unfortunately, however, good on-line courses are not quick or cheap to develop: I see little community awareness or interest in such activities.

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[2] A prime example of such a failure of communication is evident in the fast amount of early neural network literature devoted to deriving the back-propagation algorithm and various training strategies for its best use. Back-propagation is just an instance of steepest descent, a method that had been comprehensively analysed by the numerical analysis community in the previous twenty years: nevertheless poor communications between mathematicians and electrical engineers meant the neural network community did not tap into the associated accumulated mathematical expertise for quite some time.

5. In my experience, academic mathematicians act primarily as individuals: they have relatively little interest in acting corporately. Contributing factors are the nature of their training (see above) and the relatively few clear, immediate requirements of current academic positions to do so.

    a. One outcome is that Mathematics Departments and mathematicians are relatively poor both at strategic planning and in buying into any resulting courses of action. In many universities (e.g. Flinders) departments seem to be in disarray with no clear strategies to address their problems. Elsewhere stronger departments facing no immediate threat neither support their weaker brethren, nor even take advantage of others' decline to boost their own market share.

        i. One exception is the Maths. Dept. at the University of South Australia: it has made clear strategic choices as to where it will position itself and niches it will occupy, and they seem to be accepted and endorsed by all the staff in the department. In particular they have made a clear choice as to the nature of the degree they will provide, and have launched successful specialist activities such as the Hypatia scholarship program for women students and an exchange program with the University of Twente.

    b. Solipsism may in turn translate into conservatism. The basic structures and mode of operations of mathematics departments (and indeed universities) and the education program and degrees they offer have changed surprisingly little over the last fifty years; they certainly don't reflect the growth in raw numbers of mathematicians and papers published.

        i. Moreover while mathematicians as individuals have embraced the email and the web, the community as a whole has shown much less initiative in using this technology to achieve community goals. It has neither identified what the technology might be used for, nor bid for the resources to achieve this.

    c. Mathematics as a profession lacks clout, especially that part of it outside the academic sector. In particular there is no counterpart to IEAust able to impose standards or requirements on the academic community.

Finally, my best guess as to the mathematical skills that DSTO will require over the next quarter of a century is as follows:

- A declining, but nevertheless enduring and fundamental, need for the mathematical skills to analyse and model classical applied problems in optics, electro-magnetics, fluid and structural dynamics, explosives, etc. Moreover, while DSTO will employ fewer staff in these areas, it will expect more of them: they will be asked to not only analyse problems, but to use and continue development of sophisticated software codes to solve or simulate problems in these domains.

- A need that has probably now peaked, but will also endure, for sensor processing skills, e.g. in signal and image processing. Moreover the range of skills needed will also steadily expand, both due to increasingly sophisticated sensors and also pressure to move up the "food chain" requiring more work in tracking, sensor fusion and information exploitation. As in the classical applied areas, however, the long term demand will continue to be to do "more with less", especially in those areas closest to the sensor.

- A still growing need for guidance and control in areas such as robotics and autonomous vehicles, and one that is expanding into the need to develop strategies for guiding the behaviour of general autonomous agents (e.g. independent agents within simulations, or web crawlers)

- An ill-defined but expanding need for the ability to analyse the ever-growing volumes of data collected by organisations, in particular to support business process re-engineering by optimizing organisational performance. More than any other area, this places high demands on mathematicians' abilities to collaborate with others within structures, teams and organisations to meet corporate, as opposed to individual, goals.

- A further ill-defined but expanding need to support an increasing range of inter-disciplinary activities such as operations research, systems engineering, simulation and wargaming, and psycho-physics.