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Project team
Project leader: Dr Michael Hughes

Contributing authors:

- Summary and Chapters 1 and 2: Dr Michael Hughes
- Chapter 3: Dr Simon Prasad
- Chapter 4: Ms Sarah White, Dr Simon Prasad, Ms Laura Kusa
- Chapter 5: Dr Will Howard, Dr Michael Hughes
- Chapter 6: Dr Will Howard
- Chapter 7: Dr Will Howard, Ms Laura Kusa, Dr Simon Prasad, Ms Sarah White, Dr Michael Hughes

Data analysis: the contributing authors, Ms Joanne Baker[a], and Mr Ashley Stewart[b]

Images
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[a]Seconded to the Office of the Chief Scientist from the Australian Bureau of Statistics; [b]Formerly of the Office of the Chief Scientist

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FOREWORD

I doubt that too many would argue with the proposition that science, technology, engineering and mathematics (STEM) will all play an important part in the solutions we find for our future health, security, safety and prosperity as a nation, and as a planet.

I would add that, as a developed nation, Australia must be a contributor to the solutions or advances as they are made: our capabilities must be there alongside those of other nations as we aim to make the world a better place for all its inhabitants. We cannot leave it to others, and sit outside the tent waiting for the investments of other nations to seep in our direction. We must be an anticipator nation and not a follower—a nation which gives as it receives; a nation engaged in a two way flow of know-how through which we learn as we contribute to the solutions we will all desperately need.

The question is a simple one, then: do we have the capacity presently and are we sustaining the capacity to contribute our science, our talents, our knowledge and skills to the betterment of Australia and the world we share?

When I took up my appointment as Australia's Chief Scientist on 23 May 2011 I needed to understand the current state of Australian science. We decided in my office therefore to focus mainly on the supply side—the schools and universities—because we were interested primarily in our capacity to supply the talents and skills we need and will likely need even more. So we examined the available data on teaching, on research and on international linkages. We tried to build a comprehensive picture of STEM: where we are strong, where there are vulnerabilities, our research links and their quality.

The science team in the Office of the Chief Scientist embarked upon an eight month intensive research project scouring data and statistics from here and abroad. They also conducted broad stakeholder consultations. Their work has culminated in this report, *Health of Australian Science*.

We bit off a lot; and the available statistics did not always easily reveal what we needed to know. But we now have a profile. We have what we see as a broad overview—and we now know where more work needs to be done.

Our profile is analysed in the context of emerging science areas and the increasing internationalisation of science. The entire natural and physical sciences, most engineering and technology fields, and many of the health and medical science fields have been included. The project considered science education taught in secondary schools and universities, and scientific research undertaken across both university and government sectors.

The conclusion of the report is that Australian science is in good health in many areas, but with some issues at the start of the pipeline. We have many strengths, we are well represented in the international scientific arena, our researchers are some of the most productive in the world and our education systems produce graduates in many of the areas we need.

There are areas for concern, however. Much of our discipline profile is heavily dependent on undergraduate study choices—more students mean more funding, more staff and a greater mass in a discipline. Whether this outcome is in our medium- to long-term strategic interest as a nation is debatable. The options available to address the issue may well be the focus of future work. Indeed, I hope that this report will encourage more specific analysis and recommendations for Government in such areas.

I am truly grateful to the science team in my Office. They did the work and the writing. They were very ably led by Dr Michael Hughes. Along with Dr Hughes, Dr Will Howard, Dr Simon Prasad, Ms Sarah White, Ms Laura Kusa, Mr Ashley Stewart and Ms Joanne Baker all deserve my utmost thanks for their thorough research and analysis—grinding as some of it was. I would also like to acknowledge the Health of Australian Science advisory board for their important advice; Professor Warwick Anderson, Ms Anna-Maria Arabia, Ms Katharine Campbell, Professor Les Field, Professor Max King, Dr Sue Meek, Dr John Rice, Dr Paul Schreier, Professor Margaret Sheil, and Mr Trevor Sutton.

Three reports were also commissioned by my Office to specifically inform particular areas of concern. These were *The Status and Quality of Year 11 and 12 Science in Australian Schools* by the Australian Academy of Science; *STEM and Non-STEM First Year Students* by Universities Australia and *Unhealthy Science? University Natural and Physical Sciences 2002-2009/10* by Dr Ian Dobson. I would sincerely like to acknowledge and thank all external parties for their input to this report.

What follows is a high-level account of where our strengths and vulnerabilities lie. It is important knowledge. It will allow us to develop strategies to ensure that Australia retains flourishing science, technology, engineering and mathematics education and research, and that any gaps in our capability will be by design—not the unintended consequence of a failure to notice. As we make our choices, we will continue to contribute as a global citizen while sustaining a safe and socially, culturally and economically prosperous Australia for all our citizens.

Professor Ian Chubb AC
Australia's Chief Scientist

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The evidence presented in this report suggests that Australian science is generally in good health. Our school students compare well on the international stage. At present there is growth in science enrolments in universities. Our researchers produce more per capita than researchers in most other nations and have impacts at or above world standard in most discipline areas.

But there are some immediate concerns also, and challenges in the short to medium term. Science participation in the senior years of school has fallen. Although the rate of this decline has slowed, participation rates have not yet stabilised. Compared with other nations, secondary school performance in science literacy is also slipping. Despite a recent increase in science enrolments at university, the trend has been flat for most of the past decade and has not recovered to the levels achieved in the early 1990s. The research community has enjoyed increased levels of funding in the past decade, but this funding has been under increasing pressure as a result of rising demand by researchers.

Australia's output of research publications is high and overwhelmingly world class. In most scientific fields Australian researchers collaborate internationally and contribute well. This is where the strength lies in the current system. The vulnerability lies in the several narrow fields that will probably fail to maintain capability in the short to medium term if current trends continue.

Despite a robust science system overall, some disciplines that are vital to Australia's future are diminishing to an extent; examples are agriculture, chemistry, mathematics, and physics. Importantly, this includes the so-called enabling sciences (mathematics, physics and chemistry), which form the basis of education and research in all science.

There is arguably a need for a clearer focus on particular areas of education and research if we are to ensure a level of excellence in areas that are crucial to Australia's future and our place in the world. This is not an argument for supporting only those areas: Australia needs a broad base from which to work. We need to be able to anticipate new questions of importance and to use the skills from the broad base to develop our own responses and our contribution to global responses. We need also to fully develop our potential in translational research and innovation.

SCIENCE IN THE NATIONAL INTEREST

In 2008–09 gross expenditure on science-related R&D in all sectors of the economy was $24.6 billion, accounting for 2.2 per cent of gross domestic product. Australia ranked 14th in the OECD on this measure. The Natural and Physical Sciences received between $0.2 billion and $1 billion per narrow discipline area (a total of $3.67 billion); Health and Medical Sciences received $3.5 billion. R&D expenditure in these disciplines comes largely from the Commonwealth and through the higher education sector. R&D expenditure in Information Technology and Engineering comes largely from the business sector; it amounted to $5 billion and $10 billion respectively in 2008–09. The Commonwealth (including through the higher education sector) directly controls 30 per cent of gross expenditure on R&D, and a significant proportion of business sector investment is facilitated by Commonwealth programs such as the R&D tax credit. In 2011–12 the total Commonwealth appropriation to portfolio research agencies—the Australian Institute of Marine Science, ANSTO, CSIRO, DSTO and Geoscience Australia—was $1.3 billion.

In the broadest sense basic and strategic research augments our understanding of the world we live in; it adds to the bank of intellectual capital on which society draws to develop, improve and transform. Applied and experimental research develops this intellectual capital into new technologies and innovative processes that directly improve the health and prosperity of Australia and its citizens. The mix of research expenditure summed across all sectors of the system is currently 20 per cent basic research and 80 per cent applied research. In 2008–09 the Commonwealth (including the higher education sector) contributed 75 per cent of the total expenditure on basic and strategic research. In the past two decades the proportion of the Commonwealth's expenditure directed to basic and strategic research has steadily decreased, and the proportion directed to applied and experimental research has steadily increased. There is no apparent rationale for this trend.

Between 2002 and 2010 domestic (as distinct from international) undergraduate enrolments in Health courses for commencing students grew by 73.0 per cent; this compares with 23.6 per cent growth in domestic undergraduate enrolments in all fields of education. Commencing enrolments in Engineering grew by 21 per cent; enrolments in the Natural and Physical Sciences were generally flat from 2002 to 2007, but grew by 29 per cent in between 2008 and 2010. In contrast, domestic undergraduate enrolments for students beginning in Agriculture and Environment decreased by 4 per cent between 2002 and 2010, and for Information Technology they halved. The general trend in Agriculture and Environment masks a decline in the narrow discipline of Agriculture: teaching of subjects in the Agriculture discipline group to continuing undergraduates enrolled in Agriculture and Environment courses declined 31 per cent between 2002 and 2010.

It is evident that in the past decade the science-related fields and disciplines have had varying degrees of success in attracting students from a steadily growing university cohort.

Although overall performance in enrolments at the broad field of education level has been good (largely as a consequence of performance in the Health field), concerns arise when we look at the distribution of teaching among the discipline groups. Half the undergraduate teaching of subjects in the Natural and Physical Sciences discipline group is to students enrolled in a BSc or other Natural and Physical Sciences degree; the other half is 'service teaching'—that is, teaching to students enrolled in other fields, especially Health and Engineering. This service teaching is concentrated in students' first year of university. Even for students enrolled in a BSc or similar degree, study of the enabling sciences is also concentrated in their first year: only 13.0 per cent of teaching at the continuing level is in mathematics, 10.0 per cent is in chemistry, and 2.5 per cent is in physics. The biology discipline group holds the largest share at the continuing level for Natural and Physical Sciences undergraduates. In the Engineering broad field of education, teaching in Civil Engineering more than doubled between 2002 and 2010, while teaching in Electrical Engineering decreased by 41 per cent.

The gender balance is roughly even in the broad field of Natural and Physical Sciences, but each narrow discipline has a different mix of male and female students. In the case of students enrolled in a BSc or similar degree and taking subjects at the continuing level, 2010 female student participation rates in the enabling sciences of chemistry, mathematics and physics were 46, 35 and 24 per cent respectively. Female enrolments in the Information Technology and Engineering fields of education are both 14 per cent.

Students exercise choice when they decide what they want to study, and doubtless there are many factors that can be influential—interest, parents' and teachers' advice, friends, and so on. When those choices turn into enrolments, the universities are funded according to where the students enrol and what they do. This basically logical approach might well put some important disciplines at risk because they happen to lack popularity at a particular time.

Most basic research in science is funded through the National Health and Medical Research Council and the Australian Research Council. Research funding through the NHMRC more than doubled in real terms between 2002 and 2010, and funding through the ARC nearly doubled. Despite this strong growth in funding allocations by the Commonwealth, the period saw increased pressure on those research funds: success rates for applications dropped from 32 to 23 per cent for the ARC and remained relatively steady for the NHMRC.

The system of National Research Priorities provides a sensible base for broadly guiding the research effort in the science sector as a whole, yet some science disciplines are declining in spite of this. Agricultural Sciences is an example: undergraduate students represent the supply 'pipeline' to the professional, higher degree research and research sector workforces, and student numbers in Agriculture are in serious decline. It could be argued that the Commonwealth ought to have a role in identifying where the system is unacceptably weak or needs to focus on emerging disciplines and in influencing the system accordingly. So much of the Australian science profile is at present determined by what students want to study and what researchers want to investigate that it would be difficult to exercise such a strategic role within current policy arrangements.

SCIENCE TEACHING

The Office of the Chief Scientist commissioned surveys of senior secondary school students and commencing university students for this project, and both groups nominated teachers as the most influential factor in determining a student's interest in and attitudes toward science. The most interesting and stimulating styles of teaching and learning were said to be student-led research, practical activities, and the study of real-world examples within the student's sphere of experience. These styles of teaching were part of the aspirations of many teachers, but time and resource constraints, and in some cases confidence and training, limited much of secondary school teaching to a more didactic approach. There is anecdotal evidence that much university teaching is similar, although perhaps for different reasons.

The relative importance of teaching science in senior secondary school for literacy purposes, as opposed to preparation for entry to university science, is not clear. But, whether the goal is to improve scientific literacy in the community or to prepare students for studying science at university, the fact is that enrolment of senior school students in science subjects is at present on a long-term declining trend in both absolute numbers and as a proportion of the total cohort, and this shows that neither goal is being achieved. Between 1992 and 2010 the percentage of the Year 12 cohort enrolled in Biology fell from 35.3 per cent to 24 per cent. For Chemistry the decline was from 22.9 per cent to 17.2 per cent; and for Physics it was from 20.8 per cent to 14.2 per cent. Mathematics participation declined from 76.6 per cent to 72.0 per cent between 2002 and 2010, and there is a continuing shift from intermediate and advanced levels of mathematics to the elementary level.

Despite declining participation rates in mathematics and science, Australian students perform well in comparison with other nations. In the most recent rankings only five countries demonstrated significantly higher science literacy than Australian students and only 10 countries demonstrated significantly higher mathematics literacy. Although this position is positive, the change in recent years in the countries that do better than Australia suggests we are relatively static while others—particularly some of our regional neighbours—are moving ahead.

It is necessary to better interact with students at school in order to maintain the interest of existing science students and attract new students to science, to improve science literacy, and increase the supply to university science courses. It is also necessary to do better with science students at university: university enrolment and completion data show indicative completion rates of between 50 and 70 per cent in the science-related disciplines.

THE SCIENCE WORKFORCE

Science-related study prepares a student for a lifetime of critical thinking and promotes a drive to find evidence and develop an understanding of how our society fits into the broader picture of the world. These skills help prepare students for employment both in the research sector and in the broader economy and are invaluable for the development of a prosperous Australia. Scientific thinking promotes innovative inquiry, which is central to the creation of new and more efficient industries and business models. This is a workforce characteristic that will lead Australia to success in building an innovative economy.

The latest available census data show that in the workforce in 2006 there were about 338 000 Health professionals, about 144 000 Information and Communication Technology professionals, about 79 000 Engineers and about 66 500 Natural and Physical Sciences professionals. The proportions in the age group 55–64 years that either have retired since the census or will shortly retire are 14 per cent for Health, 6 per cent for Information and Communication Technology, 14 per cent for Engineering and 11 per cent for Natural and Physical Sciences. The decade from 2006 to 2016 will see about 7000 Natural and Physical Sciences professionals retiring while (on current completion rates) about 120 000 Natural and Physical Sciences graduates will enter the workforce. Once in the workforce, many science graduates at the bachelor's level work in government, education, commerce and industry in roles classified as something other than a Natural and Physical Sciences professional. The best available data suggest that most research-trained natural and physical scientists (those with a higher degree such as a PhD) are employed in the research sector.

INTERNATIONAL COLLABORATION

Australia has a relatively high scholarly output in science, producing more than 3 per cent of world scientific publications yet accounting for only about 0.3 per cent of the world's population. Australian published scholarly outputs (including fields other than science) grew at a rate of about 5 per cent a year between 1999 and 2008; this compares with a global growth rate of 2.6 per cent.

Australian research also has high impact: it accounted for 4 per cent of global citations in 2004 to 2008. In the recent Excellence in Research for Australia audit (which largely focused on university research outputs) Australian research was ranked equal to or better than world standard in all but one science and related field of research.

In many fields of science collaboration is vital to complement capability, achieve 'critical mass' and gain access to the necessary infrastructure. In astronomy, for example, Australia participates with the United States, the United Kingdom, Canada, Chile, Brazil and Argentina in the Gemini Project, allowing Australian researchers access to optical and infra-red telescopes in Chile and Hawaii. These facilities, built at a cost of about A$200 million, would be difficult for any single country, especially Australia, to establish and maintain alone. International collaborative projects also catalyse national partnerships.

Growth in Australia's research outputs and their impact has been dominated by growth in internationally collaborative publications: from 2002 to 2010 the number of research publications doubled overall; the number of internationally co-authored publications more than tripled. The landscape of Australian collaboration is, however, changing. Historically strong collaboration with North America and Europe continues, but the greatest growth in collaboration is occurring in emerging areas of scientific strength in Asia. In several fields of research—for example, mathematics, engineering, and chemistry—China is now Australia's strongest collaborative partner.

HIGHER EDUCATION AND WORKFORCE DATA

In several respects Commonwealth-collected higher education data are inadequate for determining strengths and vulnerabilities in the system. In particular, inconsistent and imprecise coding of courses makes analysis of enrolments and completions in narrow fields difficult. For example, it is impossible to know from higher education statistics how many students graduated with honours in mathematics or attempted and completed an agriculture degree. It is also impossible to gain an accurate picture of the size and diversity of the science workforce from current data sources. Inflexible access to some government databases also limits our ability to compile sound evidence for policy development. An overarching challenge for the Commonwealth at present is that there are insufficient measures that would allow for confident identification of existing and emerging vulnerabilities.

FURTHER WORK

The findings from this Health of Australian Science project raise important questions, for Australian science and Australia generally in the coming decade, that warrant further investigation and national debate:

- What are the direct implications for Australia in connection with important national concerns—food security, innovation, our place in the region—if our skills base in crucial science disciplines is further depleted? Can we confidently identify particular areas of specialist skills and research that will be essential to Australia's future?
- Do student choices align with the national interest? Do the fields where we demonstrate research excellence correlate with those areas that are essential to sustaining and building Australia's position in global science? What should be Australia's science niche?
- What is the best mix of basic and applied research to support the continuing security, health, economic growth and prosperity of Australia and all the nation's citizens? Across which sectors of the system is this mix of research effort best distributed? Is it sensible to have some of Australia's most scientifically creative people—higher degree research-trained graduates—largely isolated from commerce and industry?

ABBREVIATIONS AND ACRONYMS

Abbreviation/acronym	Full term
AAS	Australian Academy of Science
ABS	Australian Bureau of Statistics
ACER	Australian Centre for Educational Research
AIMS	Australian Institute of Marine Science
ANSTO	Australian Nuclear Science and Technology Organisation
ANZSRC	Australia and New Zealand Standard Research Classification
ARC	Australian Research Council
ASCEDC	Australian Standard Classification of Education Codes
ASJC	All Science Journal Classification
BA	Bachelor of Arts
BDG	Broad Discipline Group
BRIC	Brazil, Russia, India, China
BSc	Bachelor of Science
CPI	Consumer Price Index
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEEWR	Department of Education, Employment and Workplace Relations
DIISR	Department of Innovation, Industry, Science and Research
DSTO	Defence Science and Technology Organisation
ECR	Early Career Research
EFTSL	Equivalent full-time student load
ERA	Excellence in Research for Australia
ETC	Education and Training Committee for Victorian Parliament
EU	European Union
FoE/s	Field/s of Education

Abbreviation/acronym	Full term
FoR/s	Field/s of Research
GA	Geoscience Australia
GERD	Gross expenditure on research and development
HAS	Health of Australian Science
HDR	Higher degree by research
HERDC	Higher Education Research Data Collection
ICT	Information and communication technologies
IT	Information Technology
LIEF	Linkage Infrastructure Equipment and Facilities
MBA	Master of Business Administration
MCEECDYA	Ministerial Council for Education, Early Childhood Development and Youth Affairs
NCGP	National Competitive Grants Program
NCRIS	National Cooperative Research Infrastructure Scheme
N&PS	Natural and Physical Sciences
NHMRC	National Health and Medical Research Council
OECD	Organisation for Economic Cooperation and Development
PhD	Doctor of Philosophy
PISA	Programme for International Student Assessment
R&D	Research and Development
RD&E	Research, Development and Extension
RFCD	Research Fields, Courses and Disciplines
STEM	Science, Technology, Engineering and Mathematics
TIMSS	Trends in International Mathematics and Science Study
UA	Universities Australia
UNESCO	United Nations Educational Scientific and Cultural Organisation

CHAPTER 1

1. INTRODUCTION

In June 2011 the Chief Scientist, Professor Ian Chubb AC, announced that the Office of the Chief Scientist would carry out an assessment of the health of Australian science. This report presents the results of the first phase of the project:

- a broad-reaching evidence base that underpins high-level findings presented to government
- the foundation for further detailed analysis of specific discipline areas seen to be in the national interest and warranting a policy focus.

