Australian Academy of Science

NATIONAL COMMITTEE FOR
MATHEMATICAL SCIENCES

The mathematical sciences in Australia

Mid-term review

Australian Academy of Science

NATIONAL COMMITTEE FOR
MATHEMATICAL SCIENCES

The mathematical sciences in Australia

Mid-term review

The images in this document are from the Australia Academy of Science schools photography competition scienceXart: spot the maths. The competition was hosted in 2020 by the Academy's National Committee for Mathematical Sciences, in collaboration with reSolve. The competition was supported by the Australian Mathematical Society and the Statistical Society of Australia. This initiative was part of the Academy's celebration of the Centennial of the International Mathematical Union in 2020. The photographs are used with the kind permission of the competition entrants. The descriptions below were provided by the students for their competition entries.

Page iv: Natalia—*Island Reflection*. First Prize, Year 10–12 category. This is a photo of an island and its reflection. It displays geometry in the form of symmetry where the island and its reflection becomes exactly like another when you fold it.

Page 2: Janay—*Golden Concentric Circles*. Shortlist, Year 10–12 category. When observing the glorious sunrise captured over the Flinders Ranges, two concentric circles are seen. Formed through a lens flare, the circles share an origin point, but differing radii. Nonetheless, they share a squared relationship.

Page 4: Jan—*Succulent*. Shortlist, Year 7–9 category The growth and self-renewal of cell populations leads to generation of hierarchical patterns in tissues that resemble the pattern of population growth in rabbits, which is explained by the classic Fibonacci's sequence demonstrated in this!

Page 6: Otylia—*Sparrows on the fence*. Statistics Prize. This photo shows Welcome Swallows sitting on a fence. There are five rows of nine squares and twelve squares are taken by a swallow therefore 26.67% of the boxes in the fence are occupied by swallows.

Page 12: Andre—*Column Graph Compressed*. Shortlist, Year 7–9 category. The clustered high-rises in this photo appear as column graphs, which are visualisations of data. High-rise occupancy and demand is normally high but statistically, 80% of these high-rise rooms were unoccupied during the COVID-19 lockdown.

Page 26: Max—*Bubbles*. First Prize, Year 7–9 category. When bubbles merge, various shapes can form, due to one key property: maximisation of volume relative to surface area. While one bubble is spherical, as more join, it starts to form a hexagonal pattern, with its very efficient 120° angles.

Page 31: Ciara—*Coins*. Shortlist, Year 7–9 category. We use money for a lot of different reasons. We can use it for buying things, which requires calculating a total, and budgeting, which requires saving the right amount of money while keeping the money we need to live and feed our families.

Page 32: Zayne—*Spiral Rose*. Shortlist, Year 10–12 category. The petals of the rose are arranged in a Fibonacci spiral. The Golden Ratio (Phi) from which it derives is the basis of all life. The Fibonacci numbers on a rose show that each petal is dependent on the others preceding it. 1 2 3 5 8 13 21

ISBN (print version): 978-0-85847-874-9
ISBN (digital PDF version): 978-0-85847-873-2

Prepared by the Decadal Plan Steering Committee on behalf of the National Committee for Mathematical Sciences

Cover image: Liz Shreeve

Contents

Executive summary 1
- Findings of the mid-term review 1

1. The decadal plan 3

2. The mid-term review 5

3. Recent developments and context 7
- 3.1. The COVID-19 pandemic 7
- 3.2. Job-ready Graduates Package 8
- 3.3. University restructuring 9
- 3.4. F–10 curriculum review 11

4. Decadal plan objectives 13
- Objective I — Give all Australian schoolchildren access to outstanding mathematics teachers 13
- Objective II — Guarantee high standards of mathematical sciences teaching at Australian tertiary institutions 15
- Objective III — Achieve both global and local impact for Australian research in the mathematical sciences 17
- Objective IV — Ensure that Australian society is capturing the benefits of mathematics-based technologies 19

5. Developing issues 21
- 5.1. Gender and representation of minority groups 21
- 5.2. Funding changes from the Job-ready Graduates Package 22
- 5.3. Data science 23
- 5.4. Biostatistics (statistics in medicine) 23

6. Conclusion and general comments 25

References 27

Executive summary

The 2016 decadal plan *The mathematical sciences in Australia: a vision for 2025* presented an overview of the priorities, objectives, goals and recommendations for the mathematical sciences in Australia over the following decade. Now halfway through its lifetime, the National Committee for Mathematical Sciences presents a review of this plan and notes updates against the objectives identified by the mathematical sciences community in 2016.

The decadal plan set out objectives for Australia to improve access for school students to outstanding mathematics teachers, guarantee high standards of mathematical sciences training at a tertiary level, achieve global and local impact from Australian mathematical sciences research, and see benefits to the nation from mathematics-based technologies. These objectives informed 12 recommendations that would enable progress against the objectives.

This review has highlighted that there are significant challenges facing the mathematical sciences community. The recent impacts of the COVID-19 pandemic on the university sector have caused notable losses to the mathematical sciences research community, including the exacerbation of gender imbalances in the mathematical sciences workforce. In addition, changing governmental policies for the university sector do not align with government's stated goals and expectations and are not supported with appropriate funding for the research sector to realise them.

These impacts affect not just mathematical sciences research outputs but also the quality of mathematical and statistical education available at all levels. Many within the community are concerned about these impacts on the discipline.

Findings of the mid-term review

The review found that the original objectives of the decadal plan remain relevant and important to the community, and opportunities arising in the changing sector should continue to be identified and progressed. These opportunities can only be realised with appropriate recognition of the role of the mathematical sciences in responding to developing areas of interest from the government and research sectors, paired with infrastructure and resourcing.

In particular, the review recommends:

1. Continuing to develop programs and address current issues in teaching to give all Australian school students access to outstanding mathematics teachers
2. Urgently addressing the cuts to mathematical courses at universities, which have impacted the ability for Australian university students to access a degree in which they can major in the mathematical sciences
3. Emphasising the contributions of mathematical sciences in responding to national challenges and informing policy decisions.

1. The decadal plan

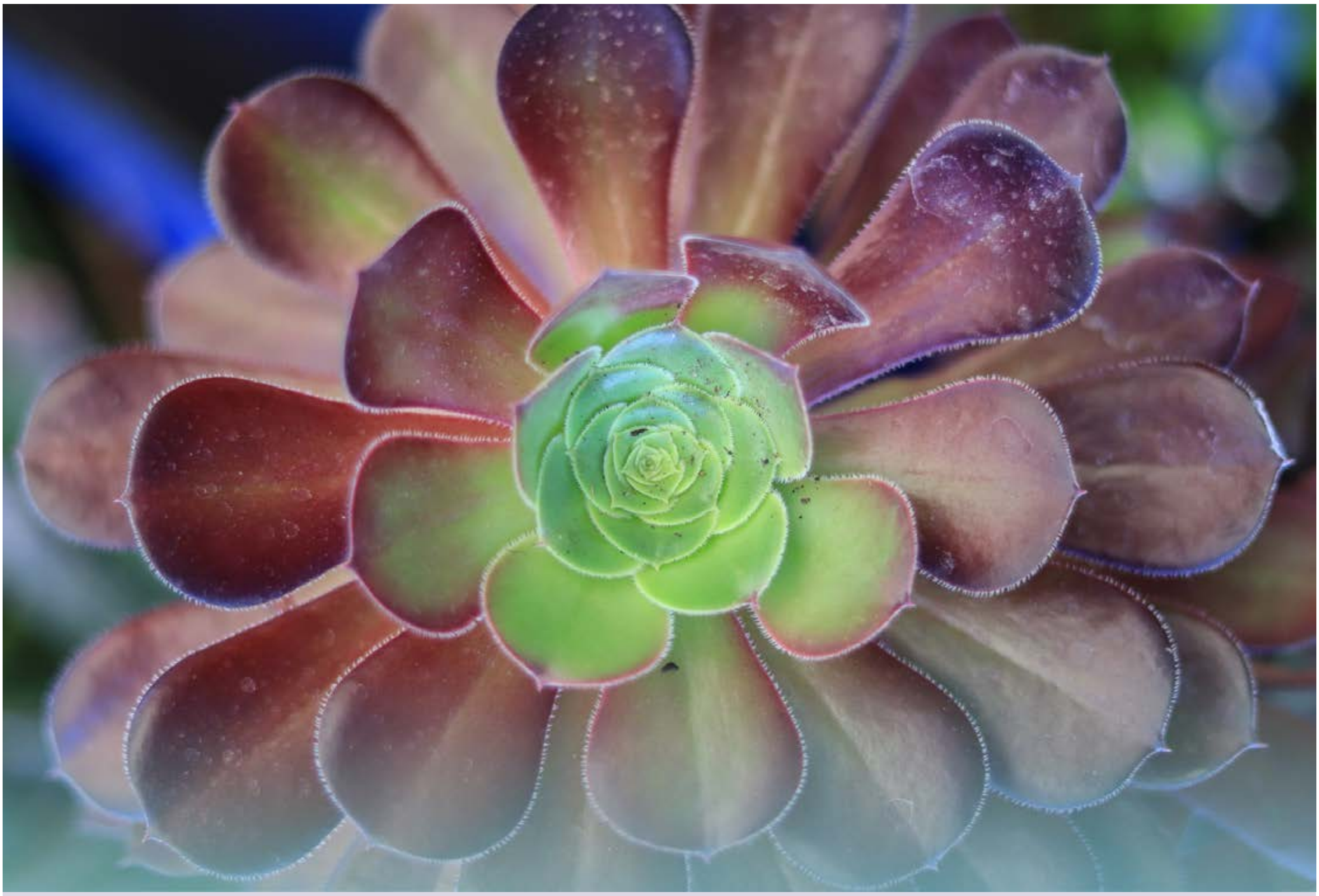
The *Decadal plan for the mathematical sciences* ('the decadal plan'; AAS 2016) was created by the Decadal Plan Steering Committee on behalf of the Australian Academy of Science's National Committee for Mathematical Sciences (NCMS) following an extensive consultation process with mathematical scientists working in schools, universities, government agencies, and industry.

