Review of Mathematical Sciences Research at South African Higher Education Institutions

International Review Panel Report

18.12.2008

CONTENTS

Executive Summary

The importance of a sound foundation and research base in the mathematical sciences is absolutely critical for national development in science, engineering, commerce, and technology. Without this foundation, attempts at establishing a knowledge-based economy and generating innovation are doomed to failure. The development and transformation of human resources in science, engineering, and technology depend in a fundamental way on mathematical understanding, and a significant presence in each field of very highly skilled mathematicians.

These imperatives are recognised in the 10 Year Plan of the Department of Science and Technology which recognises the need for expertise and training at a high level, and recommends increasing the PhD production rate five-fold. Ensuring the infrastructure exists to achieve these outputs must be an important objective in South Africa at this time.

The Panel found evidence of good research (by international standards) in all the mathematical sciences (pure mathematics, applied mathematics, statistics, and mathematics education) in Higher Education Institutions. However such research is done predominantly by a small base of NRF-rated researchers who are thinly spread across the university sector. There are many instances where postgraduates, PhDs, and academic staff are working in environments where there is no critical mass of researchers. Nationally, the cohort of active researchers is mainly in the 55+ age-group.

We identified a huge potential for improvement. South Africa has a population base that could produce significantly more researchers, and, importantly, already has the expertise required to realise this potential inside the country. All critical requirements are present, but there are several structural and resourcing blockages. Although mentioned separately, these blockages are interrelated and need to be addressed together.

Research in the mathematical sciences in South Africa suffers isolation at many levels. The inward, institution-oriented approach to research in the mathematical sciences needs to be transformed into a national approach. Notwithstanding a number of strong examples of connectivity, overall there is geographical isolation from international centres of research; there is geographical isolation of institutions within the country; there is academic isolation of individuals (postgraduates and researchers) in their research fields; and there is institutional isolation of the mathematical sciences from its applications and related disciplines.

In the mathematical sciences, research is not fully distributed across the different areas of mathematics. In particular, there are some contemporary, mainstream sub-fields that are not represented, and some research in South Africa is disconnected from areas of contemporary interest.

The means and the environment to produce effective research need to be addressed. Most critically, PhDs and academic staff do not have sufficient time to undertake high quality research. Unfilled posts and increased numbers of service courses mean increased teaching and administrative loads. Many researchers do not have effective access to research literature and necessary computing facilities. Significant numbers of postgraduates and academic staff are not part of a research culture—they tend to work alone with significant time constraints rather than in a community that values research activity as a priority.

Growth in research in the mathematical sciences requires sufficient numbers of suitably qualified people entering at every level of the system, and the nurturing and development of those moving through into higher levels.

The mathematical research pipeline begins in schools. In South Africa the number of students qualified to undertake mathematical studies at university is low. Improving the size of this pool is a critical factor if research is to be enhanced in the long-term. Students in the mathematical sciences completing bachelors, honours, or masters degrees are highly sought after by business and industry, and are offered well paid careers of many kinds. Many graduates see little future in staying in academia and research. Those who do continue are often in an environment that does not build their capacity—they are academically isolated, poorly funded, and lack regular ongoing supervision in their specialised area. Thus the numbers and education of postgraduates are insufficient to meet the staffing needs at academic institutions. The Panel feels strongly that low capacity at postgraduate level in the mathematical sciences is one of the principal issues facing the country. This was the central theme raised in our interactions with researchers, academics and institutes across the country.

Statistics is a special case. All the above blockages to research development apply, but are now at a stage that is so critical that the field is in danger of disappearing through lack of academic capacity. The closure of academic departments is a real possibility.

The panel has developed a suite of recommendations to address the blockages to research identified above. It is important for the mathematical sciences to be invigorated with more people and relevant new research thrusts. The key themes are capacity development, interconnectivity, and strengthening foundations. The special case of statistics is also considered.

We do not believe that national strategic objectives can be met using only existing institutions and centres. It is necessary to introduce a new structure, national in scope, to provide a space for academics and researchers to interact, collaborate and generate new ideas and synergy. This structure should be independent from existing tertiary institutions.

We therefore propose the establishment of a National Centre of Mathematical Science to serve the mathematical community in all universities. Such a Centre will significantly assist in the realisation of the majority of recommendations. A road-map for this development is detailed.

The Centre will expose the whole community to topical areas of research at an international level, and will provide new opportunities for connectivity between geographically dispersed researchers. A national structure will build bridges between researchers in pure mathematics, applied mathematics, statistics, and mathematics education using a programme of workshops and seminars. A Centre would also contribute strongly to much-needed secondary school teacher professional development in mathematics and serve as an interface between academics, industry, and bodies such as CSIR, NITheP, and NACI. It will also provide effective international connectivity through participation of international experts in seminars and workshops as well as interactions with similar institutes elsewhere.

A detailed model of a possible National Centre of Mathematical Science is described. The final structure for this Centre needs to be decided in consultation with interested stakeholders.

I. Background

The International Review Panel met in South Africa from 10th to 19th November, 2008.

International Review Panel

The International Review Panel was constituted to include four mathematical scientists from abroad including one from Africa, two South African mathematical scientists, and one other South African scientist from an associated discipline.

The panel is:

- Prof Bill Barton, Head, Department of Mathematics, University of Auckland, New Zealand
- Prof Naresh Dadhich, Director, InterUniversity Centre for Astronomy and Astrophysics, India
- Prof Kathy Driver, Dean of Science, University of Cape Town, South Africa
- Prof Diane Hildebrandt, School of Chemical and Metallurgical Engineering, University of the Witwatersrand, South Africa
- Prof Sunil Maharaj, School of Mathematical Sciences, University of KwaZulu-Natal, South Africa (Convenor of International Review Panel)
- Prof John Odhiambo, Vice-Chancellor, Strathmore University, Kenya
- Prof Peter Sarnak, Eugene Higgins Professor of Mathematics, Princeton University, USA

Review Oversight Committee (ROC)

The Review Oversight Committee was constituted to include representatives from each of industry and academia including a member of the South African Mathematical Society (SAMS), one of whom will be the chairperson; one representative of the Association for Mathematics Education of South Africa (AMESA); one representative of the South African Statistical Association (SASA); one representative of the Department of Education; one representative of the Department of Science & Technology; and one representative of the National Research Foundation.

The Committee is:

- Prof Nigel Bishop, University of South Africa (Chair of ROC) (SAMS)
- Prof Nic Heideman, University of Cape Town (AMESA)
- Dr Andrew Kaniki, National Research Foundation
- Mr Chief Mabizela, Department of Education
- Dr Peter Njuho, University of KwaZulu-Natal (SASA)
- Prof Michael Sears, University of Witwatersrand (Industry/Academia)
- Dr Gilbert Siko, Department of Science and Technology
- Ms Jean Skene, Department of Education

Purpose

The purpose and dimensions of the review were given in the Terms of Reference. The purpose was:

- to report on the status of research in mathematical sciences at South African Higher Education Institutes (HEIs);
- to assess the application and innovation linked to mathematical sciences research conducted in South Africa;
- to recommend key issues for consideration in the development of a strategy to improve research in mathematical sciences in South Africa.

Dimensions

A summary of the dimensions of the review is as follows.

1. The status of mathematical sciences research in South Africa in terms of:
   - its status in the context of other academic disciplines in South Africa;
   - its status compared to other countries;
   - resources available to support it; and
   - relevance (or lack of it) to the South African context.
2. The application and innovation linked to mathematical sciences research conducted in South Africa in terms of:
   - findings by South African researchers in the field of mathematical sciences that generated benefits to society, e.g. applications in other fields, interventions that reflect international competitiveness, led to new discoveries, etc.
3. Researchers at South African HEIs in the field of mathematical sciences in terms of:
   - number of active researchers and academic staff in mathematical sciences at South African HEIs, their qualifications and international standing;
   - quantity and quality of the research outputs in mathematical sciences in South Africa;
   - infrastructure at the disposal of researchers, e.g. computer facilities, journals, administrative support, etc;
   - condition of doing research at the HEIs (e.g. workload in terms of teaching, studying, research);
   - funding opportunities for mathematical sciences research in the public and private sectors, academic institutions and/or any other donor agencies; and
   - culture of using postdoctoral fellows in conducting mathematical sciences research at HEIs.
4. Capacity building in terms of:
   - training of students in mathematical sciences at South African HEIs, in particular, at the honours, masters, and doctoral level;
   - financial support available for postgraduate student training;
   - number of students at undergraduate and postgraduate level in terms of race, gender and nationality;
   - infrastructure at the disposal of students, e.g. computer facilities, books, journals, administrative support, etc; and
   - employment prospects for doctoral graduates in the field of mathematical sciences as well as further career development.

Role of the International Panel

The International Panel was pleased to receive the Marais Report *Mathematical Research in South Africa: A Status Report* which addressed as many of the statistical issues as could be accommodated within the timeframe of that study. Thus, in the ten days available to them, the International Review Panel interpreted their task as:

> **To undertake an overview of research in the mathematical sciences in its broadest sense and make suggestions on how to raise it to a higher level.**

II. Mode of Operation

Various stakeholders were identified in conjunction with the Review Oversight Committee for interviews and interaction. These included representatives from the HEIs, national research institutes, scientific societies, national government departments and representatives from industry.