1.1 THE PRIMARY AIM OF THE PROJECT

The primary aim of the Health of Australian Science project is to provide a comprehensive assessment of the available data in order to develop a profile of the strengths and vulnerabilities of Australia's current science capability. This profile is analysed in the contexts of emerging science areas and the increasing internationalisation of science. Among the main questions examined are the following:

- What is the breadth and sustainability of Australian science across all disciplines and sectors and how does this compare internationally?
- What are the emerging science areas and does Australia have the necessary skills in those areas?
- What does Australian science need to be like in 2020 to promote innovation in all sectors of the economy, deliver health and wellbeing benefits for all citizens, support defence capability, and generate the evidence required for sound decision making throughout government, business and the community?

A staged approach was adopted, the initial focus being on information gathering and analysis so as to describe the current state of the system as a whole. Detailed work on particular discipline areas, particularly in relation to the second and third points just listed, is anticipated (see Section 1.6).

1.2 THE SCOPE OF THE PROJECT

This project examines science education in secondary schools and universities and scientific research in both the university and the government sectors. The available data dictated that most of the quantitative analysis was restricted to the supply side, while the demand-side analysis was largely qualitative.

All the natural and physical sciences, most engineering and technology fields, and many of the health and medical science fields were explored. Table 1.2.1 shows the Australian Standard Classification of Education Codes and the Australian and New Zealand Standard Research Codes included in the study.

Table 1.2.1 Broad fields of education and research included in the study

ASCEDC	Field of education	ANZSRC	Field of research
01 (all)	Natural and Physical Sciences	01 (all)	Mathematical sciences
02 (all)	Information Technology	02 (all)	Physical sciences
03 (all)	Engineering and Related Technologies	03 (all)	Chemical sciences
05 (all)	Agriculture, Environment and Related Studies	04 (all)	Earth sciences
06 (all)	Health	05 (all)	Environmental sciences
		06 (all)	Biological sciences
		07 (all)	Agricultural and veterinary sciences
		08 (all)	Information and computing sciences
		09 (all)	Engineering
		10 (some)	Technology
		11 (some)	Medical and health sciences

Notes: 'ASCEDC' denotes 'Australian Standard Classification of Education Code'; 'ANZSRC' denotes 'Australian and New Zealand Standard Research Code'. The extent to which the sub-fields in each broad field were considered is shown in parentheses beside the field code.

1.3 BROAD METHODOLOGY AND RELATED WORK

This health assessment of Australian science is largely based on data collected by Commonwealth agencies, principally the Australian Bureau of Statistics, the Australian Research Council and the Department of Education, Employment and Workplace Relations. The years 2002 to 2010 were chosen as a period of common data coverage to identify trends, although information from outside this period is also provided where available and appropriate. Additional evidence was compiled by analysing Scopus and other bibliometric databases of research publications.

The project also took into account the information in numerous published reports on components of the Australian science system and reports on Australia's position in the international arena. Further, the Chief Scientist commissioned three pieces of independent work:

- an update of an earlier seminal analysis of higher education enrolment data covering the period 2002 to 2005 that had been commissioned by the Australian Council of Science Deans. The original author updated the report to cover the period 2002 to 2010; the update was released on 29 February 2012.[1]
- a survey of the attitudes of first-year university students to science. The resultant report was released on 20 January 2012.[2]
- two surveys of senior secondary school teachers and students in order to identify teaching and learning factors affecting students' choice to study science. The resultant report was released on 21 December 2011.[3]

[1] The full reference is Dobson, IR 2012, *Unhealthy Science? University Natural and Physical Sciences to 2009–10*, University of Helsinki, Monash University & Educational Policy Institute, Melbourne. The earlier work was published as Dobson, IR 2007, *Sustaining Science: University Science in the 21st Century,* Monash University & Educational Policy Institute, Melbourne.

[2] The full reference is Universities Australia 2012, *STEM and Non-STEM First Year Students*, Universities Australia, Canberra.

[3] The full reference is Goodrum, D, Druhan, A & Abbs, J 2011, *The Status and Quality of Year 11 and 12 Science in Australian Schools*, Australian Academy of Science, Canberra.

1.4 CONSULTATION

The project benefited from the guidance of an Advisory Group that had two primary tasks:

- to provide advice on the strengths and limitations of the available quantitative and qualitative information in creating a picture of the health of Australian science
- to help identify underlying factors, at either the supply side or the demand side, that might be constraining Australia's science capacity.

There were ten members of the Health of Australian Science Advisory Group:

- Prof Warwick Anderson—Chief Executive Officer, National Health and Medical Research Council
- Ms Anna-Maria Arabia—Chief Executive Officer, Science & Technology Australia
- Ms Katharine Campbell—Department of Industry, Innovation, Science, Research and Tertiary Education
- Prof Les Field—Deputy Vice-Chancellor Research, University of New South Wales
- Prof Max King—Pro Vice-Chancellor Research and Research Training, Monash University
- Dr Sue Meek—Chief Executive Officer, Australian Academy of Science
- Dr John Rice—Executive Director, Australian Council of Deans of Science
- Dr Paul Schreier—Deputy Secretary, Department of the Prime Minister and Cabinet
- Prof Margaret Sheil—Chief Executive Officer, Australian Research Council
- Mr Trevor Sutton—Deputy Australian Statistician, Australian Bureau of Statistics.

In addition, a Technical Reference Group consisting of officers from the main Commonwealth departments providing data for the project, helped with locating relevant Commonwealth data and determining the constraints and limitations of the data.

Representatives of several Commonwealth departments and agencies, peak bodies, and discipline areas were also consulted during this first phase of the project. Appendix A provides a full list of those consulted.

1.5 THE REPORT'S STRUCTURE

Chapter 2 provides an overview of the components and size of the science system in Australia. The first few sections of the chapter follow the 'pipeline' of students into a science vocation or science research. The following sections outline current research activity and the level of research funding, as well as the present policy landscape. The chapter concludes with a section on the science workforce. Australia's position in the international arena is dealt with in most of these sections. The structure of the chapter sets the framework for the remainder of the report, in that the chapters that follow offer deeper analysis and discussion of trends to describe how the system has reached its current state.

Chapter 3 begins with an overview of the secondary school science landscape—the nature of senior secondary science, the teaching and learning of science, the performance of Australian students in international benchmarking studies, teachers of science, and so on. The findings of Goodrum et al. (2011), who, as noted, were commissioned to conduct two surveys for the Health of Australian Science project, are considered in the context of a number of national reports and reviews. Chapter 3 concludes with a discussion of the different but interconnected dimensions of the school experience—curriculum, pedagogy, students, teachers and resources.

Chapter 4 presents a detailed analysis of higher education statistics. It focuses particularly on domestic (mainly Australian citizens and permanent residents) participation, since these students are the primary target of government policies and funding and will make up the bulk of the nation's future science workforce. An overview of the size and shape of the entire higher education system is presented initially, then the chapter turns its focus to the five science-related fields of education, as listed in Table 1.2.1. Details of enrolments and completions for domestic students are provided for each science field and for each of the course levels. An examination of teaching in the related discipline groups follows. The chapter concludes with an overview of the main findings of Dobson (2012) and Universities Australia (2012), both of whom were, as noted, commissioned to carry out independent work for this project.

Chapter 5 examines trends and patterns in funding, for science as a whole and for individual research disciplines, mainly through research expenditure from the competitive grant schemes administered by the Australian Research Council and the National Health and Medical Research Council. It also presents details of the trend in the past decade in government appropriations to portfolio research agencies. Further, the Cooperative Research Centres Program is discussed since it is a major funding program for national research collaboration; the mix of funding sources for the science disciplines is also examined.

Trends in Australia's scientific outputs—as measured by publications and their impact in terms of citations in the literature—are the subject of Chapter 6. The chapter looks at decadal trends and patterns, within and between disciplines in the production and impact of Australian scientific publications and compares these with global norms. Trends in the levels and patterns of Australia's international scientific collaboration are also examined, particularly in the context of the increasing globalisation of scientific research.

Finally, case studies of specific discipline areas are offered in Chapter 7 to cast light on strengths, vulnerabilities and opportunities. The studies involve mathematics, physics, chemistry and agricultural sciences. The profile of each area in all sectors of the system—that is, undergraduate enrolments, higher degree research, demand for graduates, grant funding, total research and development funding across all sectors and international research engagement—is considered.

1.6 FUTURE WORK

The analysis and findings presented in this report are largely at the level of the broad fields of education and research shown in Table 1.2.1. Some sub-fields were targeted for further analysis during the first phase of the project; the intention in those cases was to demonstrate a capability for further work. It is expected that completion of the first phase of the project will generate interest in several portfolio departments and agencies and lead to new phases that involve detailed analysis of narrower fields of science that are persuasively in the national interest.

CHAPTER 2

2. THE CURRENT SYSTEM: AN OVERVIEW

It is difficult to quantify the size of the 'science system' in Australia in terms of people, institutions, sectors and dollars: as is the case with most sectors of a modern economy, the science system interleaves with many other sectors.

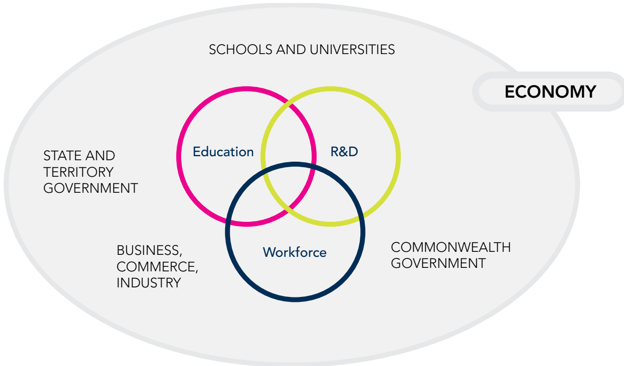
This chapter discusses the components that are central to the science system and offers a snapshot of the size of the system in 2009–10; some international context is provided where appropriate through comparison with other OECD countries. The year 2009–10 is used because that is the year for which the most recent comprehensive data are available; more recent data are, however, used where possible. The chapter sets the foundation for the ensuing chapters that explore components of the science system in greater detail and particularly the trends in recent years that have led to the current position.

2.1 MAIN FINDINGS

- In 2009 the following numbers of Year 12 students were enrolled in science subjects at school: 148 097 in mathematics; 49 681 in biology; 35 867 in chemistry and 29 532 in physics. These students represented the potential pipeline to university science courses.
- Australian school students are ranked sixth and 11th internationally in science and mathematics literacy respectively.
- There were 89 675 university completions in science-related fields of education across all course levels in 2010; this included 59 243 undergraduate completions (predominantly in Health) and 4260 higher degree research completions (predominantly in Natural and Physical Sciences).
- International students accounted for 31 per cent of all university completions across all course levels in 2010.
- In 2008–09 gross expenditure on research and development, or GERD, was $27.7 billion, which represented 2.21 per cent of gross domestic product. This R&D intensity is close to the OECD total and that applying in countries similar to Australia.
- GERD on science-related fields was $24.6 billion in 2008–09. The Commonwealth controls 30 per cent of this expenditure either directly or through the higher education sector. The business sector contributes the bulk of the remainder.
- Summed across all sectors of the economy, the proportion of GERD for basic (pure) research and applied research is roughly 20 per cent and 80 per cent respectively.. The higher education sector contributes the largest proportion to basic research and the business sector the largest to applied research.
- Australia ranks highly both in the number of research outputs per capita and in research impact. In 10 of 12 science-related fields of research Australia performed at or better than world standard between 2003 and 2008.
- It is difficult to obtain from available sources an accurate estimate of the current size and age profile of the science workforce.

2.2 COMPONENTS OF THE SCIENCE SYSTEM

Figure 2.2.1 shows the science system in Australia—its main institutional components and basic functional elements. The functional elements are education, research and development, and workforce. The system delivers educational outcomes in the form of a science-literate society and a science-trained general and R&D workforce.[1] Its R&D supports the activities of business, commerce and industry—in the form of innovation and translation, for example. R&D also supports government activities relating to policy development and regulation. Through the system's workforce function, these educational and R&D outcomes are disseminated to all sectors of the economy.



Note: Institutional components are in capital letters; the functional elements are in the circles.

Figure 2.2.1 Principal institutional components and functional elements of the science system in the Australian economy

Schools bring a level of science literacy to all Australians and provide the fundamental science competency on which universities build when training the general science workforce and the science teaching and R&D workforce. Universities also account for much of the R&D activity. The Commonwealth and the state and territory governments are major contributors to the funding of the functional elements, as well as major beneficiaries of the outcomes.

State and territory governments are responsible for the public school system and work with Catholic and independent education providers. The Commonwealth Government has responsibility for the university system—both education funding and R&D funding. R&D is funded through a variety of policy instruments such as research funding agencies (for example, the Australian Research Council and the National Health and Medical Research Council) and portfolio programs (for example, Cooperative Research Centres and the National Environment Research Program). Both levels of government also perform their own research in portfolio research agencies (for example, the Australian Institute of Marine Science, CSIRO, and state and territory geological surveys). As a consequence, government is an important employer of both the research-trained workforce and the general science workforce.

Business, commerce and industry make use of basic and applied research outcomes from elsewhere in the system in their own R&D extension (RD&E) and innovation activities aimed at transforming operations and improving productivity. They invest their own funds in RD&E, as well as taking advantage of government instruments to leverage these funds (for example, the R&D tax credit). They also employ a proportion of the general science workforce and the research-trained workforce.

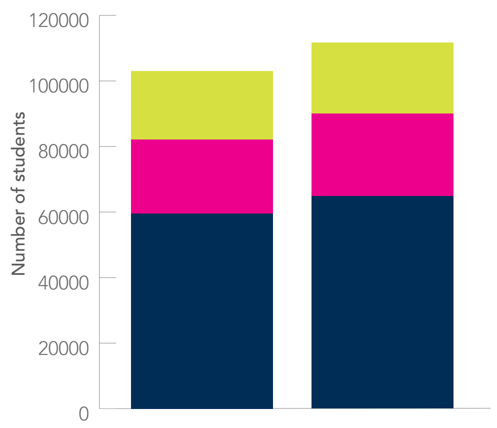
There are, of course, many ways of representing the Australian science system, but the picture just described and represented in Figure 2.2.1 is the context used for this report.

2.3 THE SECONDARY SCHOOL SECTOR

In 2010, 214 542 students were enrolled in Year 12 in Australia (see Figure 2.3.1). The bulk of these students were at government schools (58 per cent); the remainder were at Catholic (22 per cent) and independent (20 per cent) schools. Females accounted for 52 per cent of the Year 12 cohort overall and the cohort in government schools; in Catholic and independent schools females account for 53 and 51 per cent of the Year 12 cohort respectively.

[1] The general science workforce here includes science graduates working in positions in the government or private sector (for example, laboratory technicians or policy analysts). The R&D workforce includes science graduates, usually with higher-degree research qualifications, working in positions in any sector and engaged in R&D activity (for example, academics in universities or research scientists in government agencies)

The most recent data on Year 12 students doing science are for 2009, when the total number of students was 206 526 (National Schools Statistics Collection, ABS). About 72 per cent of this cohort was enrolled in some form of mathematics course (see Table 2.3.1). The discipline with the next-largest enrolment was biology, with about 24 per cent of the cohort. The proportion of the Year 12 cohort enrolled in physics or chemistry was much smaller, and only 1 per cent of the cohort was enrolled in the subject of geology and earth science. In 2010 the proportions of Year 12 students taking advanced, intermediate and elementary mathematics were 10.1, 19.6 and 50 per cent respectively (Barrington 2011). This results in a total that is larger than that shown in Table 2.3.1 and probably includes double counting of students enrolled in advanced and intermediate levels.



	Male	Female
Independent	20830	21720
Catholic	22598	25116
Government	59514	64764

Source: National Schools Statistics Collection, Australian Bureau of Statistics.

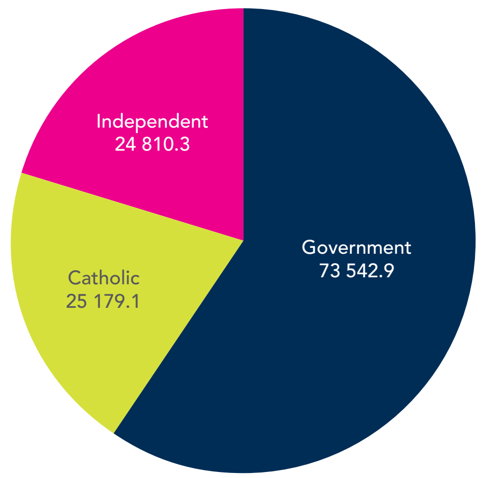
Figure 2.3.1 Year 12 students in Australia, by gender and school type, 2010

Table 2.3.1 Student enrolments in science subjects, Australia, 2009

Subject	Students enrolled (no.)	Proportion of cohort (%)
Biology	49 681	24.1
Chemistry	35 867	17.4
Geology and Earth science	2 201	1.1
Mathematics	148 097[a]	71.7
Physics	29 532	14.3
Other science	16 655	8.1

[a] The number of students enrolled in one or more mathematics courses (students enrolled in more than one such course are counted once).
Note: Table excludes enrolments in behavioural science.
Source: T Lyons, University of New England (pers. comm., February 2012)—based on data made available by state and territory boards of study and the Australian Bureau of Statistics.

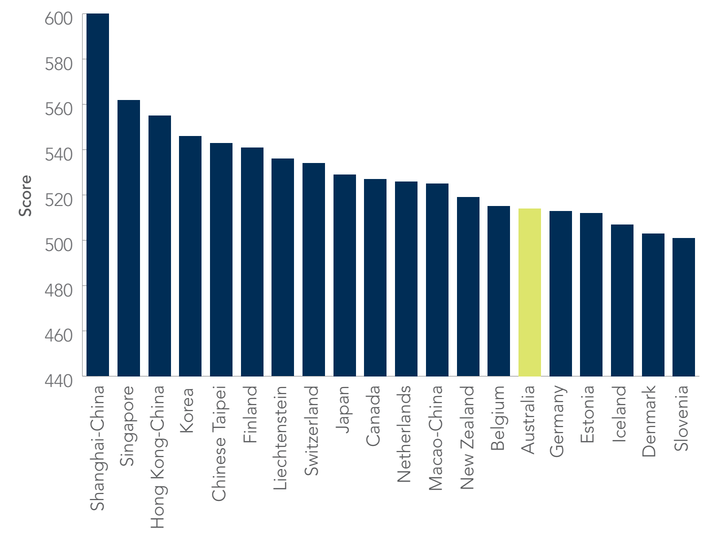
In 2010 there were 123 532.3 (full-time-equivalent) secondary school teaching staff in Australia (National Schools Statistics Collection, ABS). Government schools employed 60 per cent of them; Catholic and independent schools equally employed the remainder (see Figure 2.3.2). It has been estimated that 24.9 per cent of all secondary school teachers teach at least some mathematics and 21.9 per cent of them teach at least some science (including general science and behavioural studies) (Rowley [Principal Research Fellow, Australian Council for Educational Research], pers. comm., February 2012). This suggests there are approximately 30 440 mathematics and 26 774 science teachers, with some probably teaching in both areas.



Source: National Schools Statistics Collection, Australian Bureau of Statistics.