The mathematical sciences include mathematics, statistics, data science and mathematics-based disciplines including teaching, teacher education and educational research. These disciplines have a fundamental role in our financial, economic, communication, social and environmental systems, and drive advances in many fields of science and technology. The decadal plan set out four objectives and recommendations to ensure that Australia benefits fully from its mathematical sciences community:

1. Give all Australian schoolchildren access to outstanding mathematics teachers.
2. Guarantee high standards of mathematical sciences teaching at Australian tertiary institutions.
3. Achieve both global and local impact for Australian research in the mathematical sciences.
4. Ensure that Australian society is capturing the benefits of mathematics-based technologies.

These objectives generated 12 recommendations; these are presented and discussed in Section 4 below.

The decadal plan committed the mathematical sciences community to working collaboratively with universities, school authorities, and the Australian Government to deliver the shared vision.



2. The mid-term review

The decadal plan requires the discipline, through the NCMS, to formally monitor progress on the recommendations. At five years into the life of the decadal plan, the committee conducted a mid-term review of progress against the recommendations.

The NCMS has carried out the mid-term review by pursuing four key activities. First, for recent developments and the context of the review, the committee obtained input from the professional societies represented on the NCMS and the Australian Council of Heads of Mathematical Sciences (ACHMS). Second, the committee updated data included in the decadal plan. Third, the committee contacted the chairs of the seven subcommittees that developed the decadal plan and asked for their views on progress on the recommendations that came from their subcommittees.

Finally, the input from the chairs was summarised in a consultation document that was released to the mathematical sciences community for feedback. The COVID-19 pandemic prevented the intended face-to-face town-hall meetings to discuss the issues. Instead, feedback was invited through the professional societies represented on the NCMS and ACHMS and interested members of the community submitted their feedback online. Following discussion within the committee, four subcommittees were created to report on developing issues for the community.

3. Recent developments and context

The decadal plan (AAS 2016) identified key opportunities and challenges facing the discipline in 2016. The environment remained relatively stable until 2019, with some positive and some negative developments that are summarised in Section 4 below. However, a period of rapid change and significant external pressure began in early 2020 with the onset of the COVID-19 pandemic. This was followed by the introduction of the Australian Government's Job-ready Graduates Package in October 2020, as well as structural changes in several universities in 2020–21 that directly affected the mathematical sciences. In 2020 and 2021, the Australian Curriculum, Assessment and Reporting Authority (ACARA) undertook the Review of the Australian Curriculum, which included a 10-week public consultation period April to July 2021.

To provide context for the mid-term review, we discuss each of these events and some of their consequences for the Australian mathematical sciences community, recognising, of course, that these events have had a far wider impact. Later sections include more detailed reactions from the discipline, including some preliminary suggestions for future steps in response

3.1. The COVID-19 pandemic

The World Health Organisation declared COVID-19 a pandemic on 11 March 2020 (WHO 2020). The pandemic has caused worldwide social and economic disruption, and the Australian mathematical sciences community has felt various impacts of the pandemic.

Lockdowns and other public health measures (different in each state or territory) have impacted teaching in both schools and universities, imposing a nearly instantaneous switch from face-to-face to remote or hybrid methods of delivery. The assessment of student learning became a more widely recognised issue. Concerns about how senior secondary/Year 12 school assessments would be conducted received considerable attention (Klinger 2022), but ultimately these assessments were completed, both in 2020 and 2021. Universities saw an increase in lightly or unsupervised remote assessment that has highlighted ongoing problems in protecting the assessment integrity. In addition to the impact on teachers, lockdowns of schools required parents to provide increased care and supervision, often while trying to perform their own work.

Australia closed its international borders to most non-citizens and non-residents on 20 March 2020 (PM 2020) and, although international travel has since recommenced, severe and prolonged travel restrictions continue to have lasting impacts on the sector (Home Affairs 2021). The restrictions on international travel led to the postponement or cancellation of many face-to-face events that positively benefit research, including facilitating in-person international collaboration. However, there have been some compensatory benefits from a greater use of online technology.

In addition, following a steady increase in numbers since 2012, the number of international students studying in Australia in 2020 decreased (DESE 2020a) and a consequential loss of income put immediate pressure on many universities (Hurley 2021). While recovery has begun, it remains unclear what the long-term prospects are for attracting new international students. This is an area with the potential to significantly influence the mathematical sciences research community in coming years.

As part of its economic response to COVID-19, the Australian Government introduced the JobKeeper Payment scheme on 30 March 2020 to assist eligible businesses and not-for-profits to cover the cost of wages, which ran until 28 March 2021 (Treasury 2021). The eligibility criteria for accessing the scheme required universities to show a drop in revenue over six months (ATO 2020), instead of over one or three months as required for other businesses and not-for-profits. This effectively rendered universities ineligible for the scheme. Four private universities were granted exemptions from the requirement. This was not extended to any public universities (Zhou 2020a), however the Australian Government's Research Support Program was modified in 2021 to address challenges raised by the pandemic, and these changes were extended into the 2022 funding (DESE 2021).

Universities Australia estimated that Australian universities shed at least 17,300 jobs in 2020 and lost $1.8 billion in revenue compared to 2019 (a 4.9% fall) and predicted that the sector would lose a further $2 billion (or 5.5%) in 2021 (Universities Australia 2021).

As highlighted in the European Women in Mathematics' open letter (EWM 2021), the impacts of the pandemic have not been experienced equally. Women, early-career researchers and those with caring responsibilities have been disproportionately affected:

- Women were more likely to be experiencing high levels of psychological distress (23% of women compared with 17% of men) (ABS 2021).
- Support for domestic tasks and caregiving decreased, leaving much of the burden for these tasks on women (Batchelor 2020). When schools moved to emergency remote teaching, the task of supporting student at-home learning in addition to their own work responsibilities fell heavily on women. Women were also more likely to be providing care to a vulnerable person (19% of women compared with 12% of men) (ABS 2020).
- The number of enrolments in Australian tertiary institutions decreased by 112,500 in the year to May 2020, with 75% of those dropped enrolments coming from women (Zhou 2020b).
- The cancellation of events that support women in mathematics, including events for International Women in Mathematics Day, and an Australian Mathematical Society (AustMS) Women in Mathematics Special Interest Group (WIMSIG) conference that had been planned for 2020, had significant impact; studies show that such events lead to many positive outcomes for women, including increased promotions and pay, and increased feelings of optimism and satisfaction with their career (Achor 2018).
- Reports that women-authored research articles in various disciplines were submitted at a much lower than normal rate during 2020 (Kitchener 2020) are concerning. Before the pandemic, publication rates for women were already significantly lower than men in elite journals. Globally, less than 10% of publications in the most prestigious mathematics journals are written by women (Roy 2020).