Meetings took place with individuals from the following national bodies in government and science:

- Representatives from the National Research Foundation (NRF)
- Representatives from Department of Science and Technology (DST)
- Acting Chief Executive Officer, National Advisory Council for Innovation (NACI)
- Deputy Director-General, The Department of Education (DOE)
- Deputy Director, Statistics South Africa (SASA)
- President, Council for Scientific & Industrial Research (CSIR)
- Vice-President, Academy of Science of South Africa (ASSAf)
- Director, National Institute of Theoretical Physics (NITheP)
- Director, African Institute of Mathematical Sciences (AIMS)
- Director, South African Mathematical Foundation (SAMF)
- President, South African Mathematical Society (SAMS)
- President, Association of Mathematical Educators of South Africa (AMESA).

The panel met with directors of research, deans, academic staff, researchers, and postgraduate students from Higher Education Institutions across the country. The institutions visited were geographically spread across the country and included research universities, comprehensive universities and universities of technology. The Panel felt that the sites visited should include institutions which were both well resourced and historically disadvantaged. We met with representatives from:

- University of Pretoria
- University of South Africa
- University of Limpopo
- North-West University
- University of the Witwatersrand
- University of Johannesburg
- University of Zululand
- Durban University of Technology
- University of KwaZulu-Natal
- University of Cape Town
- University of Western Cape
- Stellenbosch University
- Cape Peninsula University of Technology.

There was also a session devoted to interaction with representatives from industry.

A detailed programme including names of those consulted is available from NRF.

Reference documents as below were made available:

- *White Paper on Science and Technology*
- *South Africa's National Research and Development Strategy*
- *The 10 Year Plan for Science and Technology*

- *2006 Annual Report of the South African Committee for the International Mathematical Union*
- *2007 Annual Report of the South African Committee for the International Mathematical Union*
- Wickham, S., Coetzee, G., Jones, B., & Metcalfe, A.(2007). *HEQC (Higher Education Quality Committee) Evaluative Study of Institutional Audits 2006.*
- *Human Capital and the South African Knowledgebase: A report to the National Advisory Council on Innovation.* Centre for Reearch on Science & Technology, Stellenbosch with Centre for Science & Technology Studies, University of Leiden. 2007
- H.C. Marais, J.W. Grobbelaar, & S.M. Gathua (2008). *Mathematical Research in South Africa: A Status Report.*

Additional documents obtained by the International Review Panel included:

- J. Engelbrecht & A. Harding (to appear). New numbers in mathematics in South Africa. *International Journal of Mathematics Education in Science & Technology*
- J. Engelbrecht & A. Harding (2003). Is mathematics running out of numbers in South Africa?. *South African Journal of Science, 99*(1/2), 17-20
- *An International Review of UK Research in Mathematics*, Engineering and Physical Sciences Research Council & the Council for the Mathematical Sciences, 2004.
- 2006. *Mathematics & Statistics: Critical Skills for Australia's Future. The National Strategic Review of Mathematical Sciences Research in Australia.* Australian Academy of Science
- African Institute for Mathematical Sciences Publicity Material (2008).

III. Overview

The Importance of Research and Development in the Mathematical Sciences

There is unprecedented demand worldwide for university graduates with mathematical skills. This arises from the power that cross-disciplinary research based in the mathematical sciences brings to finding solutions for many of our most critical and complex contemporary problems in society. Data analysis, mathematical modelling, decision-making, and all technological innovations are under-pinned by knowledge and expertise in the mathematical sciences.

In the current South African context, the following considerations are particularly pertinent.

- A high level of analytical and numerical skills is necessary in order to be able to exploit the research areas where the country has geographical advantage, for example modelling of the Southern ocean-atmosphere interaction and exchange, and analysis of SALT-generated experimental data in astronomy and cosmology.
- The critical fields of bio-informatics and drug discovery require extensive knowledge of computational and algorithmic methods.
- Mathematical analysis is a vital part of social and business development strength.
- The Department of Science and Technology 20 Year Human Capital Development Plan has, as one of its objectives, a five-fold increase in the number of PhD graduates in South Africa. In the sciences, doctoral students in every field require exposure to modern mathematical methods.

The challenge is to expand the base of students studying the mathematical sciences, and to encourage them to pursue postgraduate research. For mathematically able undergraduate students who are in the position to devote their full attention to their studies, the basic quality of an undergraduate training in mathematics in the leading South African universities compares favourably with what is offered by good institutions around the world.

Overview of Research in the Mathematical Sciences

This overview is divided into the four areas of pure mathematics, applied mathematics, statistics, and mathematics education. However the boundaries of these fields should not be regarded as distinct. There are about 150 NRF-rated researchers in Pure and Applied Mathematics, Statistics and Mathematics Education, almost all of whom hold an academic position at a university. Approximate breakdown within areas shows 105 in pure and applied mathematics, 35 in statistics and 10 in mathematics education.

The NRF rating system is rigorous and appears to be reliable.

Pure Mathematics

Research in the traditionally research-focussed universities is generally of a high quality. In other universities, there are pockets of good quality, well-coordinated research but these are few and far between. Those mathematicians who are research-active exhibit good productivity and publish articles across the spectrum from the best journals (excluding the top two) to middle and low quality journals. There are arguably too many articles of questionable quality in local journals.

The majority of NRF-rated researchers have good international contacts, collaborate on joint projects, attend international conferences, and make productive use of sabbaticals. However,

there are only a few areas of pure mathematical research that are well represented. Indeed, cutting edge frontier science fields (for example, representation theory of semi-simple groups, Riemannian geometry and related partial differential equations, harmonic analysis), hardly feature in the research agenda in South Africa. Some areas of local research in pure mathematics have become narrowly specialised and disconnected from the international mainstream. A number of these areas were active internationally 30 years ago but no longer attract much attention or activity. This is not surprising in the context of the general isolation of South Africa pre-1994. The Panel shared the view, also held by some younger researchers, that it is time to get South African pure mathematics more connected to the more fashionable and exciting areas that are undergoing rapid changes, for example, the work around the Poincaré Conjecture and geometrisation theorems of Perelman.

Thus some mathematics researchers need to be encouraged to move away from self-referential, narrow, or out-dated research niches and publish in journals that will promote an international presence. This is especially important in the context of PhD supervision where doctoral graduates need to be ready/equipped to participate in current global research areas.

Of grave concern is the age profile of active mathematics researchers. A preponderance of the top-rated and the most productive researchers are 55 or older. There are too few researchers in the 30-55 age groups and a dearth of students majoring in mathematics and enrolling for Honours, Masters or Doctoral studies. This bodes poorly for the future in terms of both further research and also for developing the next generation of mathematical science academics.

The universities of technology and the historically disadvantaged universities have not yet built their capacity for pure mathematics research. Their postgraduate students and academic staff are isolated because there is no critical mass within their academic environments, and they have minimal supervision capacity. There is also a lack of facilities that promote and enhance research, for example, online access to journals.

Applied Mathematics

All the comments made in the previous section on Pure Mathematics apply to Applied Mathematics, except that the research areas represented do include some contemporary areas. There are significant strengths in traditional classical areas, for example, astrophysics, cosmology and relativity; computational mechanics; theoretical physics; and the applications, both theoretical and numerical, of solutions of differential equations in several fields. There are also other pockets of internationally recognised research but these are rather thinly spread nationally.

Applied mathematics has the immediacy of applications that are, or could be, pertinent to the industrial sector. There are significant opportunities for research in financial mathematics but the postgraduate degrees that currently exist are orientated towards professional qualifications for graduates who seek employment in the financial and banking sector and not towards the development of a research base. The necessary underlying mathematical skills to conduct meaningful, internationally competitive, research in mathematics of finance are poorly developed and graduates with a research interest in this area usually pursue PhD studies overseas.

The level of interaction with industry is relatively weak although there have been some good recent initiatives in this direction. It is extremely important that the applied mathematics community across the country strengthen and broaden its interaction with the industrial sector.

Statistics

South African research in probability and statistics enjoys excellence in several areas of applied statistics and stochastic analysis, particularly Bayesian statistics applied to medicine and other areas, stochastic analysis applied to financial industry, statistical modelling applied to mining, medicine, and finance. There is also good work in optimal designs and applications, and nonparametric analysis. Other areas include multivariate statistical processes, neural networks, econometrics, biostatistics, linear models, and statistical learning theory. The current NRF rating list also includes some researchers with substantial international visibility, and a small number of young and upcoming researchers who show very good potential. The majority of those who have reached the status of international leaders are found in the so-called "research universities", and most of them are due to retire soon.

The panel heard in the interviews that there is acute shortage of qualified statisticians. In some of the universities the panel noted no senior person doing statistics. It was noted that some of the research cannot be published due to industrial proprietary rights. There is a danger of the imminent collapse of research activity in statistics when the present cohort of senior researchers retires.

Research in statistics, like in other areas of mathematics, tends to be built around core groups of people, as distinct from facilities or laboratories. However, for statistics to thrive it requires significant computational capacity—that is lacking in some universities.

Mathematics Education

Research in mathematics education in South Africa is strong in relation to the number of NRF-rated researchers. There is one area of particular strength, other areas of significant work, and an opportunity to become international leaders in another particular area (see below).