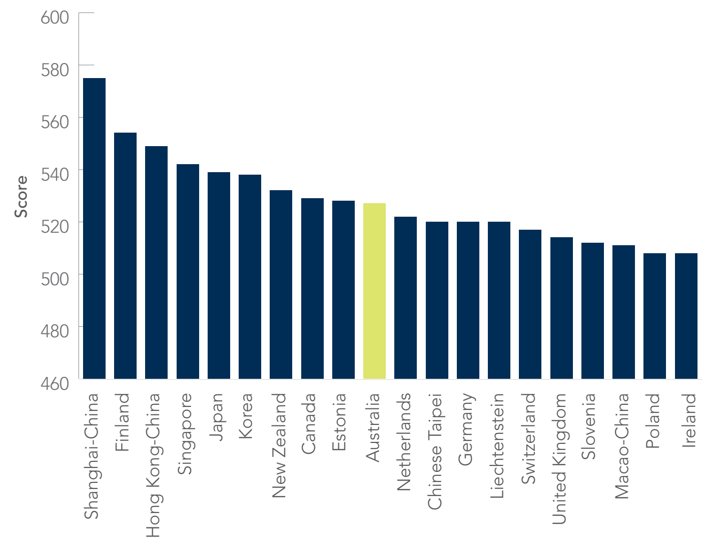
Figure 2.3.2 Number of full-time-equivalent staff teaching in Australian secondary schools, by type of school, 2010

The Programme for International Student Assessment results show the ranking of 15-year-old Australian students in mathematical and scientific literacy against other OECD countries. The latest available results show that the mean mathematical literacy score of 514(±5) for Australian students was greater than the OECD average of 496(±1) (see Figure 2.3.3). On raw scores, Australian students are ranked 15th, but only 10 countries had a ranking that was significantly greater than that for Australian students, giving the Australians a true ranking of 11th (see Walker 2011, app. B). The mean scientific literacy score of 527(±5) for Australian students was also greater than the OECD average of 501(±1) (see Figure 2.3.4). On raw scores, Australian students are ranked 10th, but only five countries had a ranking that was significantly greater than that for Australian students, giving the Australians a true ranking of sixth (see Walker 2011, app. B).



Source: Walker (2011).

Figure 2.3.3 Mean performance on the mathematical literacy scale: top 20 OECD countries, 2009

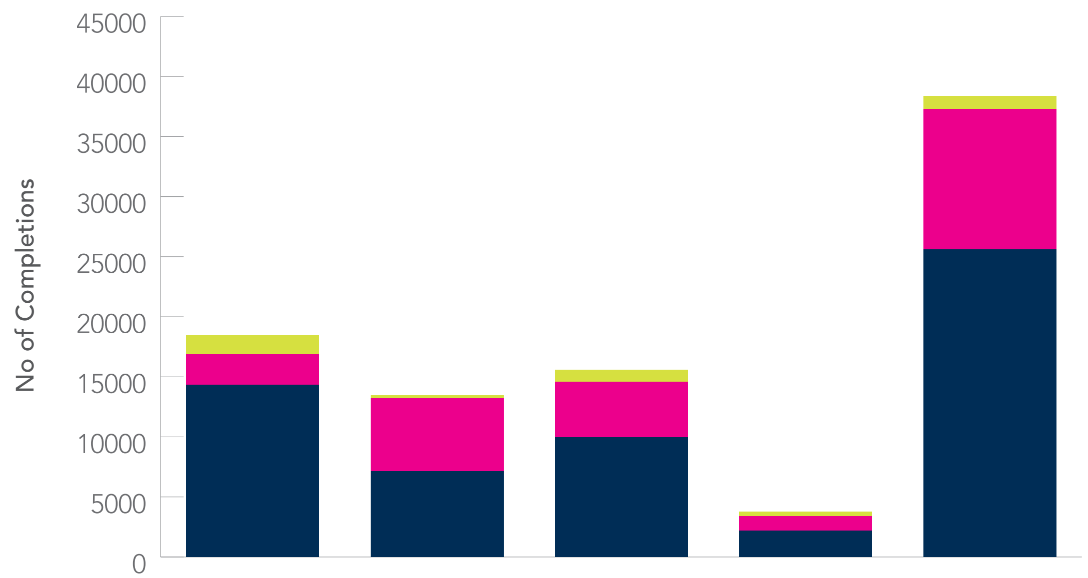


Source: Walker (2011).

Figure 2.3.4 Mean performance on the scientific literacy scale: top 20 OECD countries, 2009

2.4 THE UNIVERSITY SECTOR

Figures from the Department of Education, Employment and Workplace Relations show that in Australia in 2010 there were 286 629 course completions (domestic and international) across all course levels and all fields of education—175 809 undergraduate, 103 390 postgraduate coursework and 7430 postgraduate research completions.[2] For science-related fields of education there were 89 675 completions (domestic and international) across all award types (see Figure 2.4.1).[3] Although science-related undergraduate completions account for only 34 per cent of undergraduate completions in all fields of education, science-related postgraduate research completions accounted for 57 per cent of such completions. Combining all course levels completions in Health were a little over twice those in the Natural and Physical Sciences, Information Technology and Engineering. Agriculture and Environmental Sciences accounted for by far the fewest completions.



	N & PS	IT	Eng.	Agric. & Env.	Health
Postgraduate research	1589	262	986	370	1053
Postgraduate coursework	2535	6059	4637	1215	11726
Undergraduate	14344	7147	9967	2188	25597

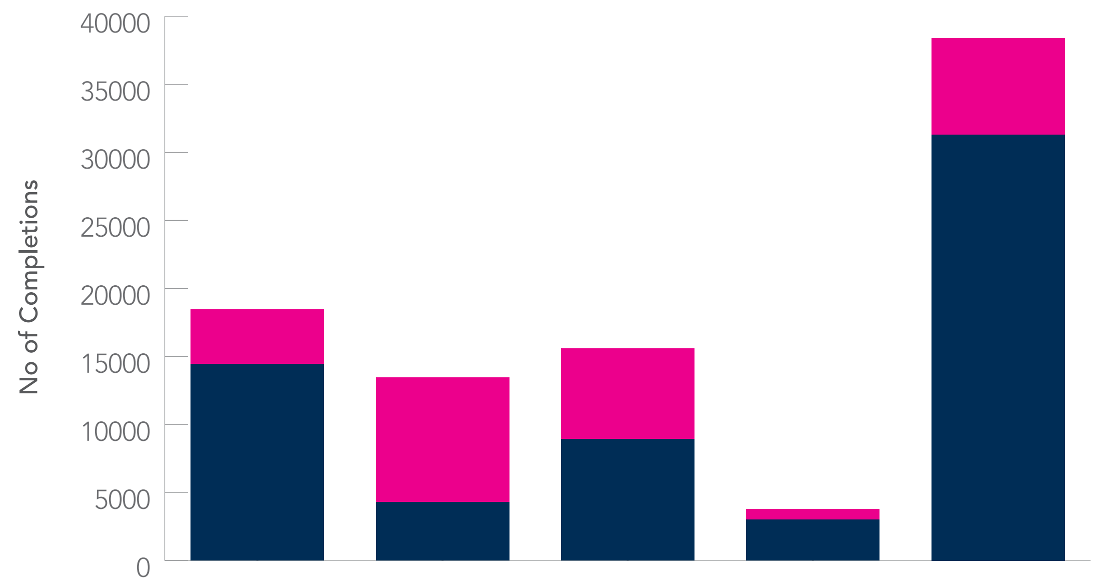
Source: Department of Education, Employment and Workplace Relations.

Figure 2.4.1 Number of student completions (domestic and international): science-related fields of education, by course level, 2010

[2]Undergraduate award courses—diploma, advanced diploma, associate degree, bachelor's pass, bachelor's graduate entry and bachelor's honours. Postgraduate coursework award courses—graduate certificate, postgraduate diploma, postgraduate qualifying or preliminary, masters by coursework and doctorate by coursework. Postgraduate research award courses—masters by research, doctorate by research and higher doctorate.

[3]Science-related fields of education—Natural and Physical Sciences, Information Technology, Engineering and Related Technologies, Agriculture, Environment and Related Studies, and Health.

International student completions for all course levels in 2010 accounted for 31 per cent of completions in science-related fields of education (see Figure 2.4.2). The proportion of international students varies widely across narrower fields of education: Information Technology and Engineering had the largest international student components, at 68 and 43 per cent respectively; Natural and Physical Sciences and Agriculture and Environmental Sciences had the smallest at 22 and 20 per cent respectively.



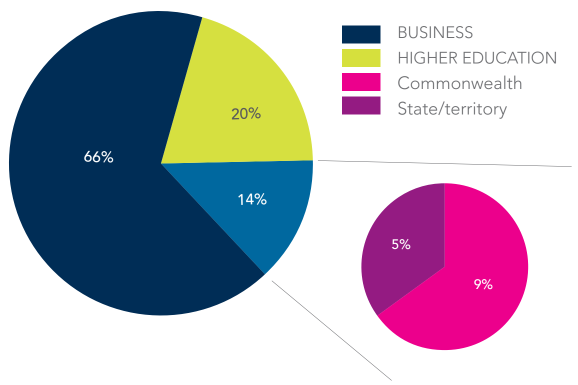
	N & PS	IT	Eng.	Agric. & Env.	Health
International	4020	9175	6655	764	7080
Domestic	14448	4293	8935	3009	31296

Source: Department of Education, Employment and Workplace Relations.

Figure 2.4.2 Number of student completions: science-related fields of education, all course levels, by citizenship, 2010

2.5 EXPENDITURE ON RESEARCH AND DEVELOPMENT

In 2008–09 gross expenditure on R&D in Australia for all sectors and all fields of research was $27.7 billion (Research and Experimental Development Tables, ABS). GERD for all sectors (excluding private non-profit) of science-related fields of research[4] was $24.6 billion, which is 91 per cent of total GERD (see Table 2.5.1). Business is the largest contributor to GERD in science-related fields of research, accounting for 66 per cent of the total (see Figure 2.5.1). The Commonwealth Government contributes the bulk of the remainder, 29 per cent, both directly and indirectly through the higher education sector.



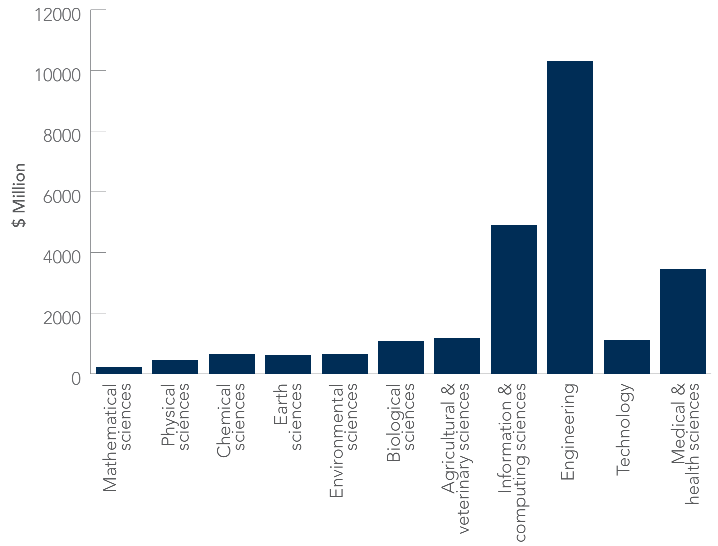
Source: Research and Experimental Development Tables, Australian Bureau of Statistics.

Figure 2.5.1 Proportion of GERD for science-related fields of research, by sector, 2008–09

Table 2.5.1 GERD for science-related fields of research, by sector, 2008–09

Sector	Expenditure ($'000)
Business	16 391 627
Higher Education	4 992 857
Commonwealth	2 121 976
State and territory	1 130 274
Total expenditure	24 636 734

In 2008–09 the total GERD summed across all sectors varied markedly according to the field of research (see Figure 2.5.2). With the exception of Biological Sciences, which received $1.1 billion, GERD on Natural and Physical Sciences varied from $213 million (Mathematical Sciences) to $660 million (Chemical Sciences) for individual disciplines. Total GERD on Agricultural and Veterinary Sciences was approximately $1.2 billion. The Engineering, Information and Computing Sciences, and Technology fields of research received the largest amounts—$10.3 billion, $4.9 billion and $1.1 billion respectively.

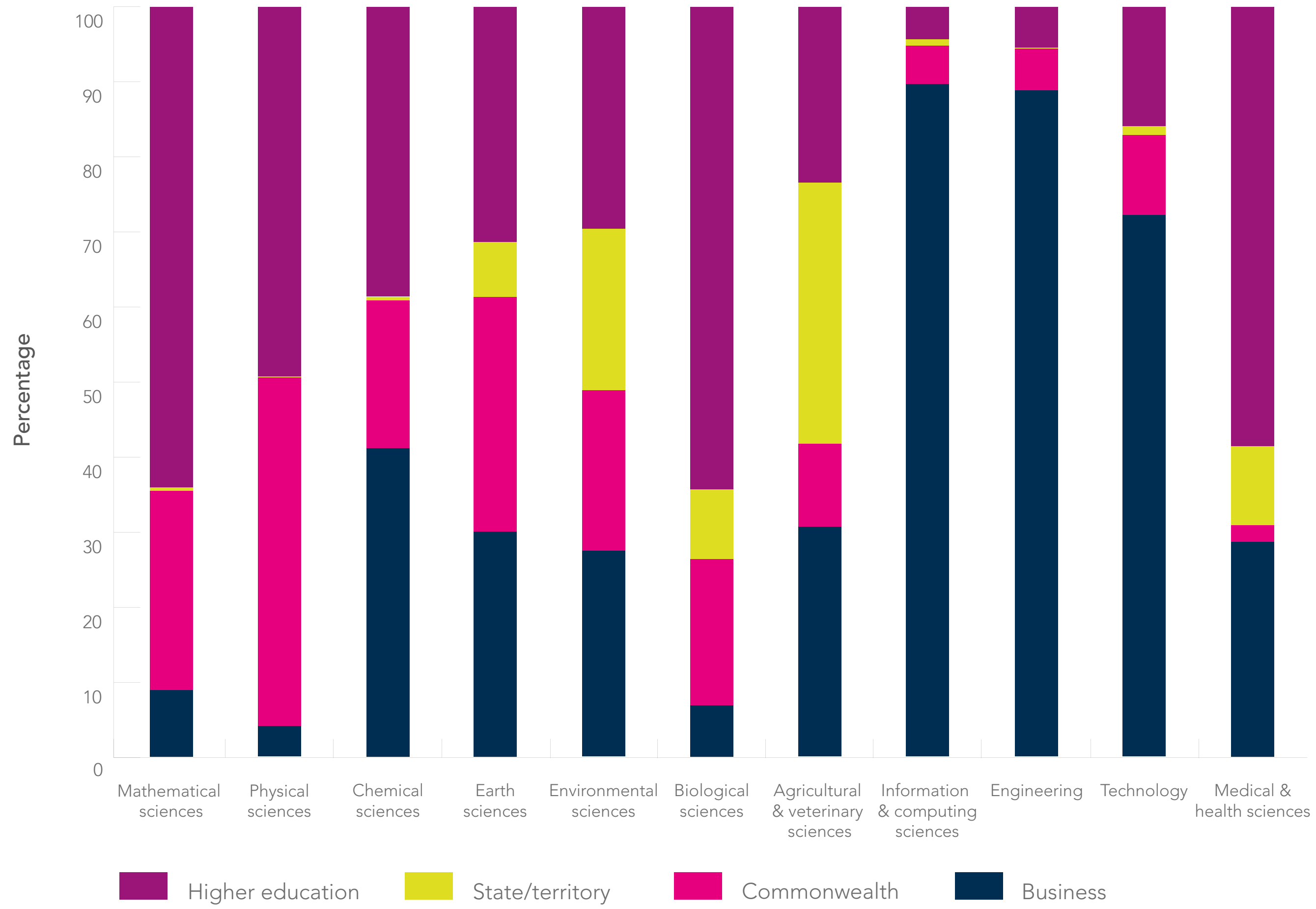


Note: Excludes expenditure in the private non profit sector.
Source: Research and Experimental Development Tables, Australian Bureau of Statistics.

Figure 2.5.2 Total GERD for all sectors, by field of research, 2008–09

[4]Science-related fields of research in this context—Mathematical Sciences, Physical Sciences, Chemical Sciences, Earth Sciences, Environmental Sciences, Biological Sciences, Agricultural and Veterinary Sciences, Information and Computing Sciences, Engineering, Technology, and Medical and Health Sciences.

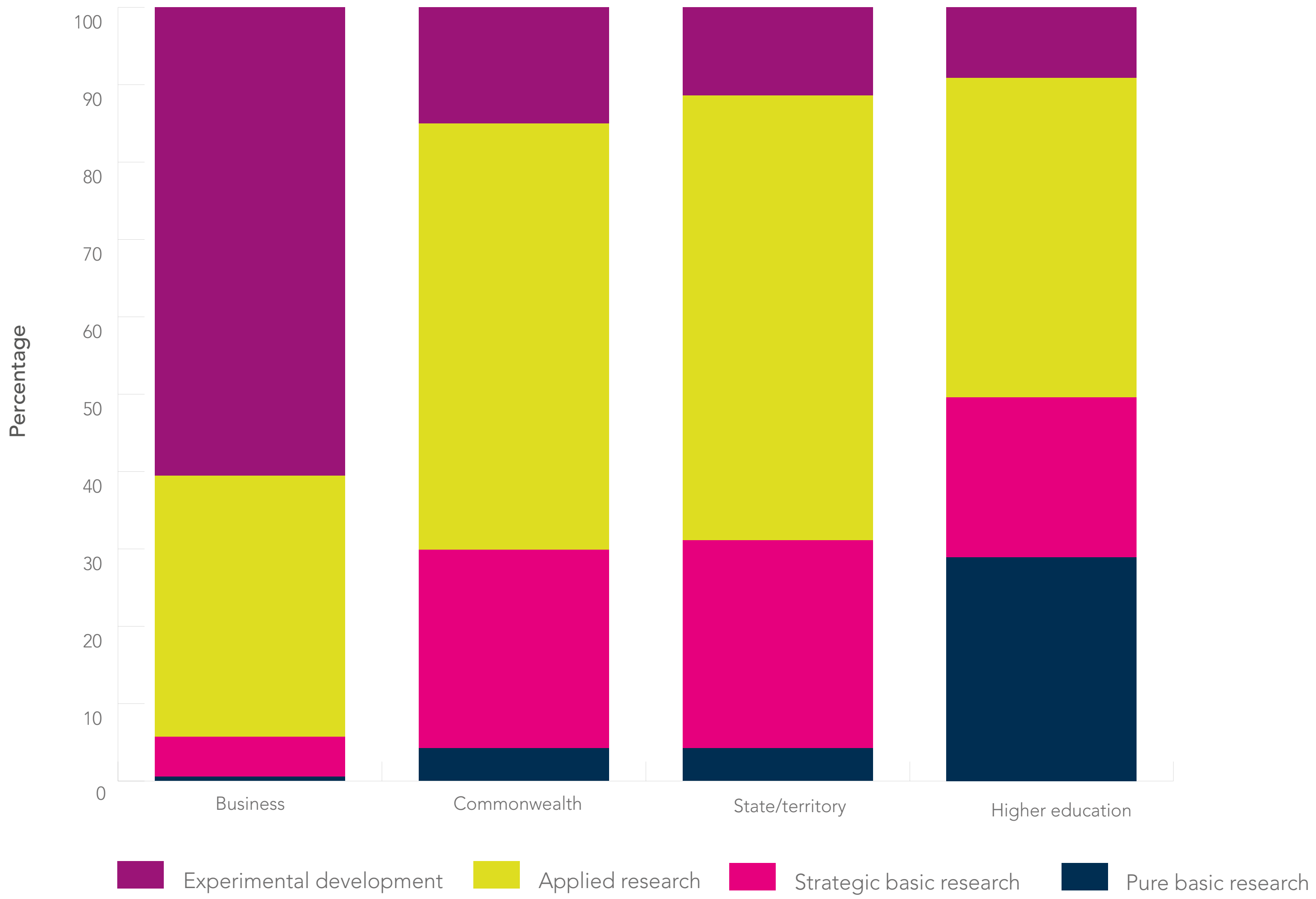
Each sector's relative contribution to GERD also varied widely according to the field of research. In 2008–09 most GERD on Natural and Physical Sciences was typically from the Commonwealth and/or higher education sector—in the range 51 to 96 per cent for the two combined, depending on the discipline (see Figure 2.5.3). Business makes a significant contribution to Chemical Sciences and Earth Sciences, at 42 and 31 per cent respectively. The greatest amount of GERD on Agricultural and Veterinary Sciences comes from state and territory governments (35 per cent), followed by business (31 per cent). The business sector dominates GERD for the Engineering (88 per cent), Technology (73 per cent) and Information and Computing Sciences (90 per cent) fields of research. The sector with the highest GERD on Medical and Health Sciences is the higher education sector, at 60 per cent.