3.2. Job-ready Graduates Package

The Australian Parliament passed legislation for the Job-ready Graduates Package in October 2020 (DESE 2020b). Notwithstanding the ongoing pandemic, the package included changes to the funding of universities that are having a major impact on the mathematical sciences.

Two key aspects of the package were:

(i) Adjustments to the student contributions of Commonwealth-supported students enrolling from 2021 onwards, intended to incentivise them to choose subjects that have better graduate job prospects or align with national priorities

(ii) Adjustments to Commonwealth contributions for the same students, based on a new estimate of cost per student across various subject areas.

Incentives for students to enrol in less costly subjects conflict with incentives for universities to maximise enrolments in subjects that attract the most income relative to cost.

In particular, the mathematics subject area was moved to the lowest band for student contributions, while the Commonwealth contribution did not increase by as much as the student contribution decreased. Consequently, there has been a 17% cut in funding to the university per enrolment in a mathematics unit by a Commonwealth-supported student.

Contributions per EFTSL for Mathematics	**Maximum student contribution**	**Commonwealth contribution**	**Total**
Pre-2021 enrolment	\$9,698	\$11,015	\$20,713
2021 enrolment	\$3,950	\$13,250	\$17,200

Reference: DESE 2020c. EFTSL = Equivalent full-time student load.

Mathematics is one of the disciplines disadvantaged by the new funding arrangements (IRU 2020). This may already have been built into forward planning in some universities. As Norton (2020) commented, 'universities are more likely to respond to financial incentives than students. Students can defer paying their student contributions through the HELP loan scheme, which reduces their price sensitivity. Universities have to meet all their costs each year. In the midst of a financial crisis, universities will examine their revenues and expenditures more closely than ever.'

Another facet of the Job-ready Graduates Package was the addition of Commonwealth-supported places for higher education 'short courses'. The trend towards universities offering short courses and micro-credentials is a potentially difficult development for disciplines that have traditionally presented their subject through the carefully ordered build-up of material that requires time to absorb and understand. Short courses can be useful for building skills targeted to the needs of particular cohorts of learners, especially when they are thoughtfully constructed as a suite of programs that provide a strong, cohesive foundation in an area. However, they are a complement, rather than a replacement, for formal university mathematics courses.

3.3. University restructuring

Restructuring and funding cuts in the universities had a major impact on the mathematical sciences in 2020–21. Redundancies in several strong mathematics departments across the country are, and continue to be, at least partially attributable to the projected cuts.

Some of the staff losses (not just in the mathematical sciences) are due to voluntary redundancies. These are often targeted at older staff, effectively becoming a form of induced early retirement. As they can be essentially random within the eligible cohort, voluntary redundancies can result in major, unplanned losses of experienced staff across the whole sector that are very difficult to replace. Other staff losses are simply resignations. In addition to experienced, senior staff departing the system, young staff are also looking to leave Australia or academia. The previously closed borders and ongoing economic situation may mask damage by making the 'brain drain' look smaller than it actually is, which may become more apparent over time.

An issue of key concern is that those people seeking to leave Australia and academia are more likely to be women or from other underrepresented groups (AAS 2021). Hence, the cuts across the sector are having a flow-on effect on gender balance in mathematical sciences departments. Also, with fewer women role models, we can expect that fewer women students will continue with postdoctoral study and academic careers, so the gender balance within mathematical sciences departments will likely worsen in future.

Murdoch University provides an example of the impact of university restructuring on the mathematical sciences community in Australia. Murdoch cancelled its majors in mathematics and statistics, as well as physics, chemistry and other disciplines, at the beginning of 2021. These disciplines, at least four of which are science, technology, engineering and mathematics (STEM) disciplines, are now required to teach into other courses and majors at Murdoch, but no longer have their own majors.

Staff at Murdoch University can be awarded research workload if they meet the performance criteria for their level and discipline and are aligned to a research focus area. The criteria for staff in mathematics are almost impossible to satisfy by anyone, including experienced, successful researchers, but they disproportionately disadvantage women and early-career researchers. At this stage, with few staff assigned any research time, the effect of the policy is similar to moving all staff to teaching-only contracts. The impact of these changes has led to the rapid departure of staff, most through resignation. At the beginning of 2020, there were 12 academic staff (six men and six women) in mathematics. By mid 2021, five academic staff had departed, leaving at total of five staff (three men and two women). In 2020, the 12 mathematics and statistics staff taught 3,000 students across multiple campuses; the same is now required of the remaining five staff.

Similar issues with restructuring have occurred around the country:

- The Statistical Consulting Unit at the Australian National University (ANU) provided high-quality statistical support for researchers and research students since its foundation in 1982. It was disestablished in mid-2021, with the loss of two of its three staff (one man, one woman, with one woman remaining).
- Macquarie University has announced a wide-ranging change proposal that includes merging mathematics (containing statistics) and physics, with the planned loss of between four to five mathematicians (level B/C) and three to seven statisticians (level C/D), who can be replaced by up to three teaching and leadership academics, with preference given to internal transfers.
- The University of Newcastle announced proposals to merge the School of Mathematical and Physical Sciences with the Computer Science and Information Technology discipline of the School of Electrical Engineering and Computing, to form a new school with the proposed name of the School of Information and Physical Sciences. The proposal merges mathematics and statistics into a single discipline of 'mathematics and statistics'. The proposal results in a loss of four positions and the replacement of several others (including replacing three level E positions in statistics with one level D position in statistics and one in data science; and replacing two level C positions in statistics with one in data science).

Losses of staff in the mathematical sciences may increase the likelihood of service mathematics courses being taught either by non-experts from the service disciplines, or by research-inactive mathematicians employed solely to deliver service teaching. Having a high proportion of mathematical science courses, including service courses, designed and taught by educators who are not up-to-date with new developments in the mathematical sciences has the potential to lead to a decrease in the quality of graduates. This is the university version of the problem of out-of-field teachers in schools.

3.4. F–10 curriculum review

In June 2020, the Education Council asked the Australian Curriculum Assessment and Reporting Authority (ACARA) to review the Australian Foundation to Year 10 (F–10) Mathematics Curriculum as part of a six-year cycle of review of the Australian Curriculum. The first draft of the review was released for a 10-week public consultation period that ended in July 2021, and the final version, the Australian Curriculum Version 9.0, was endorsed by education ministers in April 2022 (DESE 2022).

In research performed before the start of the review that informed the terms of reference, ACARA determined 'that there is no need, nor support for, a major overhaul of the F–10 Australian Curriculum, but there is broad-based recognition that the current curriculum needs refining, updating and "decluttering" to better support teachers with implementation' (AAMT 2020).

There were diverse views within the mathematical science community on the public consultation version of the review of the Australian Curriculum for Mathematics, and whether it achieved the goal of 'refining, updating and decluttering' the mathematics curriculum, or presented a more radical change. The review may yet have significant impacts on the mathematical sciences and it is potentially very important.

4. Decadal plan objectives

Objective I — Give all Australian schoolchildren access to outstanding mathematics teachers

The statement and position of this objective recognised that the most critical pipeline issue for the future health of Australian mathematics, at all levels, is that there are enough teachers who are properly qualified and supported to inspire school students with an appreciation of the fundamental utility and beauty of mathematics. However, what was already a 30-year decline in the supply of secondary mathematics teachers worsened over the first five years of the decadal plan period.

Prince and O'Connor estimate that an Australian student has a 76% chance of having at least one out-of-field mathematics teacher in Years 7–10 (AMSI 2018) and that 45% of secondary school principals reported out-of-field mathematics and science teaching in their schools (AEU 2018). The problem is becoming even more severe as a surge in primary school enrolments flows into secondary schools, with a projected 650,000 extra students by 2026 compared to 2016 (Goss 2016), while an older-than-average mathematics teaching workforce moves into retirement.

Objective I: Give all Australian schoolchildren access to outstanding mathematics teachers

Recommendation	Comments
1.1 Australian governments, schools and universities should urgently increase their provision of professional development for existing out-of-field school teachers of mathematics and enhance their commitment to the recruitment and retention of new, properly qualified staff.	The Australian Education Council's *National STEM School Education Strategy 2016–2026* (AEC 2016) has resulted in significant funding for or extension of projects in STEM education and digital technologies, including some which focus on mathematics, such as reSolve: Mathematics by Inquiry (Australian Academy of Science), Growing Mathematically: Multiplicative Thinking Teachers Manual (Australian Association of Mathematics Teachers), and Online teaching and learning resources to support mathematics and numeracy (Education Services Australia). State and territory governments have mirrored this investment to varying degrees. For example, the Victorian government, as part of its *Literacy and Numeracy Strategy Phase 2* commencing in 2018, funded professional learning opportunities through the Bastow Institute of Educational Leadership for teachers who were nominated by their schools as literacy and numeracy leaders. Resources and opportunities such as these are welcome but fall short of the required level of retraining of out-of-field mathematics teachers. A promising recent step in this direction is the Victorian government funding for an online Graduate Certificate of Secondary Mathematics at Deakin University, targeted at existing teachers. O'Connor and Thomas reported in 2019 that only the NSW Department of Education had a publicly stated plan for addressing teacher supply in areas of shortfall, including scholarships and other incentives tied to positions in schools (AMSI 2019). The supply of mathematics teachers both influences and depends on participation levels in advanced mathematics courses in Year 12, which remained around historically low levels in the first five years of the decadal plan.