Most heartening, however, is the strength of the mathematics education research networks, the increasing number of new researchers, and the structures in place to mentor and develop these researchers. The growing number of new researchers is partly a result of the restructuring of the HEIs whereby Colleges of Education became amalgamated into universities and teacher education staff now operate in a research environment. There is an important task to be done to develop the research skills of these people. The establishment of new professorships partly funded by the private sector in the area is a great impetus to development.

As is common all over the world, there is still work to be done linking research to practice by communicating research in effective ways to teachers in schools. To some extent this is dependent on the readiness of the teaching community to consider mathematics education issues—they already have more than enough on their plate in terms of their own basic qualifications, school organisation issues, and new curricula to adopt. Mathematics education research also has an important role to play in policy-making and curriculum design.

The area of particular strength is research into language issues in mathematics teaching and learning. Given the geopolitical environment, this is not surprising. The eleven official languages make South African classrooms unique worldwide in the way in which multiple languages are involved in classrooms. The research that has been done in South Africa is at the forefront internationally, with a South African researcher leading a major international study and Special Issue of the top journal *Educational Studies in Mathematics*.

There are three areas of significant work: socio-political issues, undergraduate mathematics education, and teaching & learning. As a country at the forefront of dealing with colonial and racial issues in its society, it is also not surprising that socio-political issues are well-represented

in the interests of mathematics education researchers. A small group of South African researchers have been actively involved internationally in the developing area of undergraduate mathematics education. Such work has dealt with both language and technology issues.

Work in the area of teaching and learning has probably evolved because the classroom focus of such research makes connection with teachers most likely and most beneficial. Linked to this is the area of teacher development, an area that is likely to expand as teacher-educators become more involved as researchers.

The area ripe for development is that of rural mathematics education. Internationally this is an area of need, and an area that is not being met in research activity. Again, the geographical realities of schooling in South Africa mean that there is good potential for research to occur, and the development of researchers in historically disadvantaged universities creates an opportunity for them to make an impact internationally. There would be considerable interest outside South Africa in such research.

The AMESA organisation, its conference, the SAARMSE conferences, and the Southern African regional links, provide more than adequate opportunities for development of mathematics education research. The development of national journals as a means of mentoring new researchers' work is an example of AMESA's efforts. Any new initiatives need to build on these strengths. Interaction between mathematics education graduates and faculty is generally good. The most pressing need—for which AMESA needs further assistance—is the development of new mathematics education lecturers to enter the research culture. Reduction of teaching loads is a significant issue in this respect.

It should further be noted that South Africa is playing a very strong role in the region, encouraging research, mentoring researchers, hosting conferences, and supporting activities in neighbouring countries.

As an addendum, it should be noted that there is South African researcher presence on the executive committee of the international body for mathematics education for 10 years from 2003 to 2012.

Related Institutions

SAMS/SASA/SAMF/AMESA

The professional societies in the mathematical sciences are active and effective in general. They are strong and organised sufficiently for further initiatives to be built on their work, and they have the networking and potential to do a lot more work to promote the mathematical sciences, identify talent, and undertake cooperative work if they were able to access further resources. It would help the work they do if higher proportions of academics in each area could be encouraged to participate actively.

AIMS

The AIMS project of connecting the scientific community in South Africa to the global scientific community by bringing in distinguished lecturers to give courses to postgraduate students is an innovative and remarkable experiment. It has benefited scientific graduate programmes around the country in terms of recruitment of students outside South Africa. As a pan-African endeavour it is to be applauded.

However the panel noted that there are virtually no South African graduates associated with the programme. In that sense, as an initiative to advance South African mathematical sciences, it has not been so successful.

In our interviews, there was concern expressed that AIMS has not yet connected fully with the South African mathematical community. In particular, its current timetable, which is based on the northern hemisphere academic year, is not conducive to South African student participation.

CSIR

The direction of developing relations between the CSIR and universities holds promise as one avenue of advancement for applied mathematics research. We became aware of teething problems in the development of formal collaborative relationships and funding agreements. The Panel feels that interaction between the CSIR and universities needs to be encouraged, and finding appropriate structures for collaboration needs to be pursued. This may require attention to the macro-funding arrangements of research on a national scale. An interface is needed between academics and CSIR researchers to enhance innovation.

NIThePP

NIThePP is a new national initiative to promote research in theoretical physics. The Director acknowledged to the Panel the dependence of this field on a healthy base in the mathematical sciences. He expressed keenness to develop a mutually beneficial association with researchers in mathematics.

IV Issues to be Addressed

Statistics in Crisis

Many of the professors we interviewed were unanimous that statistics was undergoing a crisis. We concur.

There are too few academics in the system, and the age profile of those who are active is heavily weighted in the 55+ age-group. The South African university system is failing to produce enough young research leaders to fill even currently available positions, let alone those which will become vacant in the immediate future. Not only is research suffering, but also the capacity to supervise at higher levels is compromised. The shortage of statisticians is a world-wide problem, so that recruitment internationally is difficult. The problem of staff retention is afflicting most universities in the country to varying extents, but is more pronounced in the previously disadvantaged universities.

One major cause of this problem is the high demand for statistics and statisticians outside the university sector. There is growing difficulty in recruiting new faculty in universities because of salaries of two or three times an academic salary being offered by industry. The effect is a vicious circle, since there are already not enough academics to produce the required number of statistics graduates for the workforce.

The quantity and quality of the research output is partly a function of the few academic statisticians, but has been further affected by excessive workload, which in turn is exacerbated by staffing shortages.

The creation of NRF research chairs is a positive development, but it was mentioned in interviews that new conditions directing applications to specific applied areas of research make it difficult for researchers in the mathematical sciences to apply. There is a case for some chairs to be allocated to statistics to strengthen research.

It is becoming increasingly difficult to attract capable students to study statistics in particular at the honours, masters and doctoral levels. There is a limited pool of students at honours level. After BSc they divert to actuarial science or financial mathematics. The bursary and scholarship amounts awarded to postgraduate students are too low to compete with the amounts offered by industry. Students often have serious financial obligations at the end of their first degree, in particular loans or responsibilities to their extended families.

Research Isolation

South African researchers in the mathematical sciences are geographically isolated at the southern tip of Africa. This means that, in order to keep abreast of new mathematical developments, as well as to grow inter-disciplinary areas that are shaping the future internationally, local mathematicians need to travel to conferences and undertake regular research visits. In addition, there should be the capacity and facility to host international colleagues to maintain healthy international involvement.

Researchers often work in pockets within the country, not fully aware of cognate research activities at other universities. Facilitating knowledge of, and contact between, colleagues with complementary research interests would stimulate productivity.

The years of international isolation prior to 1994 led to a trend in certain research areas to establish in-house journals to publish the research outputs of various groups. This type of parochial research orientation mitigates against remaining relevant in the international mainstream and should not be encouraged.

Certain important fields lack a critical mass and there is a danger that if there is not some exposure to experts in those fields, graduates will not be internationally competitive. Retaining top researchers requires a strong, modern research environment. Top level research often draws on many fields within mathematics, thus a width across the discipline is needed in the country overall (although not necessarily at every university).

There is room for much more cooperation among universities. Large/strong departments need such links, but they are absolutely vital for small/weak departments, where researchers may be isolated. Postgraduate students in all departments need mechanisms to give them a broader view of mathematics than the one that may be accessible in their own department.

Partnerships with industry can lead to interesting applied problems. Some universities have industry study groups that do research on problems generated from industry and whose solution can contribute to innovation. These industry partnerships also provide research problems for postgraduate students. High levels of cooperation between business/industry and applied mathematics/statistics is necessary in every university.

SAMF is the main structure which promotes collaboration between researchers in the mathematical sciences and researchers in mathematics education. Such collaboration is an area of under-utilised resource, and should be significantly strengthened. Not only are there research benefits to be gained by the mathematics educators from being in close contact with mathematical research, but there are teaching benefits to be gained for the mathematicians and statisticians. Collaboration between these two disciplines is especially crucial in the training of school mathematics teachers, particularly for in-service teacher professional development in mathematics.

A healthy flow in the pipeline from school to university requires that both school teachers understand university mathematics, and that university mathematicians understand what happens in schools. Mathematics educators have a mediating role to play in this process—a process that requires mutual respect of the two disciplines.

Ongoing Renewal of Research Faculty

A healthy research environment requires a steady flow of new researchers and their induction into research mathematics. For historical reasons, the demographical profile of researchers in the mathematical sciences is heavy in the 55+ age-group, with a dearth in the 30-55 age-group, and relatively few new researchers entering the system. The problem is afflicting most universities in the country to varying extents, but is more pronounced in the previously disadvantaged universities. The long-term effect of this will be severe unless the problem is addressed in the very near future. The ability of the system to mentor new staff into teaching and research will erode, leading to yet fewer new researchers who are adequately prepared.

As noted above, the situation is exacerbated by difficulty in recruiting new faculty because of competition from industry. Recruitment from other countries is difficult. The problem is not only remuneration, but also geographical. Shortages have further implications on the workload of remaining staff and hence the attractiveness of an academic career.