Source: Research and Experimental Development Tables, Australian Bureau of Statistics.

Figure 2.5.3 GERD, by sector and field of research, 2008–09

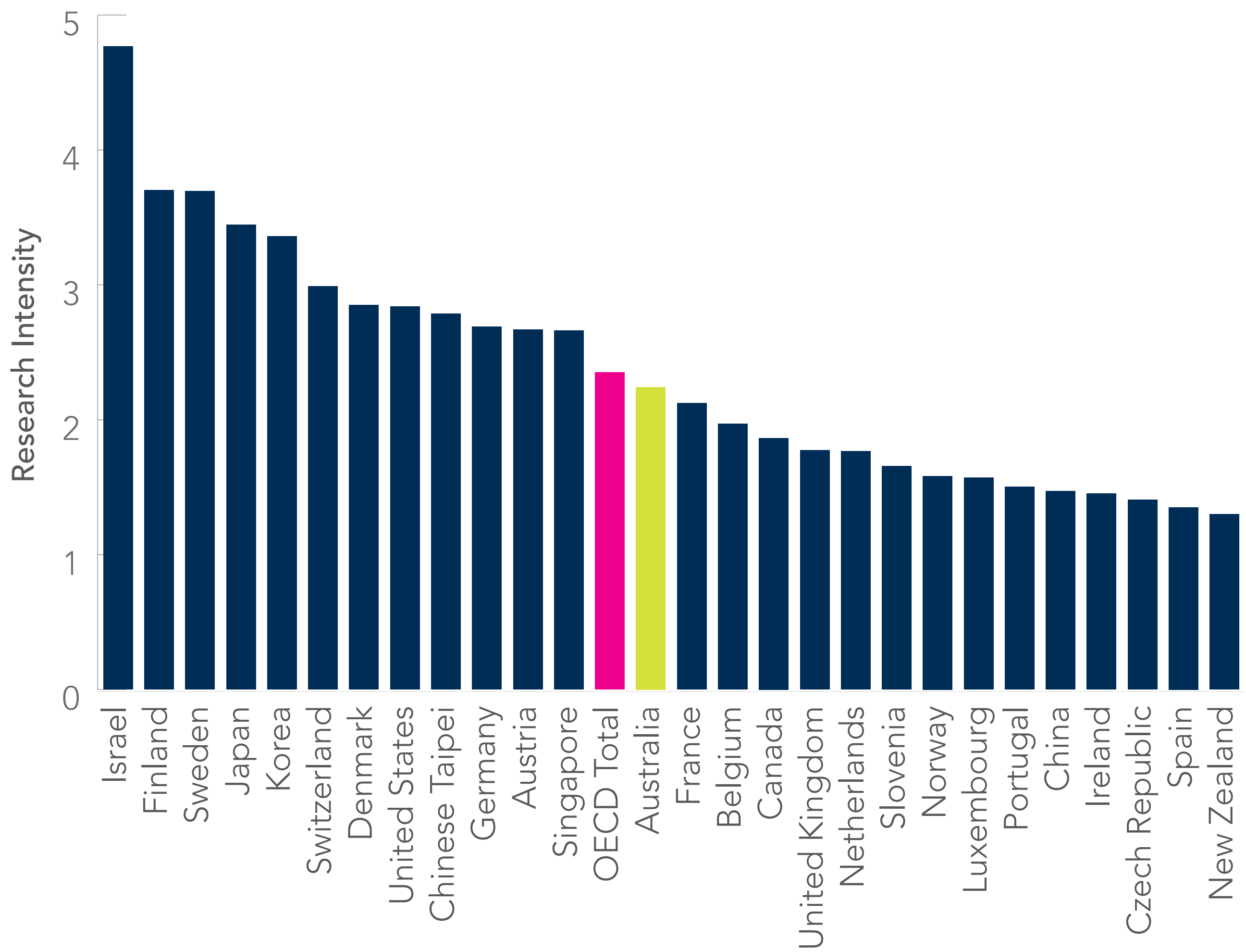
In 2008–09 the total GERD on all basic research (pure and strategic) amounted to about $5.33 billion (Research and Experimental Development Tables, ABS). The higher education sector contributed the largest amount in dollar terms ($3.33 billion) and the largest proportion of its total expenditure to this form of research (see Figure 2.5.4). In contrast, the total GERD for all applied research and experimental development was $21.67 billion (Research and Experimental Development Tables, ABS); in this case the business sector contributed both the largest dollar value ($15.90 billion) and the largest fraction of its total expenditure to this form of research.



Source: Research and Experimental Development Tables, Australian Bureau of Statistics.

Figure 2.5.4 GERD, by sector and type of research, 2008–09

Australia's total GERD across all sectors and all fields of research in 2008–09 amounted to 2.21 per cent of gross domestic product (Research and Experimental Development Tables, ABS), and the nation was ranked 14th in the OECD on this measure, known as 'research intensity' (see Figure 2.5.5). Australia's research intensity was marginally below the OECD total. In 2008–09 Australia was ranked 15th in the world in terms of 'purchasing power parity'.[5]



Note: Research intensity = GERD as a proportion of GDP.
Source: OECD.

Figure 2.5.5 Research intensity: Australia compared with other OECD countries, 2008–09

[5]When comparing countries' GERD, the OECD expresses figures in terms of purchasing power parity, which accounts for differences in national currencies and the economic strength of the various countries.

2.6 Research output and performance

Australia has about 0.3 per cent of the world's population yet produces more than 3 per cent of world scientific publications (DIISR 2011; Adams et al. 2010). The bulk of this research output is in science-related fields of research. In 2010 Australia ranked 11th in the world in terms of outputs across all fields of research in Scopus-indexed publications (SciMago 2007) and 10th in terms of papers and total citations in Thomson-Reuters indexed publications from 2001 to 2011 (Thomson-Reuters 2011). Australian research also has a high impact relative to the number of publications: Australian publications accounted for 4 per cent of global citations in 2004 to 2008 (Royal Society 2011).

The 2010 Excellence in Research for Australia, or ERA, exercise benchmarked research in Australian universities against the world on the basis of research outputs, measures of esteem and patents sealed in the period 2003 to 2008. In total, 191 270 research outputs (journal articles, conference papers, book chapters, books and non-traditional outputs[6]), 2162 esteem measures[7] and 659 patents sealed were reported in the science-related fields of research (see Table 2.6.1). Of the 12 broad fields of science-related research considered in this report, Australia performed at world standard (an ERA rating[8] of 3.0) or better in 10 of those fields (ARC 2011a).

Table 2.6.1 Research outputs, measures of esteem, patents sealed and ERA rating, 2010

Field of Research	Outputs	Esteem	Patents	Rating
Mathematical Sciences	8 659	106	0.7	3.2
Physical Sciences	13 666	192	31.0	3.7
Chemical Sciences	11 915	171	86.8	3.5
Earth Sciences	8 258	130	0.8	3.8
Environmental Sciences	4 695	77	4.1	3.3
Biological Sciences	23 404	412	95.6	3.1
Agricultural and Veterinary Sciences	8 539	60	34.7	3.3
Information and Computing Sciences[a]	24 656	101	13.8	2.7[a]
Engineering	37 382	474	195.8	3.0
Technology	621	16	13.8	5.0
Technology[a]	4 318	51	20.2	2.7[a]
Medical and Health Sciences	45 157	372	161.8	3.2

[a] The bulk of the research output was conference papers, which were not included in the ERA exercise.
Source: ARC (2011a).

[6] Non-traditional research outputs: curated or exhibited events, live performances, original creative works and recorded rendered works.
[7] ARC (2011a) define esteem measures to embody a measure of prestige and are recognised by experts within the disciplines as a highly desired, highly regarded form of accolade or acknowledgement (for example, fellowship of a learned academy).
[8] ERA rating of 3 is regarded equivalent to world standard. ERA rating of 4 and 5 are considered above world standard and well above world standard respectively (ARC 2011a).

2.7 Australian Government policy programs

The Australian Government's science, research and innovation budget tables show a total of 75 policy programs relating to science that were supported through the 2011–12 budget estimates and 50 additional programs supported through special appropriations. Fifteen portfolios administer these programs (see Table 2.7.1).

Table 2.7.1 Science, research and innovation policy programs supported by the Australian Government, 2011–12 budget estimates

Support through budget	Amount ($m)	Support through special appropriations	Amount ($m)
Agriculture, Fisheries and Forestry		**Agriculture, Fisheries and Forestry**	
Carbon farming initiative	2.3	Dairy Australia Limited	17.557
Centres of excellence—biosecurity risk analysis and research	1.719	Fishing industry research	16.297
National Weeds and Productivity Research Program	4	Grains	55.572
Climate Change Research Program	6.2	Horticulture research	41
Regional food producers/seafood industry innovation and productivity	5.8	Meat research	46.696
Rural Industries R&D Corporation	13.761	Other rural research	26.208
		Wool research	11.3
Attorney-General		**Attorney-General**	
Australian Institute of Criminology research program	7.415	Australian Institute of Criminology—Criminology Research Grant Program	0.458
Broadband, Communications and the Digital Economy			
ICT Centre of Excellence	25		
Climate Change and Energy Efficiency			
Australian Climate Change Science Program	7.8		
Carbon farming initiative	12.485		
National carbon accounting toolbox	4.032		
Defence			
Asia–Pacific Civil Military Centre of Excellence research and lessons learnt	1.153		
Defence Materiel Organisation: Capability Technology Demonstrator—extension program	10.563		
Defence Materiel Organisation—Defence Industry Innovation Centre	4.756		
Jet Fuel Exposure Syndrome Study	1.89		

Support through budget	Amount ($m)	Support through special appropriations	Amount ($m)
Education, Employment and Workplace Relations		Education, Employment and Workplace Relations	
		National Institutes Program—ANU component	178.932
Families, Housing, Community Services and Indigenous Affairs			
ARC linkage grants—FaHCSIA cash contributions	0.08		
Health and Ageing		Health and Ageing	
Attacking Lung Cancer	1.479	Health and Hospitals Fund	291.9
Australian National Preventive Health Agency research fund	8.81		
Cancer clinical trials	5.614		
Cancer data	0.407		
Cancer research	4.404		
Cooperative Research Centre for Aboriginal and Torres Strait Islander Health	0.2		
Health Sciences—Australian Longitudinal Study on Women's Health	3.129		
Indigenous Public Health Workforce Capacity Building Project, Uni of Melbourne (ONEMDA) and Deakin University Institute of Koori Education	0.261		
Investing in Hearing Research	2.265		
Jigsaw Foundation—support for craniofacial surgery	5		
Medical research infrastructure projects	201.5		
National Centre for Immunisation Research and Surveillance	0.8255		
National Public Health Communicable Disease Control—research centres	9.221		
NHMRC research grants	791.675		
Primary care policy, innovation and research	15.779		
Priority medical research	0.9		
Two dedicated prostate cancer research centres	3.5		
University of Melbourne's ONEMDA VicHealth Koori Health Unit	0.244		

Support through budget	Amount ($m)	Support through special appropriations	Amount ($m)
Human Services			
Human Services Delivery Research Alliance	2		
Infrastructure and Transport			
Funding to Transport Certification Australia—Intelligent Access Program	0.738		
Payments to Austroads/ARRB Transport Research Ltd	3.429		
Innovation, Industry, Science and Research		Innovation, Industry, Science & Research	
Australia–China Science and Research Fund	2	Australian Research Council	810.172
Australian Space Science Program	12.17068	Clean Energy Initiative	100
Automotive Transformation Scheme	185.311	Education Investment Fund —Super Science	
Clean Business Australia—Climate Ready Program	8.527	• Super Science - Future Industries	120.5
Collaborative Research Network Program	18.63	• Super Science - Marine and Climate	114.37
Commercial Ready Program	2	• Super Science - Space Science and Astronomy	27.5
Commercialisation Australia	56.235	Education Investment Fund - Round 1	
Commonwealth Serum Laboratories—Commonwealth assistance	10.6	• Institute of Photonics	0.1
Commonwealth strategic relationship with ANU		• New Horizons - Monash University Project	58
• Australian National Institute for Public Policy	1.5	Education Investment Fund - round 2	
• Building the Centre on China in the World	8	• Building the Sydney Institute of Marine Science	3
• Building the National Security College	0.17	• Centre for Neural Engineering	3.4
• National Security College	0.054	• La Trobe Institute for Molecular Sciences	15.5
Cooperative Research Centres	165.233	• National Centre for Synchrotron Science	3
European Molecular Biology Laboratory Partner Facility	2	Education Investment Fund - round 3	
Enterprise Connect	1.118264	• AuScope Australian Geophysical Observing System	6.829
Establishment of an ICT-enabled research laboratory—Commonwealth assistance	2.313	• Australian Future Fibres Research and Innovation Centres	15
Green Car Innovation Fund	136.442	• Green Chemical Futures	4.335
Innovation Investment Fund, including Innovation Investment Follow-on Fund	34.526	• Indian Ocean Marine Research Centre	8.5
International Education and Training (Australia–India Strategic Research Fund)	11.056	• National Imaging Facility	5.631

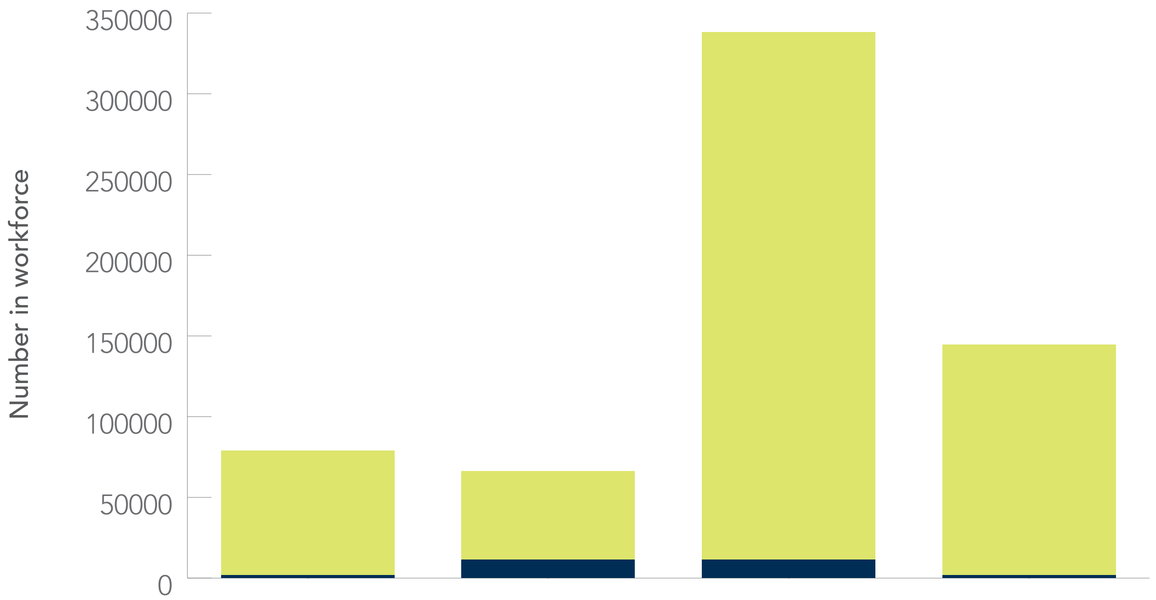
Support through budget	Amount ($m)	Support through special appropriations	Amount ($m)
Cairns Institute Tropical Innovation Hub—contribution	4.5	• The Australian Institute for Nanoscience	26.1
National Enabling Technologies Strategy	0.431	Education Investment Fund - Sustainability Round	
National Measurement Institute	9.5	• Newcastle Institute for Energy and Resources	12.098
Small-scale mammalian cell production facility	4	• Retrofitting for Resilient and Sustainable Buildings	15
		• Sustainable Energy for SKA	23.07
		Funding for higher education research promotion	5.479
		Funding for research and research training provided under HESA (2003)	
		• Australian Postgraduate Awards	218.867
		• Commercialisation Training Scheme	2.863
		• International Postgraduate Research Scholarship	20.727
		• Joint Research Engagement Program	332.489
		• Research Infrastructure Block Grants	224.467
		• Research Training Scheme	631.763
		• Sustainable Research Excellence in Universities	165.193
		Giant Magellan Telescope	15.1
		Tax incentives programs	
		• Early Stage Venture Capital Limited Partnerships	18
		• New R&D Tax Incentives - refundable	1210
		• New R&D Tax Incentives - non refundable	790
		• Pooled Development Funds	7
		• Premium Tax Concession for Additional R&D (175%)	60
		• R&D Tax Concession (125%)	-290
		• Venture Capital Limited Partnerships	11

Support through budget	Amount ($m)	Support through special appropriations	Amount ($m)
Prime Minister and Cabinet			
Anti-Doping Research Program	0.9		
Australia Council—Synapse Program	0.09		
Research support for counter terrorism	1.85		
US Department of Homeland Security collaborative research	0.4		
US Technical Support Working Group collaborative research	0.45		
Regional Australia, Regional Development and Local Government			
Regional and rural research and development grants	0.228		
Resources, Energy and Tourism			
Clean Energy Initiative			
• Australian Centre for Renewable Energy	72.625		
• Australian Solar Institute	32.665		
• National Low Emissions Coal Initiative	48.656		
Global Carbon Capture and Storage Institute	25		
Low Emissions Technology Demonstration Fund	100.45		
Sustainability, Environment, Water, Population and Communities		Sustainability, Environment, Water, Population and Communities	
Australian Biological Resources Study	2.03		
Marine and biodiversity research	2.874		
National Environmental Research Program	19.02		
Reef water quality	3		
		Veterans' Affairs	
		Australian Centre for Post-Traumatic Mental Health	0.872482
		Centre for Military and Veterans' Health	0.254
		Department of Veterans' Affairs Applied Research Program	2.000158
		Family study research	1.13
Total	**2156.889**	**Total**	**5485.23**

Source: Australian Government's 2011–12 science, research and innovation budget tables.

2.8 THE CURRENT SCIENCE-RELATED WORKFORCE

The 2006 census data show that professionals in the science-related workforce are overwhelmingly associated with health—about 338 000 people (see Figure 2.8.1). Information and communication technology professionals number about 144 000, whereas engineering and natural and physical science professionals number about 79 000 and 66 500 respectively. Although natural and physical science professionals constitute the smallest group, they include the largest proportion of doctoral graduates, at 17 per cent.



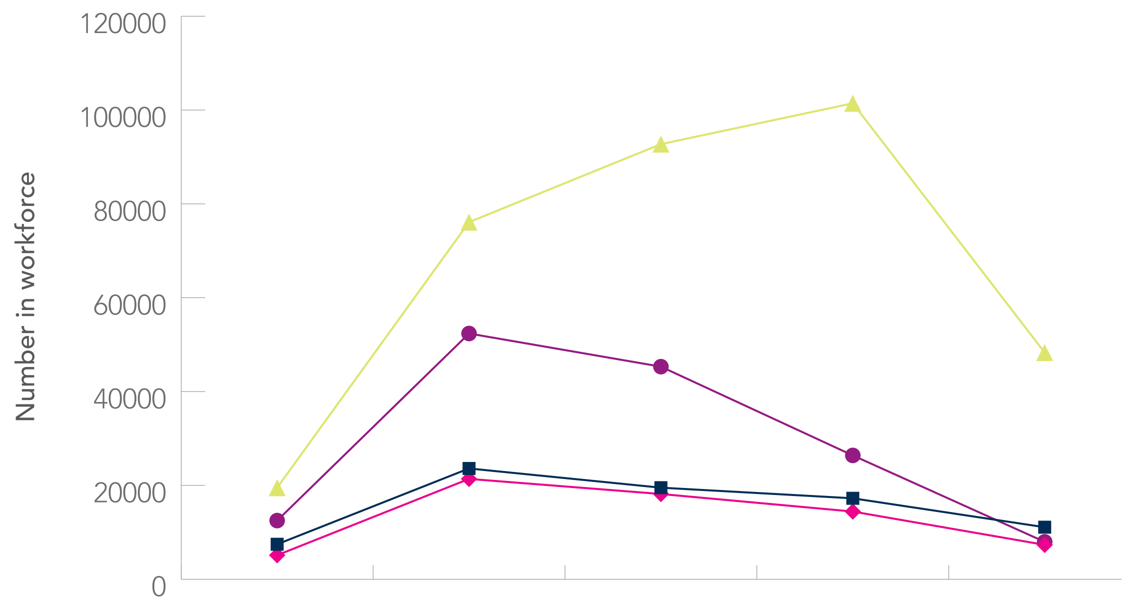
	Engineering	N&PS	Health	ICT
Other	77074	55005	326777	142832
Doctorate	1849	11433	11325	1712

Source: Australian Bureau of Statistics, 2006 census data.