1.2 Universities, governments and the mathematics teaching profession should set national standards to ensure that mathematics teachers are properly qualified and to ensure that there are universities capable of preparing mathematics teachers in every state and territory.	All initial teacher education programs are accredited by state/territory authorities against the national program Accreditation Standards and Procedures, most recently revised in 2019 (AITSL 2019a). In addition, all prospective teachers must satisfactorily complete an approved Teaching Performance Assessment and pass Literacy and Numeracy Tests before graduation. Mathematics teachers, like all teachers, also need to continue to meet the Australian Professional Standards for Teachers. However, none of these regulatory interventions are specific to mathematics, and Australia still lacks clear standards for the mathematical content knowledge of teachers comparable to those in the UK and the US. In surveys conducted by the CHOOSEMATHS program, 21% of secondary mathematics teachers with a relevant tertiary qualification reported that their degrees had not prepared them adequately for the mathematics they were teaching (AMSI 2020a). The establishment of such standards has been made more difficult by the decline in the number of Australian universities offering majors in mathematics, and the lack of mathematics graduates going into teaching is largely a consequence of a lack of mathematics graduates overall. The requirement to complete two years of postgraduate teacher education may be a disincentive for many mathematics graduates comparing teaching against other professions. Government initiatives such as Teach for Australia and the High Achieving Teachers Program are steps in the right direction but would need to be expanded to contribute significantly to the supply of new mathematics teachers.
1.3 Governments and other teacher employers should ensure that there are rewarding career paths for mathematics teachers in primary and secondary schools by providing excellent teachers with opportunities for promotion, allowing the best to lead the ongoing development of mathematics teaching within their school, across school clusters, and at regional and state/territory levels.	The Australian Professional Standards for Teachers define Graduate, Proficient, Highly Accomplished and Lead levels. These are intended to reflect career stages and thereby define a career path for teachers but are applied unevenly across the country: in some jurisdictions, Highly Accomplished and Lead teachers attract additional salary, while in others these levels are not even available. According to the Australian Institute for Teaching and School Leadership, in 2018 there were only 573 Highly Accomplished and Lead teachers in all subjects nationally (AITSL 2019b).

Objective II — Guarantee high standards of mathematical sciences teaching at Australian tertiary institutions

This objective addresses the next stage in the pipeline, the teaching of mathematical sciences subjects at the tertiary level. Since the publication of the decadal plan, an already marked division between the Group of Eight (Go8) universities and others has become even more pronounced. The total student load in mathematical sciences subjects has been rising consistently across Go8 universities for at least the past 15 years, while it has been stable across non-Go8 universities (AMSI 2020b). However, increasing financial pressures exacerbated by the COVID-19 pandemic have prompted many Australian universities, especially non-Go8 universities, to make severe cuts to mathematical sciences degrees, meaning that many students can only study the limited number of mathematical sciences subjects required for majors in other areas.

The mathematical community regards this as an extremely alarming development, with potentially ruinous implications for the overall STEM sector and for teacher training, as well as for social equity. Were a decadal plan to be written today, it is likely that a major objective would be to guarantee that all Australian university students have access to a degree in which they can major in the mathematical sciences. To meet the recognised STEM needs of Australian society in the future, we need to increase, not decrease, the number of mathematical sciences graduates.

Objective II: Guarantee high standards of mathematical sciences teaching at Australian tertiary institutions

Recommendation	Comments
2.1 Australian universities should immediately plan for the staged reintroduction of at least Year 12 intermediate mathematics subjects as prerequisites for all bachelor's programs in science, engineering and commerce. This will send an unequivocal message to school communities and significantly improve educational outcomes for tertiary students.	In 2019, the University of Sydney introduced intermediate mathematics prerequisites for bachelor's programs in science and commerce (along with engineering courses where higher entry recommendations were standard), and universities which already had such prerequisites have retained them. Otherwise there has been little change across the sector, with only around 17% of science degrees, for example, having an intermediate mathematics prerequisite (OCS 2020a). In recent years, the mathematical community's feeling around prerequisites has shifted as concern has grown about equity of access to intermediate and higher mathematics subjects in Year 12. In September 2020, outgoing Chief Scientist Professor Alan Finkel AC FAA FTSE expressed a clear preference for encouraging the uptake of school mathematics rather than a wholesale return to prerequisites (OCS 2020b).
2.2 Universities and state tertiary admissions centres should ensure that subject scaling does not discourage students from choosing advanced subjects while at high school, and universities and governments should introduce mathematical awareness programs demonstrating the career choice benefits and financial and social advantages of completing advanced courses.	In the first five years of the decadal plan, universities in Western Australia, South Australia and the Northern Territory have introduced bonuses on entry scores for students who choose intermediate or higher mathematics subjects in Year 12. In October 2019, the Office of the Chief Scientist published a position paper advocating for the removal of any remaining real or perceived disincentives to choose higher levels of mathematics (OCS 2019). Perhaps as a result of such initiatives or the prerequisites discussed above, the percentage of Year 12 students choosing intermediate or higher mathematics subjects, which had declined from over 40% to under 30% in the period 1996–2011, has been relatively stable in the past decade (AMSI 2020c).

2.3 University deans and heads of schools in disciplines outside the mathematical sciences should facilitate liaison between university mathematics departments and those expert in the mathematical needs of these disciplines to see that appropriate mathematics is being taught to students in fields such as engineering, science, commerce, economics and education.	In recent times, the vast majority (92% in 2018) of the university student load in mathematical sciences subjects has been made up of such cross-disciplinary teaching. Most mathematical sciences departments teach students in engineering, science and computer science, and around half also teach students in business, economics and finance (AMSI 2020b, p39). However, the current wave of restructuring in Australian universities is likely to result in a noticeable reduction in service teaching by mathematicians and statisticians. The Australian Mathematical Society, in its submission to the midterm review, expressed concern that some university administrators are moving away from the traditional practice of teaching by discipline experts to a model where students are taught predominantly by the department of their major.

Objective III — Achieve both global and local impact for Australian research in the mathematical sciences

There are some encouraging signs that Australian research in the mathematical sciences has gradually been growing in global impact in the past five years. In the QS subject rankings of world universities, the number of Australian universities ranked in the top 200 for mathematics increased from 12 in 2018 to 14 in 2021, while the number of Australian universities ranked in the top 200 for statistics increased from ten in 2018 to 12 in 2021 (QS 2021). The Australian Research Council's (ARC) Excellence for Research in Australia (ERA) evaluation has been completed only once so far during the period of the decadal plan, in 2018: compared to the previous evaluation in 2015, the number of universities rated as above or well above world standard in the mathematical sciences overall rose from 18 to 25, with slight increases also in each subdivision of the research area (AMSI 2020b). The 2022 ERA review is ongoing at the time of writing this report.

It will be challenging to maintain these higher standards of research in the face of the rapid changes to morale and funding as well as individual circumstances brought about by the pandemic, the Job-ready Graduates Package and restructuring within universities. Restricted travel had an immediate impact on research. The increased use of communication technology has allowed communication between researchers even during periods of isolation, but is no substitute for social interaction with other researchers, keeping up with the field, communicating work in progress and findings to one's peers, and developing and maintaining research collaboration.