Time for Research

A universal theme in the Panel's interviews with academic staff and researchers was the lack of time to pursue research. This was particularly striking at the Historically Disadvantaged Institutions. Teaching loads had increased over recent years in terms of both contact periods and numbers of undergraduate students. This was especially true for service courses in commerce and engineering. Staff indicated that there had been no proportionate increase in staffing. Consequently, staff were spending longer hours on course preparation, tutoring, administration

and lecturing, and fewer hours on research. In this environment staff prioritise undergraduate teaching. Research needs to return to centre stage.

The Panel enquired about actual hours and confirm that both South African academics and post-graduates or PhD students undertaking tutoring are teaching longer hours than the norm in developed countries.

Graduate capacity development

The Panel noted the overall small number of graduate students. The subcritical numbers as well as lack of research expertise in particular disciplines affected the overall academic ambience.

As noted above, many students completing bachelor's degree studies opt to take up jobs in industry. The amount of stipend given to postgraduate students is low compared with industry salaries, and a large number of students have large financial commitments.

The postdoctoral cohort are a critical link, and impart momentum and vibrancy to the research environment. South Africa needs to increase the number of postdoctoral researchers as a matter of urgency. Associated with an increase in students, care needs to be taken that supervision capacity and library and computing infrastructure is adequate for graduate education. At many universities this is currently not the case.

Postgraduate fellowships are few and inadequate in value for a student to be a full time researcher. The remuneration of academic appointments with similar qualifications must be a benchmark.

Mathematical background of those entering university

The International Review Panel received many indications that an important part of the development of a graduate cohort in the mathematical sciences, and hence growth in research into the future, lies in the number and quality of students entering university. The mathematical background of students was described as poor, particularly those from previously disadvantaged areas. The imperative to address this issue was expressed by one person as "there is no point in looking at the leaves of a tree that is drying out, examine its roots".

There is strong competition for the low percentage of school output that has Higher Grade Mathematics (i.e. entry to university). All sciences, medicine, commerce, and engineering compete for these students.

Our interviews with students who had chosen mathematical studies reinforced this view. Nearly all those who came from rural areas had personal stories of extreme hardship and persistence with their mathematical studies when there were no teachers or resources. All of them had a deep love of the subject, persistence, and a healthy dose of luck. We were left wondering how many talented mathematics students were lost, and how many young people in South Africa have never had the opportunity to develop a love for the mathematical sciences.

There is no doubt that the ultimate health of the mathematical sciences depends upon strengthening the foundation of mathematics in schools, identifying and nurturing the best students at the secondary level, and encouraging such students into programmes in the mathematical sciences.

The Panel understands that this issue is not part of its brief, and that national initiatives are underway to address this issue. Nevertheless, we feel strongly that the ultimate resolution of health in research lies in this area, and also that the research community has a role to play in ensuring that the flow from schools is increased.

The key to improving the situation in schools lies with teachers. Critical shortages in the mathematical sciences are evident (during the Review a newspaper article appeared reporting an

uptake of less than half of the overseas visas made available for mathematics teachers from overseas). Improving the numbers of teachers is a supply problem; but research and researchers in the mathematical sciences can assist in improving the quality.

Both local and international research in mathematics education should be given high profile in developing both policies and practice of teacher development. A lot is known about what constitutes effective professional development programmes and how they need to be organised.

A critical area in teacher development is mathematical knowledge. Many of those entering teaching have less than optimal mathematical background. Pre-service programmes are already full, but on-going in-service development in mathematics is desperately needed. Mathematicians, in partnership with mathematics educators, need to be involved.

Some universities in the country have already embarked on such initiatives to improve the quality of mathematics at school level. These innovative change projects need to be studied and replicated in other universities in the country.

Publicity & Promotion of the Mathematical Sciences

Improving the numbers of those studying mathematics, and the numbers wishing to enter mathematics teaching, also depends on the image and culture of mathematics within the general population of South Africa

Much of the population is not aware of the enormous role mathematics plays in modern day society, its role in innovation, its role in other professions, its role in the economy, and the need for mathematical skills in most careers. This is not restricted to basic level mathematics. The Panel heard from those outside universities of the value and need for graduates with advanced mathematical training.

SAMF and some individual universities have promotion programmes and materials. Increased efforts need to be made to support such activity and explore ways of communicating the vitality, utility, and beauty of mathematics to a much wider audience—and especially to students in schools and their parents. Activities such as outreach programmes by universities aimed at improving the image of mathematics and highlighting career options; mathematics contests and mathematics exhibitions; open days and fairs focusing on mathematics aimed at conscientising the public; regional and international Olympiads, all provide a way communicating and popularising mathematics at various levels.

Mathematics and Innovation

The strength of the mathematical sciences at tertiary institutions is crucial for the development of technology, engineering and other applied scientific disciplines. In addition, educational, cultural and social values emanate from a strong science base. The importance of fundamental research in mathematics and the applied sciences is emphasized in the White Paper on Science and Technology. We quote the following paragraph which highlights the link between scientific progress and basic research:

> There is a need to recognise the importance of the knowledge-generating function of research, particularly in the higher education sector. Human wonder and curiosity and the ability to recognise serendipitous discovery account for much of scientific progress. Basic enquiry, as opposed to a formula-driven approach, is absolutely essential, particularly at the universities and technikons, which deal with young minds. It is important that fundamental research activity not be regarded as impractical, because it is the preserver of standards without which, in the long term, the applied sciences will also die.

Creativity is the generation and articulation of new ideas. Innovation is defined as the application in practice of creative new ideas, which in many cases involves the introduction of new inventions into the broader society. The 10 Year Plan of the Department of Science and

Technology emphasizes the importance of innovation to South Africa. Each of the five grand challenge areas (biotechnology, space science, energy security, climate change and human/social dynamics) presupposes a high level of mathematical expertise. The existing scientific base in South Africa is struggling to meet the objectives laid down in the 10 Year Plan, for example the rate of production of PhDs in South Africa is far below that of leading knowledge economies. The 10 Year Plan recognises this shortage:

> To build a knowledge-based economy positioned between developed and developing countries, South Africa will need to increase its PhD production rate by a factor of about five over the next 10-20 years.

The required investment in human capacity development in the fundamental scientific disciplines is necessary to transform South Africa to a knowledge-based economy. A comparison with other developing countries is informative. Countries such as Taiwan, Brazil, and India are now reaping the rewards, in terms of economic growth, because of their earlier investment in education to build a knowledge-based society.

Our interactions with representatives from industry, the CSIR and National Advisory Council on Innovation reinforced the view that for any innovation training in the mathematical sciences is crucial. The mathematical sciences are the *sine qua non* of innovation and advancement.

V. Recommendations

Recommendations are listed first in five categories: capacity development, interconnectivity, strengthening foundations, statistics and the image of mathematics. All recommendations are interrelated. Following an initial listing, the recommendations are re-listed as short-term (1-2 years), medium-term (3-5 years) or long-term (more than 5 years). Note that some long-term recommendations are of high priority. Finally, a possible "Road Map" of implementation is given to indicate the way milestones may be met to achieve the ultimate full development of the mathematical sciences.

The Panel does NOT recommend specialisation within the mathematical sciences. Research will not be enhanced by arranging that particular subfields are congregated in particular universities: statistics here, mathematics education there, financial mathematics somewhere else, computational algebra in another place. The main reason is that the discipline is fundamentally interrelated. Not only are the borders between fields far from clear, but also all the applied areas need, at their core, a strong pure mathematics presence. Academics undertaking research as well as graduate students, need education and access to expertise in all basic areas. The disciplines served by the mathematical sciences would also suffer, for example, economics needs analysis, statistics, linear algebra, and so on—at undergraduate, graduate, and research levels. A university that puts all its resources into one area would very quickly lose its ability to produce graduate students having the necessary exposure. The future of the country will not be well served if there is quality training in mathematics in only a few well-resourced universities. Less advantaged universities also need to be supported to provide favourable facilities for graduate development. We emphasise the need for inward, institution-oriented approach to research in the mathematical sciences to be transformed into a national approach.

The Panel strongly recommends the establishment of a National Centre of Mathematical Science (NCOMS) as the most efficient and effective way to achieve necessary development of the mathematical sciences in South Africa. Such a Centre would address many of the recommendations below and the elements of such a centre already exist. It will be seen in the Road Map how NCOMS could be constituted immediately and then evolve into a physical centre in the medium-term.

1 *Capacity Development*

There is an urgent need to develop capacity at postgraduate and new researcher levels to fill the generational gap. Young students must be attracted to the field, supported and mentored to continue in it, and given the means to produce relevant, internationally competitive research. The key to capacity development in the long-term is the establishment at all universities of professional environments that stimulate and nurture creativity in exciting and relevant mathematics.

1.1 Few students are attracted into higher degree study in mathematics. Potential students need to be identified early and given support to pursue advanced study.

1.1a Vigorous mathematics talent searches need to be made at school level particularly from the rural areas where there is a huge reservoir of untapped talent. The existing Olympiad programme should be extended geographically, but also in scope, so that all mathematics teachers are assisted to identify and nurture new talent.

1.1b Mathematics Departments should be encouraged to identify talented undergraduates from first year, and to develop seminar series or problem solving courses that would stimulate further interest.