Figure 2.8.1 Number of science-related professionals in the workforce, 2006

Figure 2.8.2 shows the age profile of the science-related workforce. The profile for health professionals is strongly skewed towards retirement age. It is important to recognise, however, that these data are incomplete and difficult to interpret with confidence. For example, the figure suggests that 7333 natural and physical science professionals will retire in the decade 2006 to 2016, yet in the same period about 120 000 domestic natural and physical science bachelor-level graduates will enter the workforce (see Section 4.4).

These figures suggest an inconsistency between data sources since there is no commensurate growth in the science workforce. Once in the workforce, many science graduates at the bachelor level must work in government, commerce and industry in professions classified other than 'natural and physical sciences'.

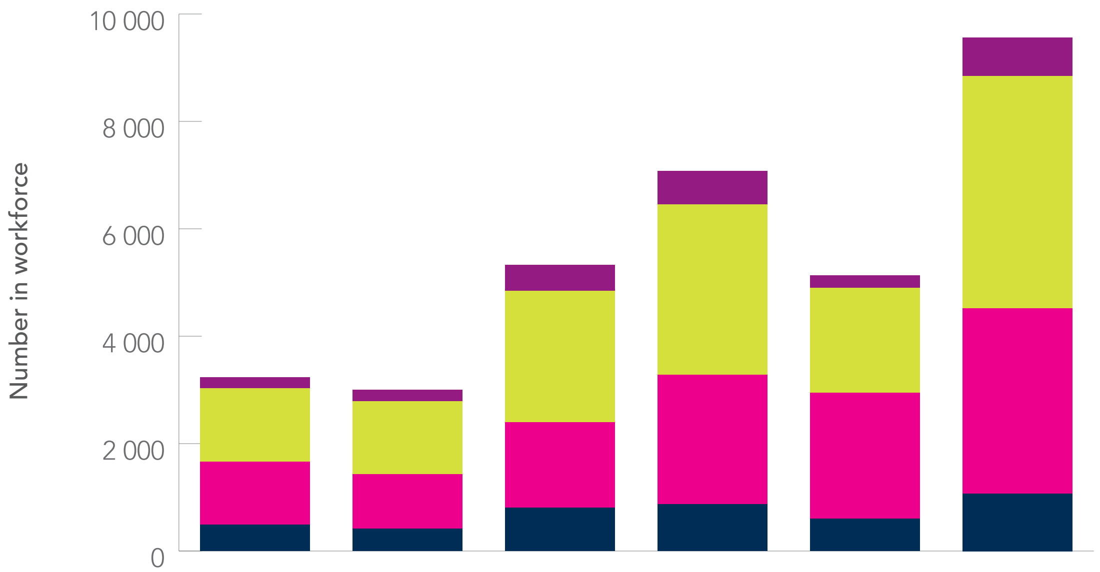


	15-24 years	25-34 years	35-44 years	45-54 years	55-64 years
Engineering ■	7456	23609	19516	17251	11091
N&PS ◆	5125	21385	18167	14428	7333
Health ▲	19507	76105	92733	101443	48314
ICT ●	12504	52373	45308	26391	7968

Source: Australian Bureau of Statistics, 2006 census data.

Figure 2.8.2 Age profile of science-related professionals in the workforce, 2006

In 2010 there were 1589 higher degree research completions in the natural and physical sciences, of which 78 per cent, or about 1200, were domestic students. Figure 2.8.3 shows the age profile of the academic workforce, as implicit in academic level. Many of the level D and level E academics can reasonably be assumed to be within five or 10 years of retirement. There is also a considerable research workforce in the portfolio research agencies, although their age profile is not available. It is reasonable to expect that this annual supply rate of around 1200 higher-degree research graduates in the natural and physical sciences can be entirely accommodated in universities and government research agencies, leaving relatively few making the transition to work in industry and commerce. The *2011 OECD Science, Technology and Innovation Scoreboard* shows that countries that are recognised as having an innovative workforce—Sweden, Denmark and Finland for example—have three times more R&D personnel in industry and commerce than is the case in Australia (Pettigrew 2012).



	Level E	Level D	Level C	Level B	Level A	Other
Engineering	486	411	809	868	597	1070
N&PS	1174	1023	1585	2412	2346	3448
Health	1374	1351	2451	3174	1954	4325
ICT	198	221	482	623	233	718

Source: Australian Research Council (2011).

Figure 2.8.3 Age profile of science-related academics from the 2010 Excellence in Research for Australia audit

2.9 CONCLUDING REMARKS

This chapter describes the main components of the science system in Australia and provides an indication of their size in terms of human and/or financial 'capital'. In broad terms, Australia's science system compares favourably with those of other OECD countries—and particularly countries of similar economic size and with a similar government model.

On the basis of the data presented it could be argued that Australian science is in a healthy state overall. The chapters that follow delve more deeply into each component of the system in order to explore details and recent trends: it emerges that in this system that appears healthy overall some vulnerabilities exist and some challenges are developing.

3. SCIENCE IN SECONDARY SCHOOLS

Secondary education—the gateway between primary and tertiary or vocational education—has recently been receiving widespread attention.

This has been promoted by concern, in Australia and overseas, about the declining proportions of high school students choosing to study science courses such as physics, chemistry, biology and advanced mathematics. There is also concern that the current generation of students might not harbour ambitions to become the innovators and creators of tomorrow, despite their extensive use of technological products such as the internet, digital audio players (iPods, for example) and smart phones. These concerns have implications for the future supply of scientists and the development of an innovative workforce for a knowledge-based economy. More broadly, they also have implications for science capacity in Australia and the science literacy of its citizens.

A number of enduring and emerging challenges associated with science education in secondary schools have come under the spotlight. Among them are apparent tensions related to the emphasis on science literacy and the preparation of students for university science, the content demands of senior secondary curricula, and the prevalence of didactic as opposed to interactive modes of teaching. There is concern about the perceived value of science and the relative lack of popularity of fundamental science disciplines among secondary school students.

This chapter relies primarily on data and findings from a recent Australian Academy of Science survey of students in Years 11 and 12 (Goodrum et al. 2012). It also takes into account several other recent national reports and reviews:

- the Choosing Science national study, which aimed to understand the factors affecting Year 10 students' choice of science subjects in Years 11 and 12 (Lyons & Quinn 2010)
- the Australian Centre for Educational Research monograph Participation in Science, Mathematics and Technology in Australian Education (Ainley et al. 2008)
- a comprehensive review of school-level engagement in science, technology, engineering and mathematics, with a focus that spans upper primary school to the point where students make subject choices for senior secondary school (Tytler et al. 2008).

Additionally, the chapter draws on data and findings from a 2012 Universities Australia survey of first-year university students and the two most recent Staff in Australia's Schools reports (McKenzie et al. 2008, 2011).

3.1 MAIN FINDINGS

- Teachers surveyed pointed to lack of time as a major constraint in teaching science. This was mentioned in relation to insufficient time for class preparation and rushing to cover the required syllabus.
- The profile of science learning activities and the views of science and non-science students suggest that students could be better encouraged to be involved in science and their interest in science better nurtured.
- Science students in high school and university saw science teachers as an important source of inspiration for science learning. Teachers therefore hold a unique and central position in influencing students' interest in and attitudes towards science.

3.2 THE SENIOR SECONDARY SCHOOL SCIENCE LANDSCAPE

3.2.1 Teaching and learning in science

It is recognised that greater emphasis has been given to the preparation of science specialists in Years 11 and 12 than to developing science literacy for the broader range of students (ETC 2006). As a result, teaching is seen as 'bogged down in memorising factual content' (ETC 2006, p. 38). Furthermore, this narrow focus on discipline-based courses for science specialists has influenced the way the science courses are generally taught.

Despite the long-recognised limitations of the transmission model of teaching, there has been resistance to adopting a more inquiry-based approach to science teaching. Several authors (Fensham 1997; Goodrum et al. 2001; ETC 2006) have argued that the heavy, specialist science courses of senior secondary school have filtered down to junior secondary school and that science in lower secondary school has consequently lacked meaning and relevance for many students. Traditional 'chalk-and-talk' teaching, copying notes and 'cookbook' practical lessons have offered little challenge or excitement (Goodrum et al. 2001). In recent years, however, considerable efforts have been made to change the pedagogy in both primary and secondary science. Examples of innovative programs to support science pedagogy in schools are the Australian Academy of Science's Science by Doing program and the CSIRO's Scientists in Schools program.

3.2.2 Science courses and participation in Years 11 and 12

Every Australian state and territory has a course or courses related to the three traditional science disciplines of biology, chemistry and physics. Following implementation of the Australian Curriculum: Science, there will be four science courses common across Australia in Years 11 and 12—biology, chemistry, earth and environmental science, and physics. The curricula are being developed and will be available in 2012 for further consideration. Individual states and territories might opt to provide additional science courses beyond these four.

Since 1991 what is now called the Department of Education, Employment and Workplace Relations has compiled consistent school enrolment data from state and territory assessment and accreditation agencies.

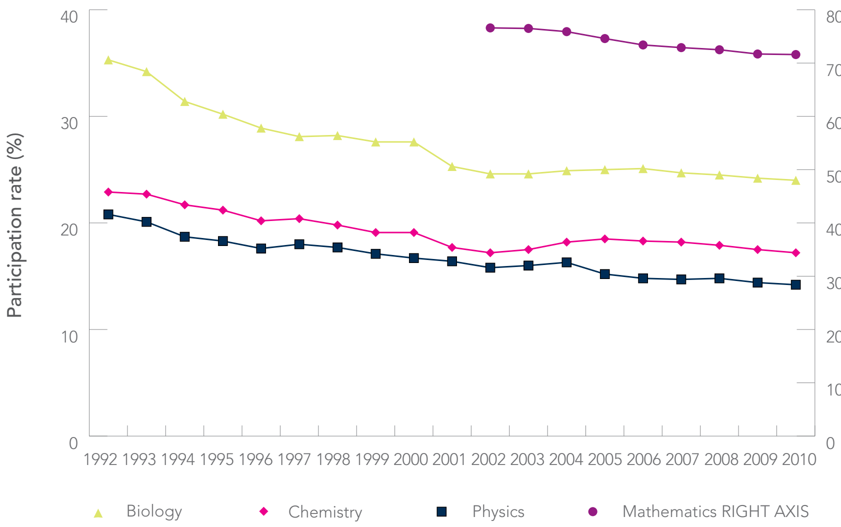
Trends in the uptake of specific science subjects by Year 12 students can be monitored by calculating subject participation rates—that is, the number of students enrolled in a specific subject as a proportion of the total number of students in Year 12 (ABS, various years, cat. no. 4221.0). In such an analysis the differing subject names used by the jurisdictions are grouped when deemed equivalent.

A longitudinal analysis of national enrolments in Year 12 science subjects shows that the percentages of students enrolled in the traditional sciences (biology, chemistry, physics and mathematics) have been in gradual but persistent decline (see Figure 3.2.1). From 1992 to 2010 participation rates for biology fell from 35.3 per cent to 24 per cent, and for physics they fell from 20.8 per cent to 14.2 per cent in the same period. The decline in chemistry participation rates was less; falling from 22.9 per cent in 1992 to 17.2 per cent in 2010.

Longitudinal analysis of national participation rates for mathematics is confounded by differences in the types of mathematics taught in the various jurisdictions and by changes in mathematics curricula over time (Ainley et al. 2008). The participation rates for all types of mathematics from 2002 to 2010[1] are much higher compared with the rates for other science courses. They declined marginally from 76.6 per cent in 2002 to 71.6 per cent in 2010.

It is noteworthy that participation rates for the subject of psychology rose from 4.9 per cent in 1992 to a peak of 9.2 per cent in 2006. Rates for geology and the other sciences remained reasonably stable, at 1 per cent and 8 per cent respectively, with minor fluctuations over the years.

[1] This is the most recent period for which there is a consistent categorisation of the different types of mathematics. The artificial categorisation of mathematics types and the counting methodology for mathematics students varied before 2002. The actual percentages for mathematics participation differ slightly from those published by Barrington (2011.)



Source: Kennedy (in prep.); Ainley et al. (2008).

Figure 3.2.1 Year 12 science participation, Australia, 1992 to 2010

There has been much speculation about the causes of this persistent decline in science subject enrolments. The reasons are complex and multi-faceted, shaped by overlapping curriculum, societal, school and student factors. Lyons and Quinn (2010) suggest that the main causal factor is an expanded menu of course options, creating increased competition among subjects vying for curriculum share. This hypothesis is supported by evidence from the Australian Council of Educational Research that shows significant changes in the curriculum shares of a range of subjects between 1993 and 2001 (ACER 2005). The result has been the decline not only of science subjects but also of other traditional subjects such as economics, accounting, geography, and political and social studies. Other data show that the proportion of students enrolling in advanced mathematics also declined between 1995 and 2004 (Forgasz 2006; McPhan et al. 2008). In contrast, subjects such as business studies, secretarial studies, hospitality, computer studies, food and catering, music and performing arts, and creative and visual arts have seen a substantial increase in enrolments.

3.2.3 International comparisons of students' achievement in science

The science achievement of Australian students in comparison with that of their peers in other countries can be ascertained from two commonly used international surveys—the Programme for International Student Assessment, derived from the OECD, and the Trends in International Mathematics and Science Study, conducted by the International Association for the Evaluation of Educational Achievement. PISA assesses the ability of students near the end of compulsory education (mostly in Year 10) to apply their understanding of reading, mathematics and science (as the three domains of assessment) to everyday problems and situations. TIMSS assesses Year 4 and Year 8 students' mastery of the factual and procedural content of mathematics and science curricula.

PISA assessments have been conducted every three years in the past decade, with a major focus on one domain and a minor focus on the other two domains in each cycle. The results for the 65 countries or economic regions (34 OECD countries and 31 partner countries or economic regions) involved in the most recent study, completed in 2009, show that Australia achieved a mean score of 527 in scientific literacy, significantly above the OECD average of 501. Among countries with scores comparable to Australia's were New Zealand, Canada, Germany and the Netherlands. Five countries, four of them from the Asia–Pacific region, performed significantly better than Australia: China (represented by Shanghai and Hong Kong), Finland, Singapore, Japan and South Korea. The countries outperforming Australia have changed over the last four PISA exercises (see Table 3.2.1).

Table 3.2.1 Countries outperforming Australia in scientific literacy in PISA exercises, 2000 to 2009

2000	2003	2006	2009
			Shanghai-China
			Finland
			Hong Kong-China
	Finland	Finland	Singapore
Korea	Japan	Hong Kong-China	Japan
Japan	Korea	Canada	Korea
Australia	Australia	Australia	Australia

Source: Goodrum et al. (2012).

It is noteworthy that the mean performance of Australian students in science literacy was unchanged in the 2006 and 2009 PISA exercises (Thomson et al. 2011).

Two TIMSS assessments were carried out in the past decade, the most recent one in 2007 and the other one in 2003. Year 8 or 9 students from 49 countries participated in the 2007 assessment. The average score in science achieved by Year 8 Australian students in 2007 was 515, significantly higher than the TIMSS average of 500. This score, however, is much lower, by 12 points, than the 2003 score (Thomson & Buckley 2009). As with the PISA rankings, in TIMSS 2007 China (represented by Hong Kong), Singapore, Japan and South Korea were among the countries performing better than Australia.

The results from the PISA and TIMSS exercises are evidence of Australia's ranking in science achievement. It is noteworthy that Australia's PISA scores have remained largely static and the TIMSS results have actually fallen.

3.2.4 Teachers of science

The quality of teaching is a crucial determinant of what students experience and achieve at school (Goodrum et al. 2001; Rowe 2003; Committee for the Review of Teaching and Teacher Education 2003) and is dependent on the training and recruitment of suitably qualified teachers.

Most available data on the supply of and demand for science teachers come from surveys (Goodrum et al. 2001; MCEECDYA 2004; Harris et al. 2005; McKenzie et al. 2008, 2011). Difficulty recruiting science teachers, particularly in physics and chemistry, has been noted since the early 2000s (MCEECDYA 2004). The problem remains, and there are notable numbers of vacancies for physics and chemistry teachers in secondary schools (McKenzie et al. 2011). Senior secondary school science teachers appear on the Skills Shortage List, Australia (2010–11), further highlighting recruitment difficulties. Exacerbating the problem is the fact that 17 per cent of secondary school teachers fall into the modal age band of 51 to 55 years and 36 per cent of all secondary school teachers are over the age of 50 (McKenzie et al. 2011).

The results of the most recent Australian Centre for Educational Research survey of teachers paint a mixed picture of the qualifications and experience of science teachers for Years 11 and 12 (McKenzie et al. 2011). About 70 per cent of chemistry teachers for Years 11 and 12 have three or more years of tertiary education in chemistry, have received training in the teaching of chemistry and have been teaching for more than five years. The figures for teachers of physics in Years 11 and 12 are a matter of concern: just over half (54.1 per cent) have at least three years of university physics study, although almost two-thirds of physics teachers have more than five years' experience in teaching physics. The current situation in Australian senior secondary schools looks solid, but there is considerable scope for improvement.

The qualifications and experience of science teachers in junior secondary schools (Years 7 to 10) is also important. These years are the 'formative years' for science attitudes among students (Tytler 2008), and junior secondary science teachers have a strong influence on student attitudes (Lyons & Quinn 2010). McKenzie et al. (2008) reported that less than half of teachers of general science (44 per cent) in Years 7 to 10 have relevant qualifications—that is, two or more years of tertiary education in science.

3.3 SCIENCE TEACHERS FOR YEARS 11 AND 12: SURVEY RESULTS

The 2012 report by Goodrum et al. contains findings from focus groups and surveys of Year 11 and 12 students and teachers. The aim of the focus groups was to discuss and validate themes and trends from the two surveys that had been conducted. The informative but qualitative findings of the focus groups are not presented here: the interested reader is referred to the original report. This section describes and discusses the main quantitative findings from the two surveys.

3.3.1 Teacher qualifications

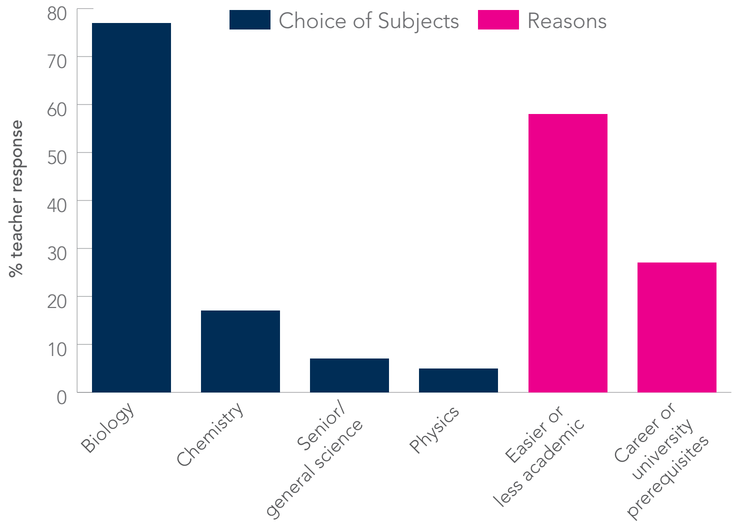
A telephone survey of science teachers for Years 11 and 12 was conducted in order to cast light on typical teaching practice and student attitudes to senior science. Ninety-nine respondents were questioned, in New South Wales (63 per cent), South Australia (26 per cent) and the ACT (11 per cent). Government (60 per cent), independent (26 per cent) and Catholic (14 per cent) sectors were represented in each jurisdiction.