Objective III: Achieve both global and local impact for Australian research in the mathematical sciences

Recommendation	Comments
3.1 Australian universities should collaborate with the discipline to source seed funding for a new national research centre in mathematical sciences with the objective of enhancing connectivity with industry and strengthening the international collaboration and visibility of Australian research in mathematics and statistics.	The Mathematics Research Institute, MATRIX, was launched in 2016 as a partnership between the University of Melbourne and Monash University. MATRIX is a residential research institute (located in Creswick, Victoria) for bringing people together to deepen mathematical knowledge, initiate collaborations and stimulate innovative thinking. The ANU became a MATRIX partner in 2020, and the ARC Centre of Excellence for Mathematical and Statistical Frontiers (ACEMS) and the University of Queensland are associate members. The Sydney Mathematical Research Institute (SMRI) was established at the University of Sydney in 2018. SMRI promotes collaboration in the mathematical sciences by funding international researchers to visit Australian universities. Both of these initiatives are contributing to meeting the objectives of a national research centre in the mathematical sciences. However, in spite of their critical importance to the mathematical sciences, neither institute has yet secured long-term and sustainable funding, leaving in question their capacity to keep fulfilling their roles. Hence there is still a need for Australian universities, the ARC and other stakeholders to obtain sustainable funding to ensure the longevity of such initiatives. The mathematical sciences is a research field that does not require the specialist equipment typically funded by the National Collaborative Research Infrastructure Scheme (NCRIS). However collaborative research centres such as MATRIX and SMRI are critical in supporting the mathematical sciences and are viewed as essential infrastructure by many in the community. Long-term and sustainable funding for these institutes should be considered as investment in the research infrastructure for the mathematical science community in recognition of the central role they play in fulfilling objective 3.1.

3.2 Australian universities should organise postgraduate training at a national level through the Australian Mathematical Sciences Institute, to ensure that postgraduate research students are receiving the coursework they need to broaden their high-level mathematical and interdisciplinary skills.	The Australian Mathematical Sciences Institute (AMSI) has been coordinating the broadcasts of short courses and seminars over the Advanced Collaborative Environment (ACE) network. These offerings tend to be targeted at the honours/masters level but are also open to more advanced postgraduate students, as are the AMSI Summer and Winter Schools and BioInfoSummer. The shift towards remote teaching in Australian universities in 2020 due to the pandemic has also increased the amount of material that is available online. Additionally, in 2020, MATRIX launched a scheme supporting online research symposia for PhD students. However, this recommendation has not yet been achieved to the extent that was intended, in that there is no postgraduate coursework program comparable in depth to what is offered to starting graduate students in North American universities. The relatively short duration of Australian PhD scholarships remains a major obstacle to the introduction of such coursework. The current high level of uncertainty due to the pandemic and the changes to funding introduced in the Job-ready Graduates Package will make it difficult to achieve this recommendation in the near future.
3.3 In their recruitment and funding decisions, universities, funding councils and government agencies should continue to nurture the growing links between the mathematical sciences and other knowledge domains such as the biological and social sciences, but not at the expense of support for the core disciplines of mathematics and statistics.	The pandemic and changes to funding and resource availability generally have increased uncertainty in Australian universities. This has led to some universities decreasing support for the core disciplines of mathematics and statistics. The reduction in support is implemented through a reduction in funding, a reduction in staff numbers and administrative reorganisation into larger, combined units that reduces the visibility of the disciplines. This is justified by a switch in focus to more service teaching, often in new areas like data science, as well as by allowing other knowledge domains to teach their own courses in mathematics and statistics. It may entail the loss of majors in the mathematical sciences. In this environment, it is difficult to nurture links between the mathematical sciences and other knowledge domains. Nurturing existing collaborations, and increasing the visibility of centrality of mathematics to disciplines such as data science, are examples of opportunities to increase support for mathematical sciences and statistics.

Objective IV — Ensure that Australian society is capturing the benefits of mathematics-based technologies

The final objective is to ensure that Australian society is benefiting from expertise in the mathematical sciences. The Australian Postgraduate Research Intern (APR.Intern) program has played an important role in connecting some industries to talented PhD students in the mathematical sciences, but more could certainly be done in this area. Specifically, the underrepresentation in mathematics courses of women and students at regional and rural schools noted in the decadal plan continues. Further, there has been limited progress in communicating the importance of the mathematical sciences to government and the general public outside of general STEM awareness programs.

The general public have been widely exposed to 'modelling' during the pandemic, as this has been and continues to be widely referenced as the basis for certain policy decisions. Thus far, this activity has been largely divorced from its mathematical and statistical underpinnings and associated more with epidemiologists, public health officials and think tanks than with mathematical scientists. However, the uptake of this terminology provides an opportunity for future work to highlight the importance of the mathematical sciences forming the foundation of this area, and to emphasise the contribution of mathematical understanding to critical challenges.

Objective IV: Ensure that Australian society is capturing the benefits of mathematics-based technologies

Recommendation	Comments
4.1 Universities, governments, funding councils and peak industry groups should review and seek to address the causes of low participation in the mathematical sciences among girls and young women, and among Australians living in rural and regional areas.	There is a persistent gender gap at all levels of mathematics education, meaning that the situation is not improving: • In 2018, around 12% of male high school students were studying higher mathematics, compared to around 7% of female high school students, percentages that hardly changed over the preceding decade (AMSI 2020b, Fig 1.27). • In 2018, women made up 38% of undergraduate students (excluding honours) and 28% of honours students in the mathematical sciences. The undergraduate percentage is a slight increase from 34% in 2012 (AMSI 2020b, Fig 2.15 and Fig 2.19). • In 2019, women made up only 41 of the 204 completions of honours and two-year coursework master's degrees from Australian universities (20%). This represents a large decrease from 2012, when women accounted for 71 of the 197 completions (Johnston 2013). While the number of honours completions in mathematics over the last decade is increasing, the number of women's completions in that period seems to be static (Johnston 2020). • In 2019, of 145 PhD completions in mathematics in Australia, only 45 were by women, or 31%. Similarly, there were 45 PhD completions by women in 2018. Just as in the case of honours completions, while the number of PhD completions is on an upward trend, the number of female completions seems to be static (Johnston 2020). The AMSI ChooseMATHS program (2015–20) funded by the BHP Foundation addressed pipeline challenges through schools outreach, careers awareness, ChooseMATHS awards and the Women in Maths Network. The impact of these programs will only be visible at some time in the future.

4.2 The discipline's learned societies and professional associations, together with AMSI and other relevant stakeholders, should embark upon a coordinated program of promotion to ensure that parents, school students and teachers understand that studying mathematics subjects at the highest level possible increases career options.	The trend for students to study lower level mathematics subjects in preference to higher level offerings has been highlighted in the AMSI Discipline Profile (AMSI 2020b) and in a 2019 position paper by the Chief Scientist (OCS 2019). The main reasons for this trend are apparently the desire of students, students' families and schools to maximise students' Australian Tertiary Admissions Rank (ATAR) or Overall Position (OP) in Queensland. Individual members of the mathematical sciences community and organisations such as AMSI have made efforts to promote the study of mathematical subjects at the highest possible level. However, it is not easy to overturn the idea that a high ATAR or OP is more important that the longer term benefits of studying mathematics at a higher level.
4.3 The discipline's learned societies and professional associations, together with AMSI, government agencies and other relevant stakeholders, should facilitate an annual showcase and strategic briefing to maintain a dialogue with state and federal policymakers about new developments and opportunities emanating from the discipline.	The Australian Academy of Science advocates generally (including to state and federal policymakers) for science, including the mathematical sciences. More specifically, AMSI advocates to government for the mathematical sciences. The professional associations also advocate for their members, either directly or through other umbrella organisations such as Science and Technology Australia (STA). However, a showcase and strategic briefing event of the type envisaged in this recommendation has not yet been held.

5. Developing issues

As seen in the previous section, many of the issues identified in the decadal plan remain significant challenges for the discipline, and some troubling long-term trends have continued over the past five years. A prime example is the continued decline in the supply of qualified secondary mathematics teachers, discussed under Objective I above, which flows through to affect all aspects of the discipline. Some of the recommendations of the last decadal plan concerning this and other areas will no doubt need to be reinforced in the next decadal plan.

In addition, the NCMS identified four broad developing issues which are foreseen as featuring more prominently in the next decadal plan. The material below is based largely on the reports prepared by subcommittees formed to consider these areas, and on the input of the AustMS Women in Mathematics Special Interest Group (WIMSIG) and the Australian Council of Heads of Mathematical Sciences (ACHMS). This material could form the starting point for specific new recommendations after appropriate wider consultation has occurred.