1.2 The drivers of research are PhD students and postdoctoral fellows. Growth in numbers in these two areas is essential for building sustainable research capacity nationally.

1.2a Attractive scholarships are required to attract new students to the field. If a fixed amount of money is available, it will be more effective to have fewer good scholarships, than several inadequate ones. The scholarships need to be available at all universities.

1.2b A basic level of academic infrastructure is required at all universities. Access to research literature is not negotiable and this may be most efficiently achieved by a block internet subscription from a central source being made available to all HEIs. Internet connectivity must be reasonably accessible, fast, and reliable. There exists an excellent programme in India where the UGC pays the block subscription for internet access for 150 universities through its INFONET project (see Recommendation 1.2c).

1.2c Computing facilities must be available for high-level computational research needs, modern teaching needs, and fast and reliable communications. All universities require advanced hardware, software, bandwidth, and support staff.

1.2d Robust mentoring systems for graduate students are required. This means facilitating access to experienced researchers (who should be available within the institution), and regular contact with a specialist researcher (who may be at a nearby university).

1.2e The shortage of academics in the mathematical sciences means that there are already many opportunities for academic careers for masters and doctoral graduates. However, to recruit and retain highly employable talent, an academic career must be seen to be attractive. Remuneration levels, working conditions and an intellectually stimulating environment are key requirements.

1.3 Each South African university needs a critical mass of research active, internationally recognised academic staff working in relevant areas and undertaking graduate supervision.

1.3a Heavy teaching loads at most universities leave very little time for research. Means need to be found to reduce teaching loads for research active staff. We recommend the establishment of one or two teaching positions in each mathematics department in each university. This may require extra central funding (see Recommendation 3.2).

1.3b Well-structured, in-service development opportunities need to be made available for all academic staff who do not yet have PhD's. This may involve time, money, promotion, or other incentives.

1.3c Post-Retirement Professorial Fellowships should be established. Retiring professorial-level staff who are still research-active could be offered limited term contracts at reduced salary (for example 50-60%) to continue to undertake research and/or supervision duties as appropriate. It may be appropriate to increase this salary if the staff member will work at a university that does not yet have such a position.

1.4 To attract and maintain graduates and international-level staff, the mathematical sciences must remain up-to-date and exhibit vitality.

1.4a University departments in the mathematical sciences should institute a regular (5-year) review cycle involving academics both from other South African universities and from overseas, to advise on the strategic development of the discipline.

Emphasis should be placed on identifying mathematical and organisational needs rather than evaluation.

1.4b National efforts should be made to recruit international mathematicians from new and developing fields to supervise graduates in these areas. Graduates embarking on research in these fields should be supported (including travel outside South Africa).

2 *Interconnectivity*

In order to obtain reasonable coverage of different research areas, to exploit developing areas of research, and to ensure that high quality undergraduate education in the mathematical sciences is available across the country, cooperation between universities at both student and academic staff levels should be established. Cooperation among universities will benefit both large/strong departments and those smaller/weaker departments, or those that experience greater isolation. Both national and international interaction needs to be at higher levels than at present to break the geographical and academic isolation.

2.1 A programme of graduate schools, workshops and meetings that draw participants from across the country should be established.

2.1a National workshops for graduate students in key areas should be organised using local expertise and/or overseas visitors.

2.1b National workshops in important, fast-moving and contemporary topics should be set up as a professional development programme, and to forge links between universities.

2.1c Attendance of academic staff at these meetings must be regarded as a normal part of their academic duties.

2.2 Country-wide video-broadcasting of lectures should be developed. This requires video-conferencing facilities in all universities, supported by IT staff and sufficient band-width.

2.3 International travel fellowships and arrangements for exchanges need to be enhanced.

2.4 Arrangements that promote university-industry collaboration in research should be encouraged in all universities. An example are industry study groups in which problems generated from industry are addressed. Such industry partnerships are also rich sources of research problems for students at masters and PhD levels.

2.5 An annual international Visiting Professor position should be established. A selected professor would be funded to visit South Africa for a period of at least three months, touring all universities to give talks and interact with staff and graduate students. This could be modelled on the German Nobel Laureats Interaction programme.

2.6 Each university should establish an annual two- or three-week visitor programme in which one academic visits two or three other universities. Such visits could be part of an inter-university examination moderation programme.

2.7 Formal links need to be established between academics in the mathematical sciences and institutes like CSIR, NITheP, NACI, AIMS, and business and industry.

3. Strengthening Foundations

The development of mathematics education in schools is a challenge which needs to be addressed for the future of research in all mathematical sciences. There is a huge pool of latent mathematical talent which remains untapped in rural South Africa. It must be marshalled into an effective intellectual force. Mathematics teachers are the key in this situation. They need to be

motivated and given opportunities for continuing development. Research mathematicians and mathematics educators all have an important role to play, without suggesting that they alone can (or should) solve the problem. A national structure needs to be established to bring secondary mathematics teachers into contact with mathematicians and contemporary developments in mathematics.

3.1 Mathematicians and research mathematics educators are a resource that could be used in specific ways for teacher in-service development.

3.1a Formal connections need to be set up between university mathematics departments and departments that are responsible for teacher pre-service and in-service education.

3.1b Mathematics Departments, in cooperation with Education Faculties, should establish links with schools in the region and provide visiting lectures about new or applied mathematics by mathematicians to senior secondary classes. Two talks per year to five schools is a realistic initial target.

3.1c Mathematics Departments, with cooperation with Education Faculties, should hold at least two in-service days for secondary teachers where they learn about some interesting aspect of mathematics.

3.2 Two 1-year internships of appropriately qualified school teachers to each university Department of Mathematics should be established. Such Teacher Fellows would contribute to undergraduate teaching and thus relieve some of the pressure on research academics. In addition, they would improve their own mathematics, and would be better able to promote tertiary mathematics study to their students upon return to their schools.

3.3 Opportunities need to be created to enable school teachers, particularly secondary teachers, to be re-inspired and further educated in the field of mathematics. This needs to be done in an environment of interaction between mathematics and mathematics education research.

3.3a Regional and/or national residential workshops for selected senior secondary teachers should be established. At these workshops, teachers will have an opportunity to interact with university lecturers and professional mathematicians in the field, listening to presentations, and working with mathematics educators to develop school-based material. Such workshops should be organised around new developments and current excitement in mathematics, rather than the school curriculum.

3.4 Programmes of mathematical talent identification and nurturing need to be strengthened and extended. The current Olympiad programme forms a good basis for further development (see Recommendation 1.1a).

4. The Image of Mathematics

The importance of a sound foundational and research base in the mathematical sciences is absolutely critical for national development in science, commerce, and technology. Without these foundations attempts at establishing a knowledge-based society and achieving innovation and development are doomed to failure. Recognition of this relationship in society at large is an important step towards creating the mathematical base needed.

4.1 Existing structures and organisations that play a role in promoting the image of mathematics (for example SAMF) must be further supported. This includes providing the means by which they can have a truly nation-wide coverage at all levels of society.

4.2 Mathematicians, and international high-profile visitors, have a role to play in mathematical promotion. Structures need to be created through which they may connect to society at large, both in the media, and through university-sponsored events.

4.3 The substantial number of undergraduate and postgraduate students who enter careers in business, finance and industry is a resource for the public recognition of the mathematical sciences. Connections need to be maintained between mathematically trained graduates in industry and the mathematics community, and mechanisms established to make them and their work visible to the public.

5 *Statistics*

The crisis in statistics must be urgently addressed if its existence into the future is to be assured. Top priority must be given to attracting and retaining a younger generation of statisticians.

5.1 Immediate, short-term overseas recruitment of statistics university staff.

5.1a A nationally organised recruitment campaign should be initiated to attract and facilitate the entry of overseas academic staff in statistics.

5.2 Partnerships with industry

5.2a An NRF-sponsored nationwide consultation between Departments of Statistics and relevant industries should be organised. The aim will be to use existing examples of academic/business partnerships and develop new models for cooperation, and initiate a process by which such partnerships become widespread across all universities.
The point needs to be made that current industry demands on graduates is destroying the universities' ability to produce enough for future needs.
Examples of possible cooperation include: jointly funded academic positions; establishing positions that are split between university and business; joint workshops on industry problems that could lead to consultancy solutions; and joint research groups.

5.2b Academic statistics positions should have increased flexibility to undertake consultancy as a way of contributing to business needs, and enhancing the income of academics. This may involve less teaching demands (possibly extra teaching appointments), flexibility to receive personal consultancy payments, and reasonable overhead negotiations.

5.3 The inadequacy of scholarships and salaries for postgraduate students and academic staff is exacerbated by the market forces for statisticians. There is a case for "scarce skills" supplements for statistics academics.

5.4 The establishment of joint industry/academic posts should be investigated, in particular industrial chairs in university departments.

5.5 Statistics staff need to be retained by offering improved salaries and working conditions.

5.5a A transparent policy allowing private work for academic staff should be in place. This would enable statistics academics to supplement their salaries by doing consulting work. For this they will need time allocation, reasonable arrangements to personally receive financial benefit, and industry-acceptable university overhead charges.

5.5b There is a case for additional externally funded posts to be created in statistics so that research staff have significantly more time for research and supervision activity.