About three-quarters of the teachers surveyed had completed a Bachelor of Science degree. This is broadly consistent with findings from the Staff in Australia's Schools reports (Mackenzie et al. 2008, 2011), which found that the majority of teachers of particular Year 11 and 12 science subjects, such as chemistry (74 per cent), have three or more years of tertiary education in their subject.

3.3.2 Relative popularity of science subjects

When asked about the popularity of science subjects at their school, 77 per cent of the teachers surveyed said biology was the most popular (see Figure 3.3.1). Much less popular and in second place was chemistry (17 per cent); physics (5 per cent) was in fourth place, behind senior or general science (7 per cent).

More than half of the teachers (58 per cent) attributed biology's popularity to the subject being perceived by students as relatively easy or involving less mathematics (see Figure 3.3.1). The second most common reason for subject choice was meeting university prerequisites or career aspirations; 27 per cent of teachers nominated this.

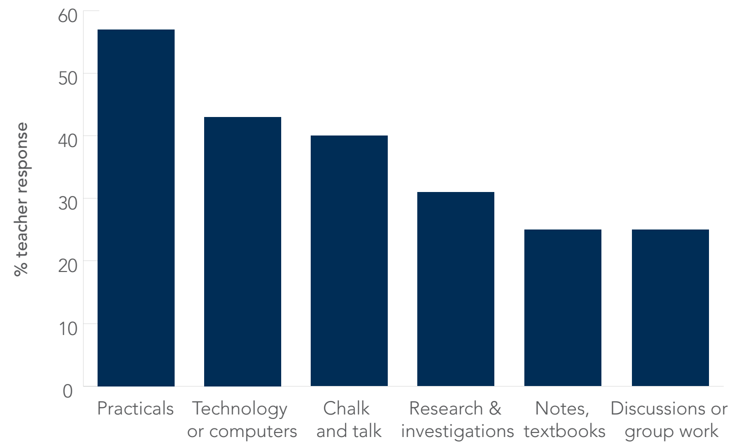


Note: Total for choice of subjects exceeds 100 per cent because teachers listed more than one subject.
Source: Goodrum et al. (2012).

Figure 3.3.1 Popularity of senior science subjects and reasons for subject choice from the perspective of teachers

3.3.3 Science teaching and assessment

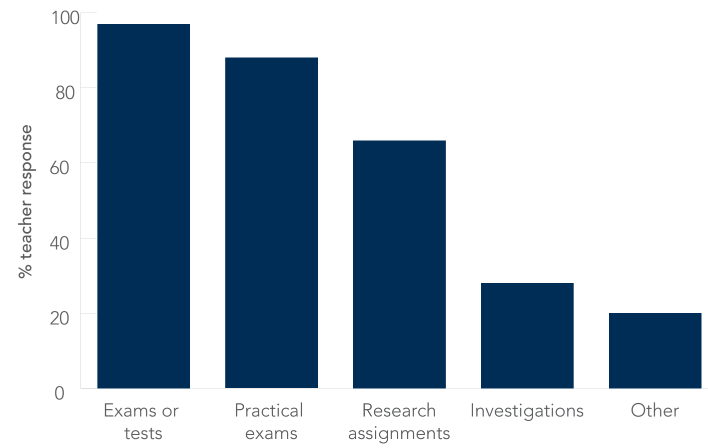
Teachers identified the use of practicals (57 per cent) and technology or computers (43 per cent) as the most common elements in their approach to teaching science (see Figure 3.3.2). The 'chalk-and-talk' or teacher-directed, approach (40 per cent) was reported to be the third most common approach. Science investigations and research did not feature prominently in the commonly applied approaches to science teaching in Years 11 and 12.



Note: Total exceeds 100 per cent because many teachers gave more than one response.
Source: Goodrum et al. (2012).

Figure 3.3.2 Common approaches to science teaching

Assessment approaches the teachers identified were dominated by exams or tests (97 per cent) and practical exams (88 per cent) (see Figure 3.3.3). Investigation-based and alternative assessment methods were not widely used. There were differences between jurisdictions; assessment methods can be influenced by what is prescribed in the syllabus.

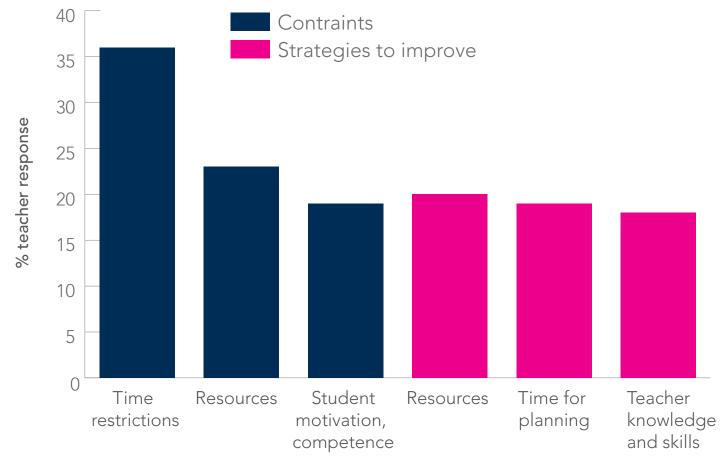


Note: Total exceeds 100 per cent because many teachers use more than one assessment method.
Source: Goodrum et al. (2012).

Figure 3.3.3 Common approaches to science assessment

3.3.4 Constraints on teaching science

Thirty-six per cent of teachers nominated lack of time as the single most important factor limiting the teaching of science (see Figure 3.3.4). Time was mentioned as a factor in several different contexts—including lack of preparation time, rushing to cover the required syllabus, and interruptions as a result of extracurricular activities. A lack of resources, generally related to laboratory equipment, was said to be a limiting factor by 23 per cent of the teachers surveyed. Other constraints were student-centred and included student motivation (15 per cent) and low student aptitude in junior secondary school (4 per cent).



Source: Goodrum et al. (2012).

Figure 3.3.4 Primary constraints on teaching science and strategies for improvement

3.3.5 Improving the quality of science teaching

Teachers provided varied responses when asked about the best way of improving science teaching in their schools. The top three responses were resources (20 per cent), time for planning or time in class (19 per cent) and improving teachers' knowledge and skills (18 per cent). Time and resources were raised and discussed briefly in relation to constraints on teaching. Just as importantly, professional development was mentioned in the context of using technology in the classroom, using the best general pedagogy techniques, and keeping abreast of the latest scientific literature so as to include relevant information in lessons.

3.4 YEAR 11 AND 12 STUDENTS: SURVEY RESULTS

To complement the teacher survey, Goodrum et al. (2012) conducted a survey of science and non-science students in Years 11 and 12. The objective of the survey was to gain insights into students' perceptions of and attitudes towards science. The survey was based on a questionnaire that was completed by 1157 science students and 363 non-science students.[2]

3.4.1 Non-science students

Of the 363 non-science students, 68 per cent were in Year 11 and the remainder were in Year 12.

Reasons for not studying science

The non-science students were initially asked about their reasons for not studying science. The most common response was that the students either disliked science or found it boring (61 per cent). Another common theme was that the students found science difficult or reported not being good at it (31 per cent). A proportion of students (26 per cent) responded that they were not studying science because it did not align with their career aspirations. A notable proportion (6 per cent) said they would have liked to study science had it not been for reasons such as timetable clashes or teachers advising them against doing science.

Previously reported views of non-science students are also informative (Lyons & Quinn 2010). Students envisage careers in a manner that is consistent with their self-identity, and Lyons and Quinn found that the most common reason for not choosing science in Year 11 was students could not picture themselves as scientists. Tytler et al. (2008) provide a broader discussion of students' self-perception and their choice of subjects and career. Among other things, evidence suggests that by the age of 14 years many students will have made identity-related decisions about their futures. In other words, the students will have largely decided on whether they will study science or pursue a career in science, in keeping with their perceived identity.

Subject choice

The non-science students were also asked to list the subjects they were studying at the time of the survey. Seventy-four per cent were studying mathematics at some level. It was not possible to ascertain whether the students were studying advanced, intermediate or elementary-level mathematics.

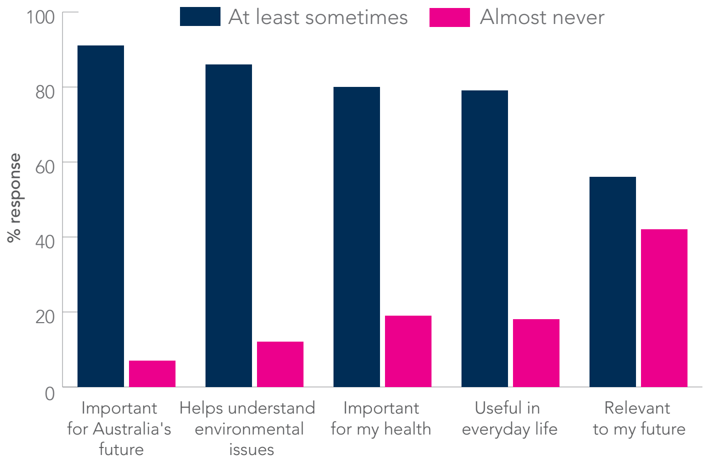
Post-school intentions

Although the non-science students nominated a range of post-school intentions, 48 per cent of them said they intended to study at university. Most of the remaining students intended to enter the workforce (20 per cent) or study at a vocational institute or enter a trade (14 per cent); 10 per cent were undecided.

Relevance of science

The non-science students were asked how relevant science was to their lives and to society generally. More than half of them (56 per cent) considered science to be relevant to their future at least 'sometimes', while 42 per cent said science was 'almost never' relevant (see Figure 3.4.1). The lack of personal relevance for such a high proportion of non-science students highlights the importance of science literacy as an aim for science education in earlier years.

In contrast, science is perceived to be more relevant at the societal level. Ninety per cent of the non-science students recognised the importance of science to Australia's future at least 'sometimes'; only 7 per cent said science will 'almost never' be important for Australia's future.



Source: Goodrum et al. (2012).

Figure 3.4.1 Perceived relevance of science: non-science students

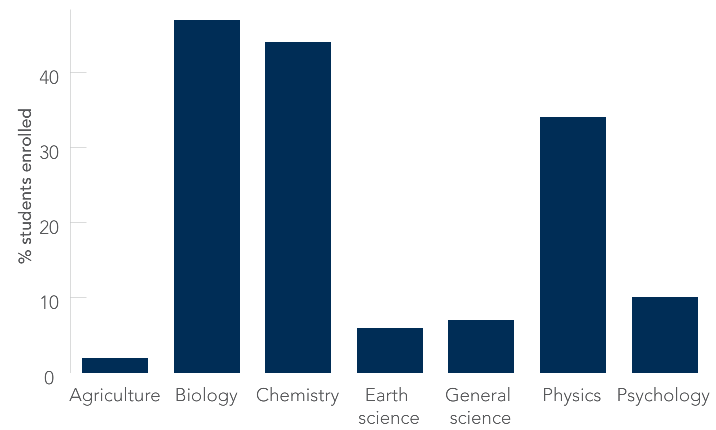
[2]The survey instrument used a combination of open-ended questions and questions with either of the two following five-point response scales: 'Never', 'Once a term or less', 'About once a month', 'About once a week' and 'Nearly every lesson'; and 'Almost never', 'Sometimes', 'Often', 'Very often' and 'Almost always'.

3.4.2 Science students

Of the 1157 science students surveyed, 61 per cent were in Year 11 and the remainder were in Year 12.

Subject choice

The science students were initially asked to list the subjects they were studying at the time of the survey. The popularity of biology, previously highlighted by the teachers, was reflected in the students' choice of subjects (see Figure 3.4.2): almost half of them (47 per cent) were enrolled in biology; this was followed closely by chemistry (44 per cent) and then physics (34 per cent).



Note: Total exceeds 100 per cent because some students were enrolled in more than one science subject.
Source: Goodrum et al. (2012).

Figure 3.4.2 Students' choice of science subjects

Mathematics

Seventy-nine per cent of the science students said they were studying mathematics. Unlike the non-science students, they provided sufficient detail to partially clarify the different levels of mathematics studied. Forty-one per cent were studying high-level mathematics and 19 per cent were studying lower level mathematics. The uptake of higher or lower level mathematics might be understated because the remaining 39 per cent of the science students did not specify their mathematics course level.

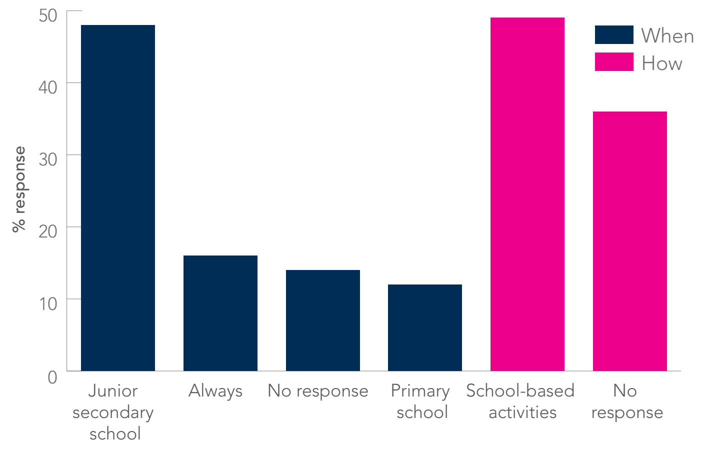
Reasons for studying science subjects

When asked about the reasons for their choice of science subjects, more than two-thirds of the students (68 per cent) nominated an interest in the subject or the relevance of the subject to their lives. Career or university intentions were the next biggest influence on subject choice (38 per cent of respondents). A recent Universities Australia survey also found that student interest in a subject was the primary reason for choosing that subject in Year 12; about 70 per cent of both STEM (science, technology, engineering and mathematics) and non-STEM first-year university students reported that their choice of Year 12 subjects was based on their interest in those subjects (Universities Australia 2012).

Origins of the interest in science

When asked about when they became interested in science, 48 per cent of the students traced the origin of their interest to junior secondary school; 12 per cent mentioned primary school (see Figure 3.4.3). A small proportion of the science students (7 per cent) said they were not interested in science.

For 49 per cent of the students the interest in science was triggered by school-based lessons or activities, including specific teachers, enrichment programs and subject information sessions. Among the minor triggers of interest were the mass media (6 per cent) and family members (5 per cent). Notably, 36 per cent of the students did not respond to the question about how they became interested in science.



Source: Goodrum et al. (2012).

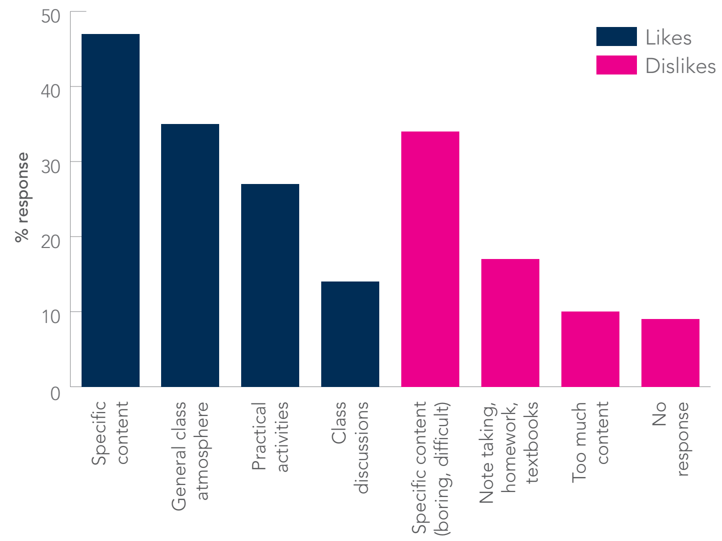
Figure 3.4.3 Origin of interest in science: when and how

The importance of school teachers in influencing students' subject choice is affirmed by the Universities Australia survey of first-year university students enrolled in STEM and non-STEM courses. The survey found that 65 per cent of STEM students were encouraged by teachers to do well in science or mathematics (Universities Australia 2012).

What students liked or disliked about their science classes

Students identified several positive aspects of their science classes. In particular, what they liked most (47 per cent) related to content (see Figure 3.4.4). They appreciated specific content such as anatomy and liked learning everyday facts or about how things worked. Other aspects highlighted were the general atmosphere in the science classroom (35 per cent) and practicals, excursions and investigations (27 per cent).

The most positive aspect of the science classroom is also the most negative aspect. More than a third of the students said that what they disliked about their science class was related to content. Among the reasons for this was the content being boring or difficult (34 per cent). Some students also mentioned that they did not enjoy specific content such as 'stoichiometry'. A further 10 per cent said there was too much content and not enough time to cover it. The way science was taught was also a problem for 17 per cent of the students, note taking, homework and textbooks being identified as areas of concern. Almost a fifth of the students (9 per cent) did not respond to this query or said there was nothing that they disliked about their science class (9 per cent).



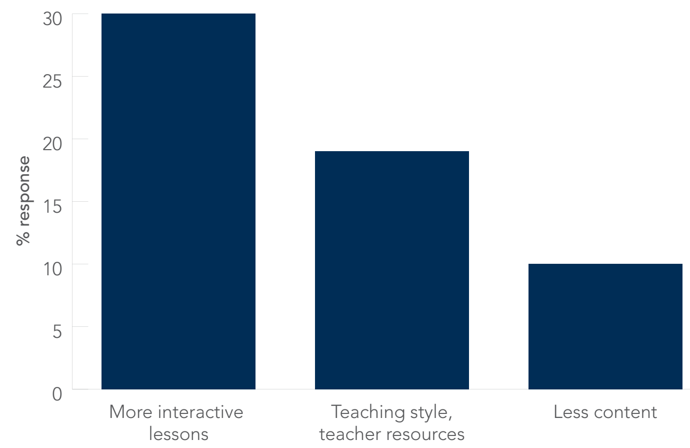
Note: Total for 'likes' exceeds 100 per cent because some students cited more than one feature.
Source: Goodrum et al. (2012).

Figure 3.4.4 What students liked or disliked about their science class

The science content in Years 11 and 12 appears to have had a polarising effect on the surveyed science students, substantial numbers either liking or disliking the content. This raises questions about the nature of the content itself and the prevailing pedagogical techniques in science classrooms. As noted, teachers also highlighted time as a constraint in the context of preparing for lessons and covering the required content.

Improving science classes

The most common suggestion the science students provided for improving science classes was to make classes more interactive by including more investigations, excursions, practical lessons or class discussions; 30 per cent of the students suggested this (see Figure 3.4.5). Nineteen per cent of the students identified a prominent role for teachers, suggesting improved teaching styles or using better teacher resources. Reducing the level of content was suggested by 10 per cent of the students. Just over a fifth of the students (22 per cent) made no suggestions for how their science classes could be improved; students who said there was nothing they disliked about their science class were probably part of this group of non-respondents.



Source: Goodrum et al. (2012).