5.1. Gender and representation of minority groups

A continuing issue in the next few years will be the unequal impact of the COVID-19 pandemic. The Australian mathematical sciences community will need to take active steps to reduce this impact and will need to actively monitor developments. The open letter from the European Women in Mathematics organisation (EWM 2021), referred to in Section 3.1, included suggestions for proactive steps that institutions should consider addressing the unequal impacts of the COVID-19 pandemic. It suggests that universities, government and funding agencies should invest in extending the contracts of researchers in temporary positions, giving particular consideration to women. These organisations should also give teaching reductions to mathematicians who lost significant research time due to digital teaching and caregiver responsibilities, again with particular consideration to women. It proposes that evaluators on hiring, promotion, prize, grant and other committees should be reminded that performance must be evaluated over a time period corrected for parental and other leaves.

The European Women in Mathematics also noted that COVID-19 has had enormous impacts on university finances. Since some short-term measures, such as a freeze on external recruitment, risk cementing gender imbalance, it suggested that universities and other employers should keep long-term ambitions, such as improving gender balance in STEM fields, in the forefront of their planning.

The AustMS WIMSIG submitted a report for this mid-term review in February 2021, which set out their vision for the coming decade to 2030. This includes increasing the proportion of professors (or equivalent in research organisations) in mathematical sciences in Australia who are women to at least 15% by 2030. These women will provide leadership in the discipline, act as mentors, trainers, and role models, and bring diverse perspectives on research, teaching, and applications to the field. Women role models should be prominently highlighted on the websites of all professional societies of mathematical societies in Australia. Women should be receiving at least 25% of awards from professional societies, and be office holders, committee members, associate and chief editors at similar rates. Steps should be taken to ensure that among PhD, master's and honours completions, and undergraduate degrees in mathematics, the proportion of women does not decrease. At least 10% of female high school students should be studying higher mathematics.

Women are the largest underrepresented group in the mathematical sciences in Australia, but there are many other groups with members who are underrepresented in Australian mathematical sciences. The decadal plan fails to include any data about such underrepresented groups and does not include any plans for increasing participation by, and retention of, members of such groups. The next decadal plan should pay particular attention to equality of opportunity for mathematicians regardless of Indigenous status, race, gender identity, sexuality, disability or ethnicity.

5.2. Funding changes from the Job-ready Graduates Package

The Federal Government's Job-ready Graduates Package of reforms to higher education, and its initial impact on the mathematical sciences, were discussed in Sections 3.2 and 3.3 above. Heads of mathematical sciences departments were surveyed about the likely effect of these changes in February 2021 by the ACHMS. Their expectation was that any rise in domestic enrolments resulting from the decreased student contribution, or from the 2021 short courses initiative which was also part of the Job-ready Graduates package, would be less significant than the cut in funding per student. For those departments which experienced a decline in international enrolments at the same time because of COVID-19 travel restrictions, the combined financial impact appeared likely to be particularly severe.

The following two responses highlight some of the major concerns:

- It isn't yet clear what the impacts of the Job-ready scheme will be on mathematics nationally. While we are supportive of lowering barriers so that students can afford to study mathematics, we are also concerned about the possible financial implications of the change in funding levels for mathematics, and, more broadly, on the adverse financial effects on students wishing to study disciplines that have become markedly more expensive for them. Whilst the data from universities provided under the previous funding model shows that universities have been prepared to use income from mathematics students to cross-subsidise other disciplines, it is unclear how much of this was due to mathematics being particularly generously funded (through Commonwealth-supported places and student fees), and how much was due to a tolerance of higher teaching loads and larger class sizes in mathematics leading to an artificially low cost per student. Such a system has likely impacted the quality of students' educational experiences compared to those disciplines funded more appropriately. The Job-Ready scheme has the potential to affect significantly the cross-subsidisation within universities. However, under the current circumstances, including the volatile international student market, changes to the global higher education sector as a result of COVID-19, the push to include employability components in teaching, and rising operating costs in other disciplines compared to income, the effect of the changes in funding for mathematics could be significantly less dramatic than feared.
- The current impact is a shrinking of mathematics departments, and a decrease in the value that university administration views mathematics departments as representing. The potential impact is the closure of mathematics departments in all but the largest universities in Australia, with service mathematics being taught either by non-experts from the service disciplines, or by research-inactive mathematicians employed solely to deliver service teaching. This will lead to stagnation of curricula with mathematics subjects designed and taught by educators who are out of touch with new

developments in mathematics; to a decrease in teaching quality and the quality of graduates, and to a decrease in mathematically and statistically trained graduates; and in Australia's international profile and competitiveness in research in the mathematical sciences.

The negative effect on mathematics appears to be a perverse or unintended outcome of the funding changes, given that Australian Government announcements emphasised the reduction in student contributions as an incentive to increase enrolments in STEM subjects (DESE 2020b). This suggests the possibility of advocating for a readjustment when funding levels are next considered.

5.3. Data science

The past decade has seen the rise of data science as a description of the activity of managing and finding insights in typically big data. Data science sits at the intersection of multiple disciplines, including mathematical, statistical, information and computer science, but goes beyond the traditional reach of most of these disciplines; data scientists need data acquisition, engineering, management, modelling, analysis, computation, and visualisation skills.

Data science is recognised by the US National Science Foundation as a discipline in its own right and is on its 2020 list of 10 Big Ideas (NSF 2020). There are also major institutions of data science in a number of countries, including the National Institute of Health Office of Data Science (US) and the Turing Institute (UK). In Australia, data science is growing. There is an increasing number of job advertisements using this term (862 jobs with search term of 'data scientist' were advertised on seek.com.au in late February 2021) and undergraduate and postgraduate degrees in data science are being introduced at many Australian universities. As of February 2021, at least 10 universities were offering undergraduate courses in data science and more than 20 were offering postgraduate (mostly master's) courses in data science or data analytics. However, data science is not identified in Australian research data, making it difficult to analyse the scale of activity, investment or international competitiveness of data science in Australia.

In its publication *Advancing data-intensive research in Australia*, the Australian Academy of Science argues for recognition of data science as a discipline and for the collection of research data to evaluate data science (AAS 2021). However, there are problems that need to be addressed. First, the Academy notes the gender imbalance in data science and calls for action to redress this. Second, some universities are endeavouring to use short courses in the mathematical sciences to transition graduates to a 'data-driven future', supporting short courses in engineering or computer science. The 'data science' short courses rarely cover mathematics and statistics at the level of formal courses, and industries and universities have found that the students graduating from these have acquired only superficial skillsets. These courses disadvantage students and will likely undermine the claimed economic benefits of short courses. Data science is a fusion of mathematical, statistical, information and computer sciences, so should complement rather than replace these disciplines. Using data science to replace the mathematical sciences will ultimately undermine data science.

5.4. Biostatistics (statistics in medicine)

Biostatistics is the theory and practice of statistics that focuses on extracting knowledge from medical and health-related data. Biostatisticians work to ensure the appropriateness of the design of health and medical research, and of the analysis and interpretation of data. They also advance the ever-evolving discipline by developing new study designs and new methods to answer novel research questions and tackle emerging analytical challenges.

The Australian Government invests heavily in health and medical research. Over four years from 2020, the National Health and Medical Research Council (NHMRC) will distribute $3.5 billion to health and medical researchers across Australia (NHMRC 2020), with further funding through the Medical Research Future Fund (MRFF 2021). The input of biostatisticians is essential at all stages of this research, from study design to the interpretation and communication of results. Without sound biostatistical support, health and medical research wastes money and resources, and at worst can harm patients, so it is appropriate that biostatisticians are called on to support applications to these schemes. However, the continuous cycle of MRFF funding calls places a strain upon the relatively small available workforce of biostatisticians, impacting the quality of proposals submitted.

Australia has world-class training for biostatisticians at career-entry level, such as the Master of Biostatistics program provided by the Biostatistics Collaboration of Australia (BCA 2021). Despite this, we are currently behind the US and UK in the training of biostatisticians to doctoral and postdoctoral levels, and in funding for biostatistical research. Active research groups are necessary to ensure active doctoral and postdoctoral training programs for junior biostatisticians, who, at the completion of their training, must have the breadth and depth of expertise necessary to lead teams.

Career paths for academic biostatisticians are well-established in the US, where many universities have departments of biostatistics. In contrast, in Australia, biostatisticians within universities are often dispersed through medical faculties. This means that Australian biostatisticians frequently lack core-funded time dedicated to biostatistical research and the critical mass needed to form active research groups in biostatistics. Further, unlike in the UK, where the Medical Research Council has specific funding dedicated to methodological research (MRC 2021), biostatisticians seeking funding through the NHMRC must compete with researchers focusing on specific health and medical research problems. Due to the nature of methodological work and the citation patterns within the mathematical sciences, biostatisticians are often at a disadvantage compared to other medical researchers in such competitive grant schemes. The lack of recognition of biostatistics as a scientific discipline in its own right with dedicated funding pathways for research in biostatistics presents a challenge for the advancement of biostatistics in Australia.