5.5c Overheads received by the universities from consultancies could be directed into producing a physical environment comparable to that of industrial colleagues.

6 *National Centre of Mathematical Science*

Research in the mathematical sciences has reached a threshold of capacity and expertise but urgently needs to move to a higher level. A vision and means by which this can be actualised is required. Such a vision must also address the areas of critical need and development identified above.

We therefore recommend the establishment of a National Centre of Mathematical Science (NCOMS) to serve all South African universities.

Such an institute would have the capacity to host focused programmes in the mathematical sciences, provide opportunities for academic staff and student connectivity and development, and allow cross-fertilisation and cooperation between mathematics, mathematics education, industry, and research institutions in related disciplines. The Centre would need to be independent of any particular university, but would exist to serve them all. It would draw expertise from the universities in South Africa as well as from abroad. The centre would focus on capacity development and high quality research.

(See the following section for details of a National Centre)

NCOMS establishment could be achieved in stages.

6.1 Short term

6.1a Establish positions associated with a National Centre of Mathematical Science.

6.1b Permanently fund, enhance and centralise the Olympiad, teacher outreach and promotional aspects of SAMF under NCOMS.

6.1c Establish visiting professorships associated with NCOMS.

6.2 Medium term

6.2a Build a national centre complex, including library, computing facilities and administrative infrastructure

6.2b Establish a programme of residential graduate workshops, research schools, and associated teacher residential seminars.

6.2c Establish 6- to 12-month national research fellowships.

Recommendations Re-Listed

Short-term Recommendations (1-2 years)

6.1a Establish positions associated with a National Centre of Mathematical Science.

6.1b Permanently fund, enhance and centralise the Olympiad, teacher outreach and promotional aspects of SAMF under NCOMS.

6.1c Establish visiting professorships associated with NCOMS.

1.1a Vigorous mathematics talent searches need to be made at both school level. The existing Olympiad programme should be extended geographically, but also in scope, so that all mathematics teachers are assisted to identify and nurture new talent.

1.1b Each Mathematics Department should identify its top undergraduates from first year, and develop information programmes that help such students widen their knowledge of opportunities, both as academics but also in professional fields. Such students should also be more closely advised on their courses. (Such programmes could be developed nationally).

1.2a Adequate scholarships and honoraria are required to keep new scholars in the field. If a fixed amount of money is available, it makes more sense to have fewer attractive scholarships, than several mediocre ones. They need to be distributed across all the universities.

1.2b Academic infrastructure, in particular, reasonable access to research literature must be enstablished. This may be most efficiently achieved by a block internet subscription from a central source being made available to all HEIs. Internet connectivity must be accessible, fast, and reliable (see Recommendation 1.2c).

1.3a Heavy teaching loads leave very little time for research. Means need to be found to reduce teaching loads for research active staff. We recommend the establishment of one or two teaching positions in each mathematics department in each university. This may require extra central funding (see Recommendation 3.2).

1.4b National efforts should be made to bring to South Africa mathematicians from new and developing fields to encourage graduates to take up these areas. Graduates entering these fields should be supported to get the required resources and supervision (including travel outside South Africa).

2.4 Arrangements that promote university-industry collaboration in research should be encouraged in all universities. An example are industry study groups in which problems generated from industry are addressed. Further such groups should be developed. Such industry partnerships are also rich sources of research problems for students at masters and PhD levels.

2.5 An annual international Visiting Professor position should be established. A selected professor would be funded to visit South Africa for a period of at least three months, touring all universities to give talks and interact with staff and graduate students. This could be modelled on the German Nobel Laureats Interaction programme.

2.6 Each university should establish an annual two- or three-week visitor programme in which one academic visits two or three other universities. Such visits could be part of an inter-university examination moderation programme.

3.2 Two 1-year internship of adequately qualified school teachers to each university Department of Mathematics should be established. Such Teacher Fellows would contribute to undergraduate teaching and thus relieve some such pressure on research academics. In addition, they would improve their own mathematics, and would be better able to promote tertiary mathematics study to their students on return to their schools.

3.4 Programmes of mathematical talent identification and nurturing need to be strengthened and extended. The current Olympiad programme forms a good basis for further development (see Recommendation 1.1a).

4.1 Existing structures and organisations that play a role in promoting the image of mathematics (for example SAMF) must be further supported. This includes providing the means by which they can have a truly nation-wide coverage at all levels of society.

4.2 Mathematicians, and international high-profile visitors, have a role to play in mathematical promotion. Structures need to be created through which they may connect to society at large, both in the media, and through university-sponsored events.

5.1 Immediate, short-term overseas recruitment of statistics university staff.

5.1a Negotiations should be made with Government Departments involved with immigration of skilled labour to make recruitment for academic staff in statistics to be allowed as a priority.

5.1b A nationally organised recruitment campaign should be initiated to attract and facilitate the entry of overseas academic staff in statistics.

5.3 The inadequacy of scholarships and salaries for postgraduate students and academic staff is exacerbated by the market forces for statisticians. There is a case for temporary special supplements in statistics.

Medium-term Recommendations (3-5 years)

NCOMS will also be an innovative world leader in bringing together secondary teachers, mathematics educators, and mathematicians to develop mathematical knowledge for teaching as an important discipline that is an integral part of the secondary teacher profession.

6.2a Build a central NCOMS complex, including library, computing facilities and administrative infrastructure

6.2b Establish a programme of residential graduate workshops, research schools, and associated teacher residential and distance seminars.

6.2c Establish 6- to 12-month NCOMS national research fellowships.

1.2c Computing facilities must be adequate for high-level computational research needs, modern teaching needs, and fast and reliable communications. All universities must have advanced hardware, software, bandwidth, and support staff.

1.2d Robust mentoring systems for graduates are required. This means both frequent access to experienced researchers (which must be available within the institution), and regular contact with a specialist researcher (who may, in the short term, be at a nearby university).

1.3c Post-Retirement Professorial Fellowships should be established in all universities. Retiring professorial-level staff who are still research-active should be offered limited term contracts at reduced salary (for example 50-60%) to continue to undertake research and/or supervision duties as appropriate. It may be appropriate to increase this salary if the staff member will work at a university that does not yet have such a position.

1.4a University departments in the mathematical sciences should institute a regular (5-year) review cycle involving academics both from other South African universities and from overseas, to advise on the forward development of the discipline. Emphasis should be placed on identifying mathematical and organisational needs rather than evaluation.

2.1 A programme of graduate schools, workshops and meetings that draw participants from across the country should be established.

2.1a National workshops for graduate students in key areas must be established using local expertise and/or overseas visitors.

2.1b National workshops in cutting edge contemporary mathematics topics need to be set up as a professional development programme, and to forge links between universities.

2.1c Attendance of academic staff at these meetings must be regarded as a normal part of their academic duties.

2.3 International travel fellowships and arrangements for exchanges need to be enhanced.

2.7 Formal links need to be established between academics in the mathematical sciences and institutes like CSIR, NITheP, NACI, AIMS, and business and industry.

3.1 Research mathematicians and research mathematics educators are a resource that must be used in any programme of teacher in-service development.

3.1a Formal connections need to be set up between university mathematics departments and departments that are responsible for teacher pre-service and in-service education.

3.1b Each university Mathematics Department, with cooperation from its Education Faculty, should establish links with schools in its region and provide visiting lectures about new or applied mathematics by mathematicians to senior secondary classes. Two talks per year to five schools is a realistic initial target.

3.1c Each university Mathematics Department, with cooperation from its Education Faculty, should hold at least two in-service days for secondary teachers where they learn about some interesting aspect of mathematics.

3.3 Opportunities need to be created to enable school teachers, particularly secondary teachers, to be re-inspired and further educated in the field of mathematics. This needs to be done in an environment of interaction between mathematics and mathematics education research. Such opportunities may need incentives parallel to those mentioned in 1.7 above for tertiary staff.

3.3a Regional and/or national residential workshops for selected senior secondary teachers should be established. At these workshops, teachers will interact with university lecturers and professional mathematicians in the field, listening to presentations, workshopping the mathematical material, and working with mathematics educators to develop school-based material. Such workshops will be organised around mathematics, rather than school curriculums.

4.3 The substantial number of undergraduate and postgraduate students who enter careers in business, finance and industry is a resource for the public recognition of the mathematical sciences. Connections need to be maintained between mathematically trained graduates in industry and the mathematics community, and mechanisms established to make them and their work visible to the public.

5.2 Partnerships with industry

5.2a An NRF-sponsored nationwide consultation between Departments of Statistics and relevant industries should be organised. The aim will be to use existing examples of academic/business partnerships and develop new models for cooperation, and initiate a process by which such partnerships become widespread across all universities.
The point needs to be made that current industry demands on graduates is destroying the universities' ability to produce enough for future needs.
Examples of possible cooperation include: jointly funded academic positions; establishing positions that are split between university and business; joint workshops on industry problems that could lead to consultancy solutions; and joint research groups.

5.2b Academic statistics positions should have increased flexibility to undertake consultancy as a way of contributing to business needs, and enhancing the income of academics. This may involve less teaching demands (possibly extra teaching appointments), flexibility to receive personal consultancy payments, and reasonable overhead negotiations.

5.4 The establishment of joint industry/academic posts should be investigated, in particular industrial chairs in university departments.