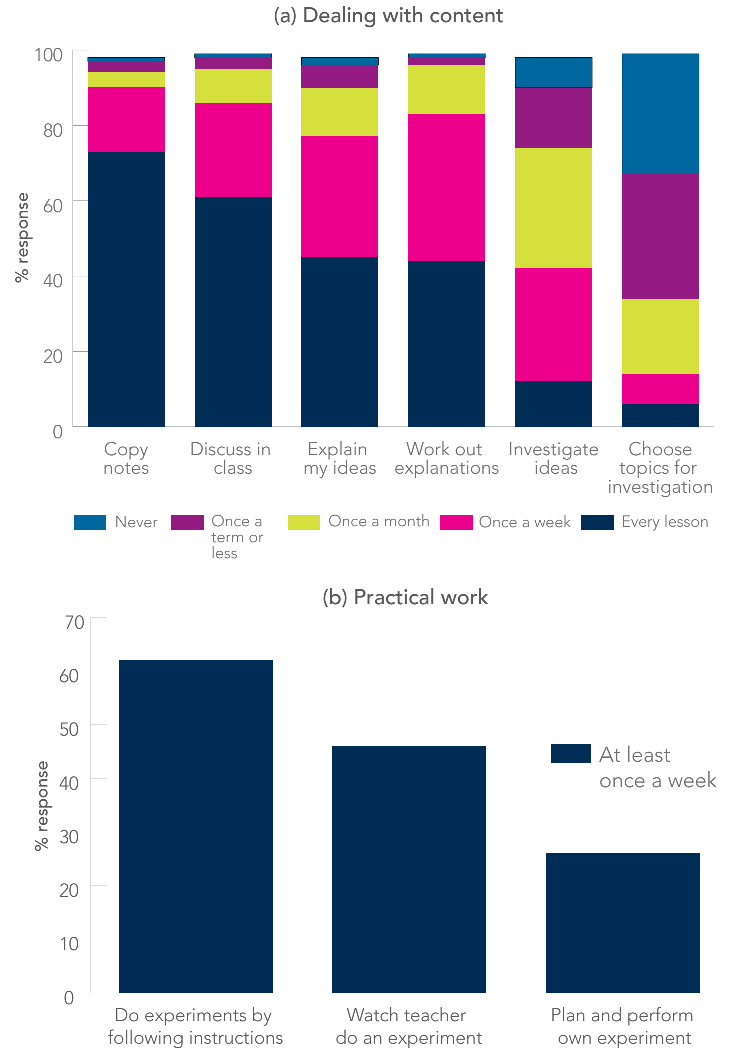
Figure 3.4.5 Improving science classes

Post-secondary intentions

Almost two-thirds (64 per cent) of the science students said they intended to study at university following the completion of Year 12. Within this sample, 25 per cent specified that they would enrol in a science-related course and 39 per cent said they would study another course or did not specify their intended course. Twenty-two per cent of the students intended to enter the workforce, while another 10 per cent were undecided.

Learning activities: dealing with content and practical work

Questions about learning activities in a science class revealed that copying notes from the teacher was the most common activity: 73 per cent of the students said they did it nearly every lesson (see Figure 3.4.6a) (As discussed, taking notes had been highlighted as a disliked feature of science classes). Among other activities, students said class discussions occurred regularly, while group work was less frequent. The extent of student-led investigations was limited: 33 per cent of the students said they chose their own topic for investigation once a term or less, 32 per cent said they never had that opportunity.



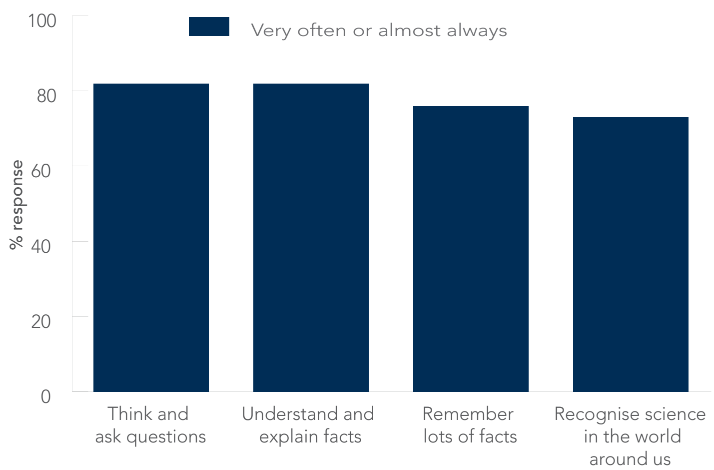
Source: Goodrum et al. (2012).

Figure 3.4.6 Frequency of learning activities: dealing with content (a) and practical work (b)

Responses to questions about the practical component of senior science showed that 62 per cent of the students conducted experiments at least once a week (see Figure 3.4.6b), although often they simply followed 'recipe-style' protocols. A considerably smaller proportion (26 per cent) reported independent planning and execution of their experiments at least once a week. The argument for an inquiry-based approach to science learning is a recurring theme in the science education literature (Goodrum et al. 2001; Osborne 2006; Goodrum & Rennie 2007).

Thinking about science

Science study calls for a curiosity about the world and an ability to think critically. These attributes were reflected in students being required to think about science most of the time in class. The majority of students (73 to 83 per cent) felt they needed to be able to ask questions, remember and explain facts, and see science manifested in the world around them very often or almost always (see Figure 3.4.7).

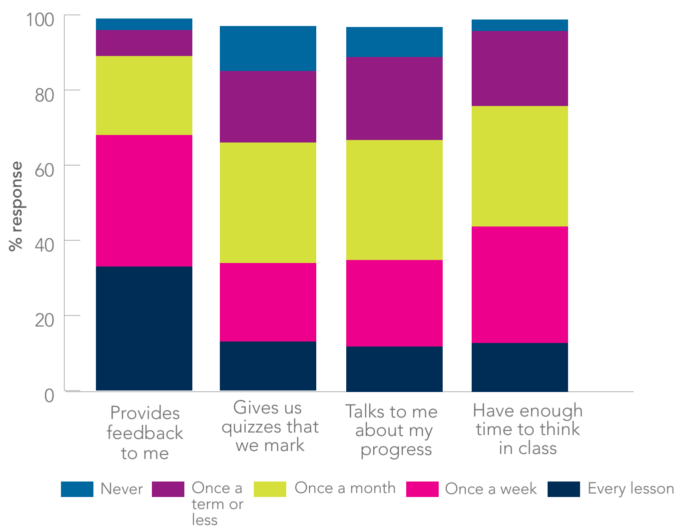


Source: Goodrum et al. (2012).

Figure 3.4.7 Thinking skills required for science

Teacher feedback and guidance

The prominent role of teachers in engendering and nurturing interest in science has already been discussed. Sixty-eight per cent of the science students reported that their science teacher told them how to improve their work at least once a week (see Figure 3.4.8). Additionally, 66 to 67 per cent reported assessment in the form of quizzes and discussion with teachers at least once a month. A notable 8 per cent of students, however, said their teacher never talked to them about how they were faring in class. Consistent with a rapid pace of learning necessitated by a content-laden curriculum and what students dislike about science, as discussed, only 13 per cent of students felt they always had enough time to think about what they were learning.

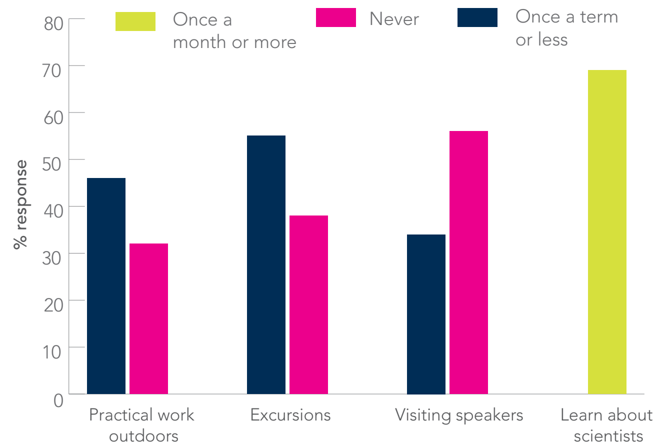


Source: Goodrum et al. (2012).

Figure 3.4.8 Frequency of teacher feedback and guidance

Science outside the classroom

The connection between science in the classroom and science in the real world is crucial to making science understandable, interesting and relevant for students. The experience in senior science classrooms seems, however, to ignore this: 78 to 93 per cent of science students reported that they seldom had the opportunity to study science outside of their classrooms (Figure 3.4.9). Students reported limited exposure to practicals in natural settings such as the bush or the beach, science excursions and visiting science speakers. In contrast, learning about scientists was more common: more than two-thirds of the students said this occurred at least once a month.

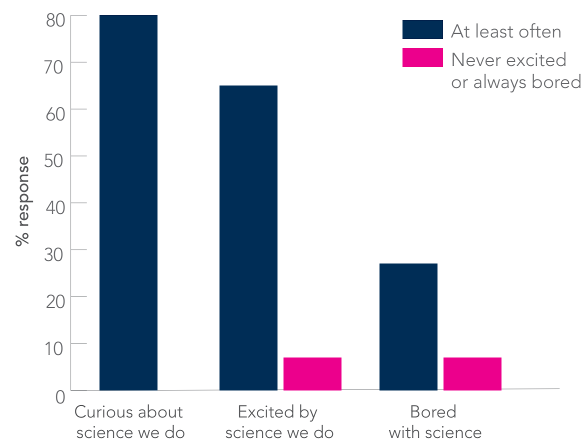


Source: Goodrum et al. (2012).

Figure 3.4.9 Science outside the classroom

Enjoyment and curiosity in science

The majority of science students surveyed (65 to 80 per cent) had had positive experiences, being at least regularly excited and curious about the science they were learning (see Figure 3.4.10). But 27 per cent of the students reported being bored often or more than often. A relatively small yet notable proportion of students seemed disengaged: 7 per cent were never excited or were always bored.

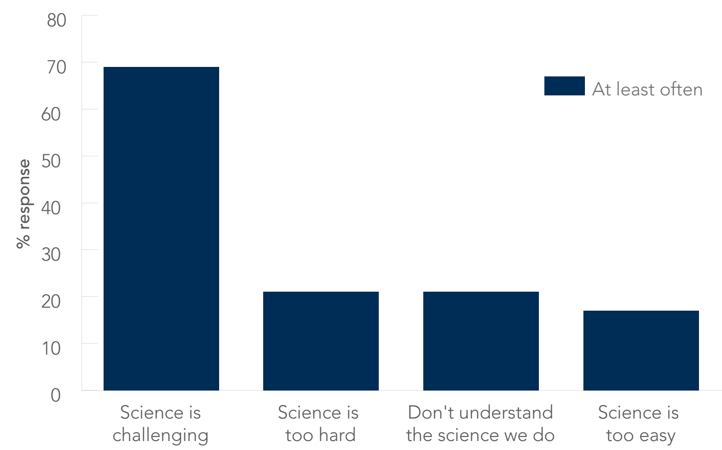


Source: Goodrum et al. (2012).

Figure 3.4.10 Attitudes towards learning science: enjoyment and curiosity

Perceived difficulty and challenge of science

Sixty-nine per cent of the students were at least regularly challenged by the science they were doing (see Figure 3.4.11), but about a fifth found it too difficult or too easy often or more than often. A comparable proportion of students (21 per cent) reported that they at least regularly did not understand the science they were being taught.



Source: Goodrum et al. (2012).

Figure 3.4.11 Attitudes towards learning science: perceived difficulty and challenge

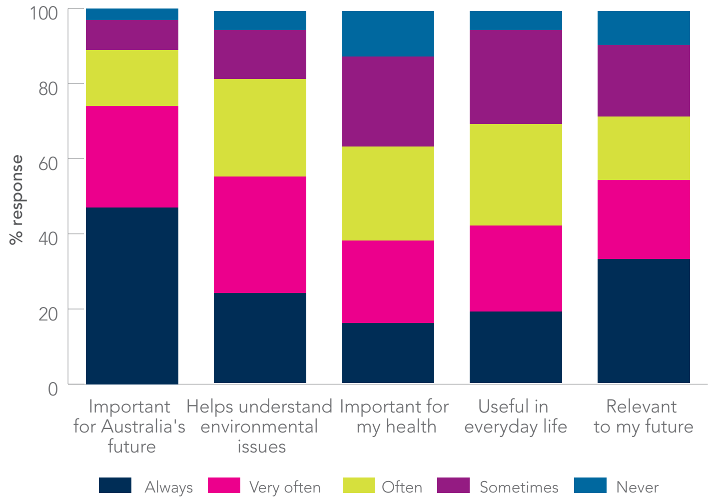
As discussed, both teachers and non-science students highlighted the perceived difficulty of science subjects as an influence on either choosing science subjects that are thought to be easier (such as biology) or not choosing science subjects at all. Perceived difficulty has been linked to self-efficacy—a student's perception of their own level of competence and confidence—in relation to studying science (Zimmerman 2000).

Lyons and Quinn (2010) examined the question of perceived difficulty and related it to the utility value (strategic benefits) of subjects. They contended that students essentially perform a cost–benefit analysis when choosing subjects, weighing up the anticipated difficulty of subjects (science and non-science) against the anticipated rewards. The decline in Year 12 enrolments in science subjects would suggest that the perceived utility value of subjects such as physics and chemistry has declined in the past two decades. Indeed, Lyons and Quinn suggested that the utility value of physics and chemistry is now 'less tangible' and that the subject of utility value as part of student considerations warrants further research.

Perceived relevance of science

The majority of the science students (63 to 89 per cent) at least regularly saw the relevance of the science they were learning in a range of settings (see Figure 3.4.12). The relevance featured most prominently in the contexts of Australia's future (89 per cent of the students) and understanding environmental concerns (81 per cent). About 70 per cent of the students at least regularly saw science as personally relevant to their future and useful in everyday life. Further, science was relevant at least regularly in the health decisions made by 63 per cent of the students. Notably, about 10 per cent of students reported that science almost never guided their decisions about their health or had almost no bearing on their future.

Despite the ubiquity of products developed through science and technology—microwave ovens, vaccines, televisions, digital music players and radios, smart phones and cars, and so on—only 19 per cent of science students always recognised the usefulness of science in everyday life.



Source: Goodrum et al. (2012).

Figure 3.4.12 Attitudes towards learning science: relevance

3.5 DISCUSSION AND SUMMARY

Several common themes emerge from the findings of the Goodrum et al. (2012) study and other recent and related studies (Lyons & Quinn 2010; McKenzie et al. 2008, 2011; Ainley et al. 2008; Universities Australia 2012). These themes can be considered in the light of the different but interrelated dimensions of the school experience—curriculum, pedagogy, students, teachers and resources.

3.5.1 The science curriculum

Embedded in the science curriculum for Years 11 and 12 is an apparent tension between teaching science for science literacy and meeting the needs of students intending to study science at university. The views of both teachers and students reported by Goodrum et al. (2012) suggest that senior science favours preparation for university science over the promotion of science literacy.

Two particular flow-on effects can at least be partially attributed to a curriculum geared to preparing students for university science. First, there is a tendency to create an overcrowded and content-laden curriculum in senior secondary schools. Second, a content-laden curriculum reinforces both the traditional transmission model of teaching science in Years 11 and 12 and a narrow and rigid assessment regime (Goodrum et al. 2012).

It has been suggested that curriculum content could be reduced and a deeper focus given to fewer areas, so that students can better involve themselves in science (Tytler et al. 2008). Further consideration can also be given to what are the essential or optional components of the science curriculum. The Australian Curriculum: Science, currently being developed, is expected to recognise and respond to these concerns (Australian Curriculum Assessment and Reporting Authority 2012).

3.5.2 Students' engagement in science

Although the level of interest in science among the current generation of students might not have declined (Lyons & Quinn 2010), there is evidence that students could be offered a more engaging learning experience. The profile of science learning activities and the views of science and non-science students reported by Goodrum et al. (2012) suggest that students could be better involved in science and their interest in science better nurtured.

Senior science students mostly have a positive experience when studying the subject. The bulk of them were curious and excited about the science they were learning, but they did highlight some concerns—for example, the prevalence of note taking during science lessons, limited opportunities for student-led investigations, and virtually no opportunity to learn science outside the classroom. More than a quarter of science students were at least regularly bored with the subject.

The views of non-science students, as reported by Goodrum et al. (2012), are also informative. A large proportion of these students either disliked science or found it boring. This is supported by the findings of Lyons and Quinn, who reported that non-science students found it difficult to picture themselves as scientists, a view probably based on an inadequate appreciation of the diversity in science career pathways (Lyons and Quinn 2010).

Evidence suggests that by the age of 14 years many students will have made identity-related decisions about their futures (Tytler et al. 2008). In other words, they will probably have developed an enduring interest in science, or the contrary, before senior secondary school. Junior secondary science in particular might therefore play a crucial role in the formation of student attitudes to science. While it requires further investigation, the science experience in junior secondary school and earlier appears to build and/or strengthen the foundation for students' interest in science (Goodrum et al. 2012; Lyons & Quinn 2010). Almost half the science students Goodrum et al. surveyed placed the origin of their interest in science in junior secondary school. There is also evidence among the students not choosing science subjects in Year 11 that they made this decision because they found junior science uninteresting (Lyons & Quinn 2010).

In stressing the importance of the junior secondary science experience, science teachers have previously proposed making junior science lessons more exciting, enjoyable, interesting and relevant as their primary recommendation for reversing the gradual but persistent decline in science enrolments in Year 12 (Lyons & Quinn 2010).

It has also been suggested that pedagogical changes, targeting junior secondary school and earlier, appear to be the key to improving engagement in science (Tytler et al. 2008).

Such changes would be based on an inquiry-based approach to science teaching and learning, as opposed to an emphasis on canonical concepts (Tytler 2007). Among the specific changes science students suggested in the Goodrum et al. (2012) survey were lessons that are more interactive and more investigative and practical work.

3.5.3 Teachers' capability and support

Science teachers hold a unique and central position of influence, and Years 7 to 10 of school are particularly 'formative years' for the development of science attitudes among students. Students need teachers who are enthusiastic, motivated, well trained and confident in the subject areas they teach. But fewer than half of general science teachers (44 per cent) in Years 7 to 10 have relevant qualifications—that is, two or more years of tertiary education in general science (McKenzie et al. 2008).

The qualifications of senior secondary school teachers also warrant attention. It is estimated that about 70 per cent of chemistry teachers for Years 11 and 12 have three or more years of tertiary education in chemistry, have received training in the teaching of chemistry, and have been teaching for more than five years (McKenzie et al. 2011). In the case of physics teachers for Years 11 and 12 the figures raise concern: just over half (54.1 per cent) are estimated to have had at least three years of tertiary education in physics. Nevertheless, almost two-thirds of physics teachers for Years 11 and 12 have more than five years' experience in teaching the subject.

Teachers surveyed in the study by Goodrum et al. (2012) identified lack of time and resources as main factors limiting the teaching of science. Time was mentioned as a factor in a range of settings, including lack of preparation time and rushing to cover the required syllabus. A lack of resources was usually mentioned in relation to laboratory equipment. Teachers' suggestions for improving science teaching were naturally centred on these identified shortcomings.

Teachers also stressed that fulfilling their professional development needs was equally important for improving science teaching.