The need to recognise biostatistics as a critical discipline for health and medicine by universities, research institutes, and funding bodies is a key issue that needs to be addressed now and in the next decadal plan. Recognition would strengthen the capacity of Australia's research workforce in biostatistics by providing the environment and funding to support career pathways for research-active leaders in biostatistics (Lee 2019). By strengthening the discipline of biostatistics in Australia, health and medical research in Australia, and thus Australian healthcare, will be strengthened, ensuring that Australia remains at the forefront of health and medical research globally.

6. Conclusion and general comments

The 2016 decadal plan took a huge community effort to put together. It identified important issues for the mathematical sciences in Australia and benchmarked the aspirations of the mathematical sciences community. Progress has been made in some areas, but there are also key areas where progress has been limited, and new issues and areas are evolving. This means the decadal plan should be treated like a living document that needs to be revisited, modified and updated.

The appropriate time to do this is during the preparation of the next decadal plan. The mid-term review has shown that the responsibility for achieving specific goals needs to be clearly identified and that recommendations should, whenever possible, include agreed specific targets. In the meantime, the hope for the mathematical sciences community is that this mid-term review will promote re-engagement with the decadal plan and a stronger commitment to driving the recommendations of the plan, as well as lay some foundations for writing the next decadal plan.

The mathematical sciences underpin areas of critical interest for Australia and provide a basis for many of the skills desirable in the current climate. This review has highlighted the need to continue to progress the recommendations of the decadal plan, which remain highly relevant. The opportunities provided by the mathematical sciences community can only be realised with appropriate recognition of its role in responding to developing areas of interest from the government and research sectors. This must be paired with infrastructure and resourcing to support excellent mathematical and statistical work for the research that underpins many solutions to contemporary challenges, and to ensure high-quality education to equip the next generation of Australians with the mathematical science knowledge needed for the future.

References

AAMT 2020—The Australian Association of Mathematics Teachers, *Review of the Australian Curriculum: Mathematics*, 8 September 2020. https://aamt.edu.au/review-of-the-australian-curriculum-mathematics/

AAS 2016—*The mathematical sciences in Australia: a vision for 2025*, Australian Academy of Science, Canberra, 2016. https://www.science.org.au/support/analysis/decadal-plans-science/decadal-plan-mathematical-sciences-australia-2016-2025

AAS 2021—Australian Academy of Science, Advancing data-intensive research in Australia, October 2021. https://www.science.org.au/supporting-science/science-policy-and-analysis/reports-and-publications/advancing-data-intensive-research-australia

ABS 2020—Australian Bureau of Statistics, *Household impacts of COVID-19 survey*, November 2020. https://www.abs.gov.au/statistics/people/people-and-communities/household-impacts-covid-19-survey/nov-2020

ABS 2021—Australian Bureau of Statistics, *Household impacts of COVID-19 survey*, June 2021. https://www.abs.gov.au/statistics/people/people-and-communities/household-impacts-covid-19-survey/jun-2021

ACARA 2021—Australian Curriculum and Assessment Reporting Authority, *Review of the Australian Curriculum*. https://www.acara.edu.au/curriculum/curriculum-review

Achor 2018—Achor, S. 'Do women's networking events move the needle on inequality?', *Harvard Business Review*, 13 February 2018.

AEC 2016—Australian Education Council, *National STEM school education strategy 2016–2026*. https://files.eric.ed.gov/fulltext/ED581690.pdf

AEU 2018—Australian Education Union, *State of schools 2018 report*.

AITSL 2019a—Australian Institute for Teaching and School Leadership, *Accreditation Standards and Procedures*, 2019. https://www.aitsl.edu.au/deliver-ite-programs/standards-and-procedures

AITSL 2019b—Australian Institute for Teaching and School Leadership, *Spotlight: highly accomplished and lead teachers*, 2019. https://www.aitsl.edu.au/docs/default-source/research-evidence/spotlight/spotlight_halt.pdf

AMSI 2018—Prince, G., and O'Connor, M., 'Crunching the numbers on out-of-field teaching', *Australian Mathematical Sciences Institute Occasional Paper 1*, 2018. https://amsi.org.au/wp-content/uploads/2018/11/amsi-occasional-paper_out-of-field-maths-teaching.pdf

AMSI 2019—O'Connor, M., and Thomas, J., 'Australian secondary mathematics teacher shortfalls: a deepening crisis', *Australian Mathematical Sciences Institute Occasional Paper 2*, 2019. https://amsi.org.au/wp-content/uploads/2019/05/amsi-occasional-paper-2.pdf

AMSI 2020a—Li, N., and Sprakel, J., *CHOOSEMATHS school survey and teacher survey (2016–2019) key findings*, Australian Mathematical Sciences Institute. https://amsi.org.au/wp-content/uploads/2020/06/teachersurveykeyfinding_withcover_questionnaires.pdf

AMSI 2020b—Australian Mathematical Sciences Institute, *The state of mathematical sciences 2020*, May 2020, University of Melbourne. https://amsi.org.au/wp-content/uploads/2020/05/amsi-discipline-profile-2020.pdf

AMSI 2020c—Wienk, M., and O'Connor, M., *Year 12 participation in intermediate and higher mathematics remains stubbornly low*, 2020, Australian Mathematical Sciences Institute. https://amsi.org.au/?publications=year-12-mathematics-participation-in-australia-2008-2019-2

ATO 2020—Australian Tax Office, *Turnover test for universities*, 16 September 2020. https://www.ato.gov.au/General/JobKeeper-Payment/In-detail/Turnover-test-for-universities/

Batchelor 2020—Batchelor, R., 'The impact of COVID-19 on women and work in Victoria', *The McKell Institute Discussion Paper*, August 2020. https://mckellinstitute.org.au/research/articles/the-impact-of-covid-19-on-women-and- work-in-victoria/

BCA 2021 - The Biostatistics Collaboration of Australia, *Program objectives*. Accessed 15 February 2021. https://www.bca.edu.au/

DESE 2020a—Department of Education, Skills and Employment, *International student data 2020*. https://internationaleducation.gov.au/research/International-Student-Data/Pages/InternationalStudentData2020.aspx

DESE 2020b—Department of Education, Skills and Employment, *Job-ready Graduates Package legislation passed parliament*, 23 October 2020. https://www.education.gov.au/job-ready/announcements/job-ready-graduates-package-legislation-passed-parliament

DESE 2020c—Department of Education, Skills and Employment, *Improving accountability and information for providers*, 9 December 2020. https://www.education.gov.au/job-ready/improving-accountability-information-providers

DESE 2021—Department of Education, Skills and Employment, *Research support program*, 17 December 2021. https://www.education.gov.au/research-block-grants/research-support-program

DESE 2022—Department of Education, Skills and Employment, *Education Ministers agree a new Australian Curriculum*, 1 April 2022. https://ministers.dese.gov.au/robert/education-ministers-agree-new-australian-curriculum

EWM 2021—European Women in Mathematics, *An Open letter from the EWM*. https://www.europeanwomeninmaths.org/ewm-open-letter-on-the-covid-19- pandemic/

Goss 2016—Goss, P., 'Should you worry about a schools shortage? It really depends on where you live', *The Conversation*, 22 January 2016. https://theconversation.com/should-you-worry-about-a-schools-shortage-it-really-depends-on-where-you-live-53296

Home Affairs 2021—Department of Home Affairs, *Travel restrictions and exemptions*, 20 September 2021. https://web.archive.org/web/20210923055610/https:/covid19.homeaffairs.gov.au/travel-restrictions Archived website.

Hurley 2021—Hurley, P., '2021 is the year Australia's international student crisis really bites', *The Conversation*, 14 January 2021. https://theconversation.com/2021-is-the-year-australias-international-student-crisis-really-bites-153180

IRU 2020—Innovative Research Universities, *Job-ready Graduates Package: overview*, July 2020. https://www.iru.edu.au/wp-content/uploads/2020/07/Job-Ready-Graduates-overview-and-IRU-position-July-20.pdf

Johnston 2013—Johnston, P., 'Higher degrees and honours bachelor degrees in mathematics and statistics completed in Australia in 2012', *Gazette of the Australian Mathematical Society*, 2013, 40(5), pp317–323.

Johnston 2020—Johnston, P., 'Higher degrees and honours bachelor degrees in mathematics and statistics completed in Australia in 2019', *Gazette of the Australian Mathematical Society*, 2020, 47(5), pp221–227.