5.5 Statistics staff need to be retained by offering improved salaries and working conditions.

5.5a It must be made easy for academic staff to obtain extra money with consultancy work. For this they will need time allocations, reasonable arrangements to personally receive financial benefit, and industry-acceptable university overhead charges.

5.5b There is a case for additional posts to be created in statistics so that research staff have significantly more time for research and supervision activity.

5.5c Overheads received by the universities from consultancies should be directed into producing a physical environment comparable to that of industrial colleagues.

Long-term Recommendations (5+ years)

1.2e The shortage of academics in the mathematical sciences means that there are already many opportunities for advancement for young postgraduates. However an academic career must be seen to be attractive. An academic career must be seen to be well-rewarded (a mix of financial remuneration and working conditions) and intellectually stimulating (time and facilities for research and sensible involvement in undergraduate and graduate teaching). These are addressed below.

1.3b In-service development opportunities need to be made available for all academic staff. This may involve time, money, promotion, or other incentives.

2.2 Country-wide video-broadcasting of important lectures should be developed. This requires video-conferencing facilities in all universities, supported by IT staff and sufficient band-width.

VI. A National Centre of Mathematical Science

Research in the mathematical sciences has reached a threshold of capacity and expertise and is ready to move to a higher level. A vision and means by which this can be actualised is required. Such a vision must also address the areas of critical need and development identified above.

We therefore recommend the establishment of a National Centre of Mathematical Science (NCOMS) to serve all South African universities.

Such an institute would have the capacity to host focused programmes in the mathematical sciences, provide opportunities for academic staff and student connectivity and development, and allow cross-fertilisation and cooperation between mathematics, mathematics education, industry, and research institutions in related disciplines. Such a centre would need to be independent of any particular university, but would exist to serve them all. It would draw expertise from that available in universities in South Africa as well as from abroad. The centre would focus on capacity development and high quality research.

Rationale

The International Review Panel considers a National Centre to be the optimal way of addressing the suggested recommendations.

- A National Centre would ameliorate the geographical and psychological disconnectedness observed between universities at both researcher and graduate student level. It would provide a physical and academic environment for collaborations to occur, allow critical masses of researchers and graduates in sub-areas of mathematics to meet and conduct workshops and research activity, provide a means by which international visitors are shared around all universities, and provide a structure for cross-institutional visits. (Recommendations 2.1–2.6)
- A National Centre creates an opportunity to expose the South African community to the new, frontier, cutting edge fields in the mathematical sciences. By attracting top international researchers and ensuring they meet all relevant researchers and graduates in the community, the impact of such visitors can be maximised and graduate student interest in new areas can be sparked and nurtured. (Recommendation 1.4)
- A National Centre would provide an environment for intensive research development in the mathematical sciences. The establishment of a place where researchers could be freed of administrative and teaching demands for periods of time would address the prime blockage to research expressed by those interviewed. (Recommendation 1.3)
- A National Centre would enable the development of capacity in graduate students, post-doctoral fellows, and young academic staff. By bringing together graduates from all universities, it would be possible to provide specialised courses delivered by local and visiting academics that would not otherwise be broadly available. (Recommendation 1.2)
- A National Centre would provide an environment within which synergy can be generated between mathematicians, mathematics educators and teachers. The combined efforts of mathematicians and mathematics educators working together on a national basis is needed to enhance the level of mathematics exhibited in schools, the mathematical quality of teachers and teaching, and the universal provision of quality undergraduate mathematics learning. (Recommendations 3.1, 3.2, 3.3)
- A National Centre would provide a place where teachers can be exposed to the discipline of mathematics, be re-inspired and continue to update their own mathematical knowledge. The vertical integration of mathematical sciences can only take place on a national level.

Workshops are needed where teachers interact with mathematicians and mathematics educators, meet cutting edge mathematics and modern applications, and learn about university mathematics courses so that they may properly prepare and inspire their students for tertiary mathematical study. (Recommendation 3)

- A National Centre would become a central clearing-house and production centre for materials enhancing the image of mathematical sciences amongst the South African population, particularly young people. (Recommendation 4)
- A National Centre would have a close connection with AIMS, possibly including joint programmes, to maximise the contact with international researchers and promote interchange between graduate students. (Recommendations 2.1, 2.3)
- A National Centre would be a mathematical conduit inward and outwards, both bringing to South Africa top mathematicians in all fields and facilitating contact with all universities, and also show-casing South African mathematical science for the outside world. (Recommendation 2)
- A National Centre would facilitate linkages inside South Africa between *all* academics and related academic centres (For example, NITheP), government institutes (for example, CSIR), and business and industry. (Recommendations 2.4, 2.7)
- A National Centre would be a central resource of research in South Africa. It would facilitate connecting all South African mathematicians using the web: shared courses, information about conferences and visitors, access to online mathematics journals, the centre of distributed interactive video lectures, and it would be a focus for production and dissemination of research. (Recommendations 1.2, 1.3, 2.2–2.4)
- A National Centre would be the centre of national activities in the mathematical sciences, for example, initiatives aimed at identifying and harnessing the country's latent mathematical talent. (Recommendation 1.1)

Aim

The aim of the centre will be to facilitate research in the mathematical sciences, develop of mathematical science research capacity, and promote mathematics and mathematical learning at all levels of society.

Objectives

The objectives will be:

- to facilitate research workshops that bring together researchers in all the mathematical sciences (including mathematics education) from different institutions with overseas experts to undertake high level research collaborations on critical contemporary problems;
- to provide a forum for discussion about mathematical sciences research and its applications with other stakeholders in South Africa, including academic, business, and governance institutions;
- to promote the innovative development and application of mathematical sciences research;
- to develop capacity in the graduate student body by arranging opportunities for all graduates to undertake study under the top mathematical sciences researchers available;
- to embody a national structure for the development nationwide of mathematical knowledge for teaching through interaction between mathematicians, mathematics educators and secondary teachers;
- to nurture developing talent from school level upwards;

- to promote the mathematical sciences amongst the South African community.

Deliverables

If NCOMS is established in such a way that the essential recommendations are implemented, then we could expect the following deliverables are reasonably achievable in 5 years and 10 years respectively.

Within 5 years:
a) The number of students majoring in the mathematical sciences will increase by 50%;
b) The number of graduates entering secondary teacher preservice will increase by 20%;
c) The number of publications in international journals will increase by 30%;
d) The number of joint publications with leading academics should become visible particularly from previously disadvantages universities;
e) The number of researchers, including faculty, postgraduate students and postdoctoral fellows will increase by 20%;
f) There wll be a visible increase in activity to raise the profile of mathematics in schools.

Within 10 years:
a) The numbers of students undertaking Honours or Masters in the mathematical sciences will increase by 50%;
b) The numbers of enrolled PhDs in the mathematical sciences will increase by 50%;
c) The numbers of teachers entering secondary teacher preservice will increase by a further 30%;
d) The number of publications in international journals will increase by a further 30%;
e) The number of publications in international journals by younger academics (aged less than 40) will increase by 30%;
f) There will be a more than 300% increase in students qualifying for science courses at universities;
g) There will be an overall visible vibrancy in mathematical teaching and research at school and university through participation in Olympiads, workshops, and teacher upliftment initiatives.

In addition, we expect other improvements to the mathematics base in South Africa over the next 5 to 10 years. These will include the following:
1) The younger age profile (less than 40 years) and regional profile (South African born) of academics and researchers in mathematics, applied mathematics and statistics will have improved to more than 60%.
2) The major topics of active research in mathematics will be developed in South African universities. All major contemporary areas will be significantly represented in at least five universities.
3) The positive impact (on levels of instruction and image of mathematics amongst high school students) of teacher training through visits by high school teachers to workshops at the Centre will be measured by keeping track of these teachers and their activities. At least 10 teachers who have been on fellowships to the Centre will be in active leadership roles in the national mathematics teaching community.
4) The Centre's activities through its high profile public lectures on developments in modern mathematics, mathematics education and in technology, mathematics competitions will have enhanced the image of mathematics in South Africa.
5) We can expect successful bids for running the 2018 International Congress of Mathematics and the 2016 ICME Congress.

Features of NCOMS

The development of NCOMS will be negotiated with all interested parties and will depend on funding and availability of space, etc. However the Panel recommends the following essential physical and operational features.

- NCOMS will be a common central facility separate from any university, but serving all.
- NCOMS will have the infrastructure for undertaking research in the mathematical sciences, that is, library, computing, and administrative services.
- NCOMS will have the facilities to host residential workshops of up to 50 people.
- NCOMS is to be a centre for undertaking research and a forum for research collaboration in pure mathematics, applied mathematics, statistics, and mathematics education.
- NCOMS is to be a place where graduates can undertake specialised courses.
- NCOMS is to be a centre for promoting interaction between the mathematical sciences and associated disciplines and centres.
- NCOMS is to be a world leader in having a national structure to bring together mathematicians, mathematics educators and teachers.
- NCOMS must be the central facility for the promotion and dissemination of mathematics and mathematical research.

The success of NCOMS will depend to a large extent on its directors and Board. It is important that the persons chosen can address the goals of the centre.