Kitchener 2020—Kitchener, C., 'Women academics seem to be submitting fewer papers during coronavirus', *The Lily*, 24 April 2020. https://www.thelily.com/women-academics-seem-to-be-submitting-fewer-papers-during-coronavirus-never-seen-anything-like-it-says-one-editor/

Klinger 2022—Klinger, C. R., Klinger, D. A., & Volante, L. 'High school grades matter for post-secondary study, but is pandemic assessment fair?', *The Conversation*, 18 April 2022. https://theconversation.com/high-school-grades-matter-for-post-secondary-study-but-is-pandemic-assessment-fair-177187

Lee 2019—Lee, K.J., Moreno-Betancur, M., Kasza, J., Marschener, I.V., Barnett, A.G., & Carlin, J.B., 'Biostatistics: a fundamental discipline at the core of modern health data science', *Medical Journal of Australia*, 2019, 211, pp444-446. doi: 10.5694/mja2.50372

MRC 2021—Medical Research Council, *Better methods, better research*. Accessed 25 January 2021. https://mrc.ukri.org/funding/science-areas/methodology-research/

MRFF 2021—Australian Government Department of Health and Aged Care, *Medical Research Future Fund*. Accessed 15 February 2021. https://www.health.gov.au/initiatives-and-programs/medical-research-future-fund

NHMRC 2020—National Health and Medical Research Council, *Budget 2020–21*, 6 October 2020. Accessed 25 January 2021. https://www.nhmrc.gov.au/about-us/news-centre/budget-2020-21

Norton 2020—Norton, A., 'Three flaws in Job-ready Graduates Package will add to the turmoil in Australian higher education', *The Conversation*, 9 October 2020. https://theconversation.com/3-flaws-in-job-ready-graduates-package-will-add-to-the-turmoil-in-australian-higher-education-147740

NSF 2020—National Science Foundation, *10 big ideas for future investments*. https://www.nsf.gov/news/special_reports/directors_notes/nsf_10_big_ideas.pdf

OCS 2019—Office of the Chief Scientist, *Australian informed choices for higher education: A strategy to improve the continuum between senior secondary schools and universities*, 2019. https://www.chiefscientist.gov.au/sites/default/files/2020-09/australian_informed_choices_position_paper.pdf

OCS 2020a—Finkel, A., Brown, T., Wright, J., and Wienk, M., *Mapping university prerequisites in Australia*, Office of the Chief Scientist, 2020. https://www.chiefscientist.gov.au/sites/default/files/2020-09/mapping_university_prerequisites_in_australia.pdf

OCS 2020b—Finkel, A., *Let's be honest about what subjects are needed for university*, Office of the Chief Scientist, 2020. https://www.chiefscientist.gov.au/news-and-media/lets-be-honest-about-what-subjects-are-needed-university

PM 2020—Prime Minister of Australia, media release, 19 March 2020. https://parlinfo.aph.gov.au/parlInfo/download/media/pressrel/7250182/upload_binary/7250182.PDF

QS 2021—World University Rankings by subject, 2021. https://www.topuniversities.com/subject-rankings/2021

Roy 2020—Roy, M.-F., Guillopé, C., Cesa, M., Ivie, R., White, S., Mihaljevic, H., ... Chiu, M.-H. 'A global approach to the gender gap in mathematical, computing, and natural sciences. How to measure it, how to reduce it?', *Zenodo*, 4 March 2020. https://zenodo.org/record/3882609

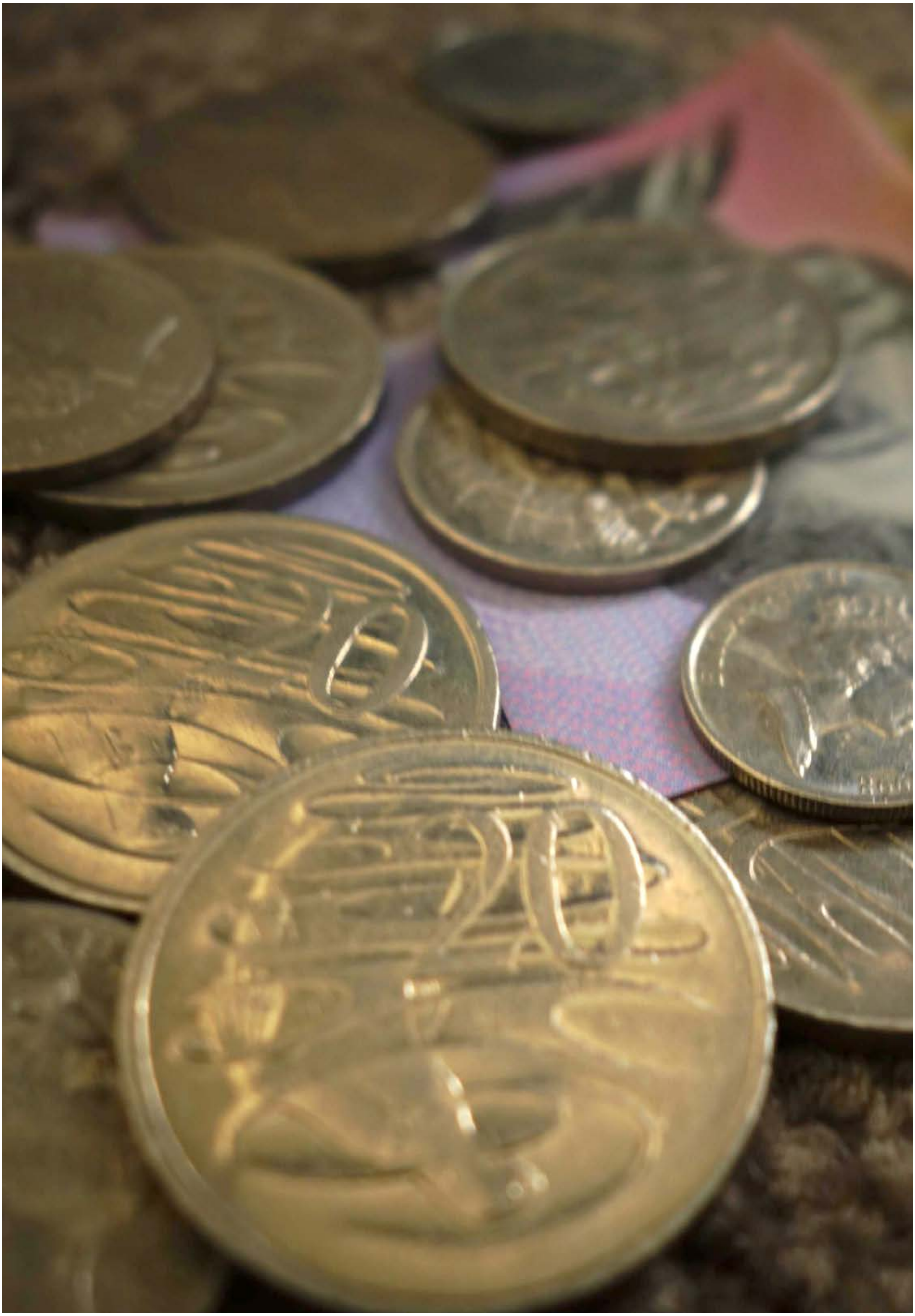
Treasury 2021—The Treasury, *JobKeeper Payment*. https://treasury.gov.au/coronavirus/jobkeeper

Universities Australia 2021—Universities Australia, *17,000 uni jobs lost to COVID-19*, media release, 3 February 2021. https://www.universitiesaustralia.edu.au/media-item/17000-uni-jobs-lost-to-covid-19/

WHO 2019—World Health Organisation, *Listings of WHO's response to COVID-19*, 29 January 2021. https://www.who.int/news/item/29-06-2020-covidtimeline

Zhou 2020a—Zhou, N., 'Four private Australian universities allowed to access JobKeeper payments', *The Guardian*, 25 May 2020. https://www.theguardian.com/australia-news/2020/may/25/four-private-australian-universities-allowed-to-access-jobkeeper-payments

Zhou 2020b—Zhou, N. 'Female enrolment at Australian universities dropped by 86,000 in 2020 as "pink recession" hit', *The Guardian*, 12 November 2020. https://www.theguardian.com/australia-news/2020/nov/12/female-enrolment-at-australian-universities-dropped-by-86000-in-2020-as-pink-recession-hit



The mathematical sciences in Australia: Mid-term review