National Centre of the Mathematical Sciences

The following detailed description is intended as a statement of possibility, not a prescription for the design and operation of the Centre. It is intended to give a feel for how it could work in practical terms. In reality, the design, development and functioning of such a Centre would need to respond to input from many stakeholders, primarily the university departments it serves, but also the practicalities of people and existing organisations.

Physical Environment

The Centre would consist of a suite of about ten academic offices, 5 administrative offices, administration/reception centre, 3 or 4 seminar rooms, a medium-sized lecture theatre (≈100-seat), an a common area. There would also be a residential complex for 50 people and associated dining rooms, kitchen, laundry. It should include (or be located close to) recreational facilities (gym, swimming pool). The Centre would need to be close to shops and not too distant from larger conferencing facilities.

It would have a library, with full access to on-line journals and MathSciNet. It would have a growing journal collection. It would have high-speed and reliable IT facilities, including a computer laboratory and relevant software.

Staff

The Centre would have a permanent staff of:

Scientific Director	A senior academic on 3-5 year secondment from their university.
Associate Director	A senior academic on 3-5 year secondment from their university. This person has responsibility for the Programmes.

(one of these two positions should be filled by a Pure Mathematician)

Development Director	A senior academic with a mathematical background AND experience in mathematics education and/or in-service teacher development.
Administrative staff	Two administrative staff and an IT support person. (If it incorporates SAMF then there may need to be a publicity coordinator and other staff).

Staff to run the Residence.

University Liaison	Each university will have an existing staff member who is appointed as an NCOM Liaison person who is charged with ensuring that NCOMS activities and opportunities are made available to staff, and to act as a means by which university needs are communicated to NCOMS.

Governance

A Board with representatives from universities, NRF, CSIR, DST, DoE, Business.

Programmes

The Centre would have two prime functions:

a) Programmes
   A programme will consist of a 3-4 week period of academic activity centred around a particular field within the mathematical sciences. It will take many forms, but would

normally involve short term visiting academics, a graduate course, and a teacher outreach component. There could be 6-7 such programmes within a year.

b) Visitors
The Centre will host 3-5 academics for longer periods (up to 6 months) who are academics from within South Africa on sabbatical. It is suggested that these academics be replaced in their universities by NCOMS-funded Teacher Fellows with teaching responsibilities (see Recommendation 1.3a).

The Centre will have other associated activities:

i) Embedded Professors. There should be three or four long-term (6-12 month) overseas visitor positions. These visitors would be members of the Centre but would be embedded in one of the universities for their stay. They would be expected to be available to the Centre for one or more programmes during the period of their stay. They may also be required to travel to other universities on a visiting lecture programme. Such positions would normally be overseas academics on sabbatical leave.

ii) It should have a publicity and coordination function of the kind currently undertaken by SAMF (indeed it makes sense that the existing SAMF be part of the Centre).

iii) Talent scouting and nurturing.

iii) It could host small conferences in the periods when a programme is not in operation.

iv) It could host national Olympiad workshops or mathematics competitions.

v) It would organise keynote lectures and make them interactively accessible to all university centres.

vi) The centre would develop a national in-service programme for secondary teachers on mathematical knowledge for teaching, using mathematicians and mathematics educators in collaboration. This programme may be a distance education programme, or be run collectively through the universities.

Sample Year

The following outlines a sample year's activities: including 6 Programmes, two mini-conferences, the Olympiad workshop, a Stakeholder seminar, and an Industrial seminar. (The programmes would include two in each of Pure Mathematics and Applied Mathematics, and one in each of Statistics and Mathematics Education).

Programmes
Each programme would have three parts: a School which would operate for the entire period, a Graduate Course and Teacher Seminar which would operate one after the other in parallel with the School.

School: The School would involve the gathering of 10-15 academics and accompanying graduates from a particular area of the mathematical sciences, including at least two overseas high-level academics (possibly one of the Embedded Professors). This group would stay together for four weeks, and organise their own interactions and activities (lectures, seminars, problem-solving, individual or collaborative work). They would live and work at the centre intensively over this period.

Graduate Course During weeks 2-3 of the programme there would be a graduate course in which 25-30 Honours/Masters/PhD students would come to the Centre for a series of lectures, workshops, tutorials, and to interact with the programme

visitors. This course could include an assessment and become credit-bearing under circumstances suitable to each university.

Teacher Seminar. In the final week of the programme the Graduate students would be replaced by 25-30 secondary teachers including a few mathematics education academics for a seminar programme related to the theme of the programme. This would consist of suitably targeted lectures by the programme visitors, workshops on the relation of that topic to school mathematics curriculum, and possibly other sessions on mathematics education issues of the day.

We should emphasise that these activities do not replace the work of other institutions (e.g. AIMS) since NCOMS will perform a different function and be more comprehensive in scope. Bringing together people will help to counteract the negative feelings of psychological isolation that we encountered in our review.

Road-Map to NCOMS

The Panel views the establishment of a national centre as essential in the middle-term. We recognise that it will not be possible to immediately commit to purchase a building or start construction on a purpose-built facility, however we strongly recommend an early signal to the community that a centre will exist. A steering group should be immediately formed, and a Governing Board quickly established.

There are many functions of a centre that can be initiated immediately. While we warn against allowing functions to become "owned" by existing universities, the temporary location of some activities there on a rotating basis is quite feasible. Furthermore it will be possible to initiate centre faculty and administrative positions quickly, and begin to develop programmes and workshops. Where existing organisations will become part of the centre (for example SAMF), these can, with everyone's agreement, be rebranded and form the nucleus of the centre.

The urgency for creating a nominal centre is as much psychological as functional. Getting involvement and cooperation on a national level will not, in current conditions, be easy. The inward, institution-oriented approach to research in the mathematical sciences needs to be transformed into a national approach. SAMS and AMESA need to be supported to be better able to serve the research community so that they attract a much higher proportion of the community as active members.

Below is a suggested Road-Map of actions that may be taken towards the establishment of NCOMS. It will, of course, be modified by the steering body and then the governance body as these are established, but may be taken as a blueprint from which to move forward.

2009

- Initial commitment of intent and seeding funds from DST
- Establishment of a Steering Body, to include representatives of all universities, of all mathematical sciences (pure mathematics, applied mathematics, statistics, and mathematics education), from CSIR, and from business and industry.
- Advertising and appointment of the Scientific and Development Directors. (The second of these could, in the first instance, be ex officio, the Director of SAMF).
- A decision made on the ultimate general location of the centre. The Panel recommends that somewhere in Gauteng be considered, but understands that the decision is likely to be a function of considerations well outside the Panel's purview).
- Develop an NCOMS website.

- An initial school/workshop be organised towards the end of the year with high-profile overseas guests. Such a workshop could be timed to occur around the international DELTA conference on Undergraduate Mathematics to be held in the Cape region in November. This would also be an obvious time to have a nominal "Opening" of the centre with public and media involvement.

  Given the urgency of the situation in Statistics, we recommend that this first workshop be on a statistical topic, and that associated publicity focus on society's needs for a strong statistical resource.

2010

- Establishment of a temporary office in the region in which the full centre will ultimately reside. This could be a suite of offices and a seminar room in another building. The Panel recommends that this NOT be sited on an existing university campus, but might be close by.
- Negotiate a national e-journal subscription covering all relevant journals and accessible by academics from all universities through the NCOMS website.
- Establish office staff to be associated with NCOMS. This may include SAMF staff with a commitment to permanent funding.
- Negotiate with universities to find a mechanism to give credit to graduates attending NCOMS schools.
- Begin a cycle of NCOMS school/workshops to be hosted by universities. Preference should be given to disadvantaged universities. Funding needs to be provided to bring high-profile mathematicians from within South Africa and internationally, and to support graduate students in significant numbers. Gradually develop a programme such that each research workshop has a parallel graduate school, a parallel teacher workshop, and an event for local senior school students. Three workshops per year could be the target, possibly only two in the first year. Workshops should rotate around the mathematical sciences in the approximate ratio Pure Mathematics : Applied Mathematics : Statistics : Mathematics Education = 2:2:1:1.
- Appoint a National Research Fellow. We recommend as follows. This first Fellow be an early- or mid-career academic who shows promise to produce international level research. The first Fellowship should be a six-month appointment in the second half of 2010. Subsequent Fellowships may be six- or twelve-months. This person should be located in the temporary office of NCOMS, but needs to be funded to travel to other universities in South Africa. An expectation of the Fellowship would be to give seminars in at least three universities, two of which would not be a top-tier university.
- Appoint an NCOMS Teaching Fellow. This person would be associated with the National Research Fellow. The Teaching Fellow would be a suitably qualified secondary teacher who would be appointed on full pay to the university of the National Research Fellow, and would undertake undergraduate teaching at first year level (thus relieving the teaching burden of the absence of the Research Fellow). The school would be funded for a replacement teacher.

2011-12

- Continue Schools/Workshops, Research Fellowship(s) and associated Teacher Fellowships.

- Initiate interactive video lectures with equipment available in all universities.
- Establish regular NCOMS forums with business and industry, associated centres, and government/policy-makers.
- Move towards a permanent dedicated centre.
- A national in-service programme on Mathematical Knowledge for Teaching to be available to all secondary teachers.

2013-4

- Permanent Centre to be built. Target date for opening: 2014