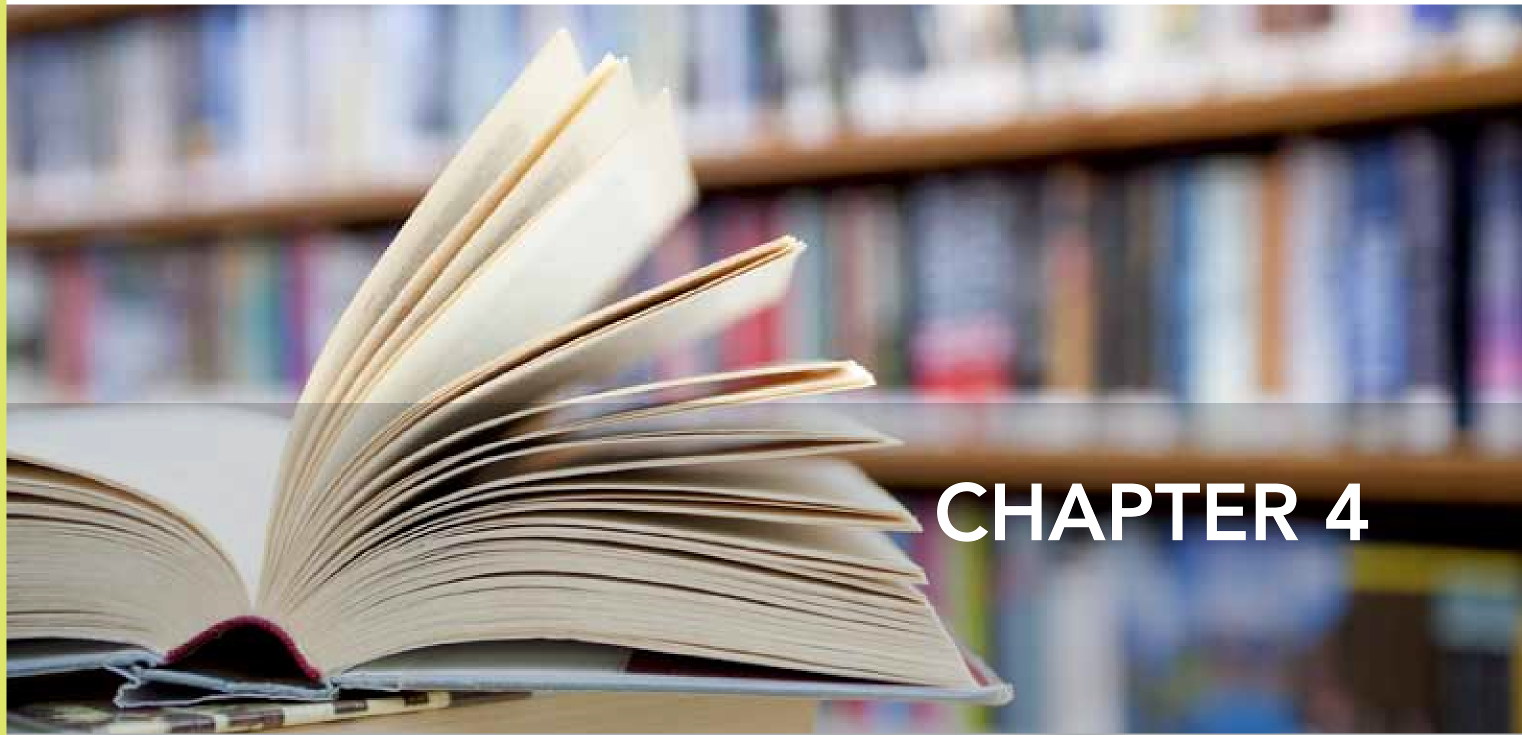
They mentioned professional development in the context of using technology in the classroom, using the best general pedagogy techniques, and keeping abreast of the latest scientific literature so as to include such material in their lessons.

The available statistics relating to professional development of secondary school science teachers are sobering. The latest estimates from McKenzie et al. (2011) show that about a third of chemistry teachers and about half of physics teachers teaching Years 11 and 12 do not have relevant training in teaching methodology. Similarly, it was estimated that almost half of general science teachers for Years 7 to 10 do not have training in the relevant teaching methodology (McKenzie et al. 2008).

3.5.4 Concluding remarks

Students' choices are determined by a complex interplay of identity and other factors such as the nature of school science and the societal position and role of science.

Secondary school science faces three particular challenges: finding a balance between developing the pool of future scientists and promoting science literacy; better engaging students in science through suitable curriculum and pedagogical changes; and better supporting science teachers in their central role of delivering science education in Australia.



CHAPTER 4

4. HIGHER EDUCATION

The Australian higher education system comprises universities and other higher education institutions.

These providers of education offer courses of study for the award of a host of tertiary (post–secondary school) qualifications, ranging from undergraduate to research-based higher degrees. Universities and other providers fulfil a range of educative roles, from education of professionals and development of the research workforce to personal development of students and nurturing of the leaders of tomorrow (Australian Government 2009).

Higher education plays a crucial role in Australia's science system. A science or related qualification from a provider of higher education represents the gateway to the vast majority of workforce roles in the Australian science system—from science and mathematics teachers to engineering and technology professionals, from medical practitioners to government science advisors, from agronomists to researchers.

It is for this reason that this chapter takes a detailed look at Australia's higher education system. The chapter has a particular focus on domestic (mainly Australian citizens and permanent residents) participation, since these students are the primary target of government policies and funding, and are going to make up the bulk of the nation's future science workforce. That is not to say that the education of international students is an unimportant component of the system: it is important. An overview of international student participation in Australian higher education is therefore also included.

The classification of higher education courses and the subjects that make up those courses falls into 12 broad areas. 'Courses', such as a BSc or an MBA, are classified into fields of education; individual 'subjects', such as chemistry 101 or French A, are classified into discipline groups. Five of these areas are chosen for detailed analysis here—Natural and Physical Sciences; Information Technology; Engineering and Related Technologies; Agriculture, Environmental and Related Studies; and Health. They are referred to as the 'science-related' fields of education or discipline groups. Some might argue that particular 'narrow fields of education' (subsets of the broad fields) included here do not belong in a report about science; for example, that public health, which is part of Health, is not 'science'. However, most of the data supplied can give reliable enrolment information only at the broad field of education level. Therefore, individual narrow fields of education cannot be excised even were a decision made to do so.

Following this introduction, Section 4.1 highlights some main findings from the chapter. Section 4.2 provides background information on the data and methodology used in the analysis, plus a description of important terminology. The results of the analysis are presented in Sections 4.3 to 4.8. Section 4.3 looks at domestic students' overall participation in the higher education system, with a focus on the science-related fields of education. Sections 4.4 to 4.8 respectively present data on enrolments in and the teaching of Natural and Physical Sciences; Information Technology; Engineering; Agriculture, Environmental and Related Studies; and Health. The chapter concludes with Section 4.9, which deals with some findings from two independent studies commissioned for the Health of Australian science project.

4.1 MAIN FINDINGS

This section presents some key findings from Chapter 4. More comprehensive overviews of the findings are presented at the beginning of each results section (Sections 4.3 to 4.9).

- During the period 2002 to 2010 the total number of commencing and continuing domestic student enrolments across all fields of education and all course levels grew.
- During the period 2002 to 2010 the total number of commencing and continuing international students across all fields of education and all course levels grew by a similar magnitude to domestic student enrolments, which equates to a significantly larger proportional growth.
- For individual fields of education enrolment patterns varied greatly. For example, commencing bachelor's level enrolments: were largely flat in the Natural and Physical Sciences (with a recent increase); decreased in IT, and Agriculture and Environment; and increased in Engineering and Health.
- Trends in teaching within the narrow discipline areas and service teaching across the broad fields of education also displayed a variety of trends, depending on the discipline or field.
- The gender balance varied widely between narrow science-related disciplines; ranging from an over representation of women to an over representation of men.
- The enabling sciences of mathematics, chemistry and physics all suffered declines in popularity among undergraduate science students in the 1990s, especially at the continuing level. These losses have not been recovered in the 2000s: the disciplines have remained at their late-1990s lows.

4.2 DATA SOURCES AND TERMINOLOGY

Two main data sources were used for this chapter: independent reports commissioned for the Health of Australian Science project and data from the Student Collection: Higher Education Statistics supplied by the Department of Education, Employment and Workplace Relations[1]. Following descriptions of these resources is an overview of the methodology applied to the data supplied by DEEWR; the section concludes with an explanation of terminology used in the remainder of this chapter.

4.2.1 Independent reports

Australia's Chief Scientist commissioned two pieces of independent work as contributions to the Health of Australian Science project:

- an update of an earlier analysis of higher education enrolment data covering the period 2002 to 2005 that had been commissioned by the Australian Council of Science Deans.[2] The report was updated by the original author to cover the period 2002 to 2010 and was released in February 2012.
- a survey of first-year university students' attitudes to science. The resultant report was released on 20 January 2012.[3]

[1] In this chapter the shortened form DEEWR is used in most places to describe the Australian Government's 'education department'. When this project began the office was receiving data from the Higher Education Group of DEEWR. Since 15 December 2011 the group responsible for universities has become part of the expanded Department of Innovation, Industry, Science, Research and Tertiary Education. For consistency, however, DEEWR is given as the source of the higher education data used here.

[2] The full reference is Dobson, IR 2012, *Unhealthy Science? University Natural and Physical Sciences to 2009–10*, University of Helsinki, Monash University & Educational Policy Institute, Melbourne. The earlier work was published as Dobson, IR 2007, *Sustaining Science: University Science in the 21st Century*, Monash University & Educational Policy Institute, Melbourne.

[3] The full reference is Universities Australia 2012, *STEM and Non-STEM First Year Students*, Universities Australia, Canberra.

4.2.2 The Higher Education Statistics Collections

In addition to the commissioned reports, the Office of the Chief Scientist carried out a detailed analysis of higher education data for domestic students. Unless otherwise stated, all the data presented in this chapter are results of the in-house analysis. The office acknowledges the support of Ian Dobson during the analysis. The descriptions of higher education statistics provided here are modified excerpts from Chapter 2 of *Unhealthy Science?* (Dobson 2012).

DEEWR directly supplied to the Office of the Chief Scientist most of the information in the form of summary tables containing data from the Student Collection of DEEWR's Higher Education Statistics. Other data came from the DEEWR DataCube[4], which provides data from the same statistics collection. Staff of the office also asked DEEWR for specific tables. All the data covered the period 2002 to 2010 since this is a period when consistent counting methodologies and field and discipline classifications were used (Dobson 2012). Enrolment, completion and student load data for domestic students were obtained for all course levels. Some course levels were combined to leave four groups: bachelor's (pass and graduate entry), honours, postgraduate (coursework) and higher degree by research (see table 4.2.2).

The tables DEEWR supplied contained a breakdown of student numbers and load according to such attributes as citizenship, gender, commencing status, field of education and discipline group. For privacy reasons some data cells in the tables supplied were suppressed because of the small number of observations (less than 10) or were confidentialised. When data were summed across a number of categories—for example, commencing plus continuing—the suppressed cells were treated as zero. This might result in some of the figures reported being lower than their true value.

[4] Available at www.highereducationstatistics.deewr.gov.au.

4.2.3 Terminology and notes on higher education data

In brief, the terminology adopted here is that a 'course' is a study program such as a BSc, BA, MBA or PhD. The components of courses are 'subjects', and the relative number of subjects being taken by a student is their 'student load'.

Universities code the courses they offer so that the courses can be aggregated into fields of education. The subjects students study within those courses are coded into discipline groups. The list of both fields and disciplines is the same, but the distinction between the two is crucial. The field and discipline classification is divided into 12 broad FoEs/broad discipline groups and subdivided into 83 narrow FoEs/discipline groups and 439 detailed fields/disciplines. These are expressed with a two-, four- and six-digit code respectively. Table 4.2.1 lists the broad fields and disciplines examined in this chapter; also included is a selection of narrow (four-digit) science fields and disciplines. Appendix B provides a full list of narrow fields and disciplines. Table 4.2.2 explains a number of important terms associated with higher education.

Table 4.2.1 Broad discipline groups or fields of education (science-related) and the narrow disciplines within the Natural and Physical Sciences

Code	Field of education or broad discipline group	Short name used in this study
01	Natural and Physical Sciences	N&PS, science/sciences
02	Information Technology	IT
03	Engineering and Related Technologies	Engineering
05	Agriculture, Environmental and Related Studies	Agriculture and Environment
06	Health	Health
	Narrow field of education or narrow discipline in natural and physical sciences	
0100	Natural and Physical Sciences, not further defined	N&PS, nfd
0101	Mathematical Sciences	Mathematics
0103	Physics and Astronomy	Physics
0105	Chemical Sciences	Chemistry
0107	Earth Sciences	
0109	Biological Sciences	Biology
0199	Other Natural and Physical Sciences	Other N&PS

The unit of measurement for enrolments and completions is individual students, who are each coded according the applicable field of study for their course, as determined by their institution. Student load takes into account both the number of students enrolled and how many subjects they are taking—their subject load: it is measured in terms of equivalent full-time student load, or EFTSL, where 1 EFTSL is the load attributed to a student studying full time in standard academic sessions for the year. A student studying full time but for only one semester of the year would have an EFTSL of 0.5 for the year; similarly, a student studying one half of the standard load across two standard semesters would have an EFTSL of 0.5.

Some courses, such as a PhD course, might not have a classroom component and therefore might not consist of individual subjects as such. The PhD student's student load will still be coded by the universities into disciplines. Some students enrol in more than one course (either as a double degree or as two separate courses). The terminology adopted in the DEEWR statistics used here is that the first course is the 'primary' course and any others are 'supplementary' courses. [5]

Figures on commencing enrolments for most course levels indicate how many new students are entering the system at that course level. The exception is honours in bachelor's courses, where this qualification can be taken as an extra (typically a fourth year), such as Bachelor of Science (Hons). This is typical in Natural and Physical Sciences bachelor's courses.[6] In this situation one needs to combine both commencing and continuing enrolments to gain an idea of how many are taking an honours year, since some of these students are classified as commencing while others are continuing. The combined total gives us the best idea of how many students are attempting honours. The number of completions tells us how many students have fulfilled the academic requirements of their course at each course level; it is essentially an indication of how many graduates are produced for each field of education.

Dobson (2012) provides a full description of DEEWR's Higher Education Statistics. He highlights a number of caveats that need to be considered during the analysis and interpretation of the statistics. Significant among these is that non-uniform coding practices are employed by different universities, and a change in classification, coding or degree arrangements at one or more institutions can have important impacts on trends observed in the DEEWR data.

[5] For this analysis, a student was deemed to be enrolled in a particular field of education if either their primary or supplementary course was in that field.

[6] Other fields of education have different criteria for the awarding of honours. An example is Engineering, where honours might be awarded to a student who is enrolled in the bachelor's pass course, not an honours course. Honours could be awarded as a result of high performance during that course, rather than after the completion of a separate year of study. These students may not be enrolled in an Honours course at all, they may just be counted as an honours completion. For this reason, in Engineering and IT an analysis of honours enrolments would be less useful than one of honours completions.

Table 4.2.2 Some higher education terminology

Term	Definition	Shortened version used in this report
Bachelor's Pass and Graduate Entry	The standard post–Year 12 tertiary qualification awarded by Australian higher education institutions. Also called an undergraduate degree. Included in this group are bachelor's (graduate entry) courses.	Bachelor's (pass and grad. entry); bachelor's
Broad field of education	*see* Field of education.	
Commencing student	Students enrolled at an institution for the first time at a particular course level. Commencing status applies only in the first calendar year.	First-year student
Continuing student	In the years after a student's commencing year they are considered to be continuing.	Later year student
Completion	When an enrolled student is deemed by their institution to have fulfilled the requirements of their course, they are counted in the completions data.	
Course level	Courses are offered at different hierarchical levels, including bachelor's, honours, master's and PhD. Students typically are required to complete a tertiary course at a lower course level before being admitted to a higher level. For instance, a bachelor's course is usually required for entry to a postgraduate course. A bachelor's course with honours or a master's are usually required for entry to a PhD.	Degree level
Discipline group—broad, narrow	A means of classifying subjects according to the content being studied or researched. Examples of broad disciplines are Natural and Physical Sciences and Health. Narrow disciplines are subsets of the broad disciplines. Examples of narrow disciplines are chemistry and biology, which are narrow disciplines in the broad discipline group Natural and Physical Sciences.	Broad discipline, narrow discipline
EFTSL	Equivalent full-time student load—*see* Student load.	
Field of education	A classification of a course according to the vocational intent or the principal subject matter of a course.	FoE

Term	Definition	Shortened version used in this report
Honours	Honours is awarded to bachelor's students who have achieved beyond the standard of a regular bachelor's pass degree. For some FoEs honours is awarded on the basis of an extra year, during which a research thesis is completed. This typically applies to Natural and Physical Science courses. For other FoEs, such as Engineering and IT, honours can be awarded on the basis of academic performance during the pass degree.	Hons
Management and Commerce	The broad field of education and discipline group with code 08	Management
Postgraduate (coursework)	These postgraduate courses are typically offered to students who have completed a minimum of a bachelor's pass degree. The course levels include doctorate and master's by coursework, graduate certificate, and various postgraduate diplomas.	Postgraduate
Primary or supplementary course	Students enrolled in a single degree program are enrolled in a 'primary course'. Those enrolled in a double degree will have both a 'primary course' and a 'supplementary course'.	
Science/s	Natural and Physical Sciences—the broad field of education and broad discipline group with code 01.	N&PS
Service teaching	Teaching of subjects in one broad discipline to undergraduate students who are enrolled in a different field of education. For example, service teaching of mathematics to students enrolled in Engineering courses.	
STEM	Science, technology, engineering and mathematics.	
Subject	An individual unit taken to give credit towards a course of study. An example is Mathematics 1A, which might count towards the course Bachelor of Science.	Load
Undergraduate student	A student who is taking a course at the bachelor's level, including pass, graduate entry and honours.	

4.3 DOMESTIC STUDENT PARTICIPATION IN THE HIGHER EDUCATION SYSTEM AND THE SCIENCE-RELATED FIELDS OF EDUCATION

This section describes the size, growth and broad characteristics of the higher education sector so that comparisons can be made between overall system behaviour and that in the individual fields of education. Later in the section enrolment and completions data are compared for the five science-related FoEs—Natural and Physical Sciences, Information Technology, Engineering, Agriculture and Environment, and Health.

In brief, the findings are as follows:

- In 2010, 203 512 domestic students commenced a course at the bachelor's (pass or grad. entry) level. They joined 386 671 continuing students, being outnumbered by almost two to one. Commencing enrolments grew by 23.6 per cent between 2002 and 2010.
- The average student load at the bachelor's level in 2010 was 0.8 EFTSL per enrolled student.
- The average indicative completion rate[7] for students beginning a bachelor's course across all FoEs was 66 per cent.
- Postgraduate (coursework) enrolments grew by 32 per cent between 2002 and 2010, from 65 029 to 85 733. Average load for postgraduate (coursework) students was 0.26 EFTSL per student.
- About 9000 domestic students began a higher degree by research each year from 2002 to 2010. The average indicative completion rate was 62 per cent.
- In 2010 the science-related FoEs held the following shares of domestic commencing bachelor's enrolments: Health, 17.9 per cent; Natural and Physical Sciences, 10.5 per cent; Engineering, 6.1 per cent; Information Technology, 3.1 per cent; and Agriculture and Environment, 1.8 per cent.
- Average undergraduate indicative completion rates varied across the science-related FoEs: Health, 73 per cent; Natural and Physical Sciences, 69 per cent; Engineering, 58 per cent; Agriculture and Environment, 56 per cent; and Information Technology, 50 per cent.
- There was substantial growth in honours completions in the Natural and Physical Sciences between 2009 and 2010. This did not follow a surge in bachelor's enrolments in the preceding years and was spread across a number of states and institutions.
- Apparent national increases in honours completions in both Engineering and Health resulted from large increases in reported completions at just one institution for each FoE. This suggests a change in degree arrangements or coding practices at each university. It is of note that for these FoEs honours can often be awarded on the basis of academic performance during the bachelor's degree, as opposed to completion of a separate honours year.
- HDR indicative completion rates for the science-related FoEs were generally higher than the sector-wide average of 62 per cent. The exception is Information Technology HDRs, for which the average completion rate from 2002 to 2010 was just 51 per cent. The highest completion rate was achieved by HDR students enrolled in Natural and Physical Sciences.

4.3.1 Enrolments, completions and load: all fields of education

Undergraduates

Commencing domestic enrolments for bachelor's (pass and grad. entry) students grew by 23.6 per cent between 2002 and 2010. The low was in 2004; from then until 2010 enrolments grew 29 per cent (see Figure 4.3.1 and Table 4.3.1). Continuing enrolments grew less than commencing enrolments, at 14 per cent from 2002 to 2010. Strong growth in commencing enrolments in 2009–10 should flow through to growth in continuing enrolments in 2011 and onwards (data were not available at the time of writing). Total enrolments (commencing and continuing) grew by 17 per cent from 2002 to 2010.

[7] Completion rates are difficult to calculate because students take different times to complete their degree requirements, some students complete both a pass degree and an honours degree and others commence in one course then switch universities and commence again in another course. The 'indicative completion rate' shown here simply compares completions in one year to commencing enrolments from some time earlier (the time shift used depends on the course level). It is meant as a rough estimate only of the proportion of students who commence a particular course level then go on to complete it. See Section 4.3.1 for a full explanation.

Commencing enrolments account for about one-third of all domestic bachelor (pass and grad. entry) enrolments. This means that for each commencing student there are two continuing students. This is consistent with an average student spending one year as a commencing student and then two years as a continuing student. Of course, some students will spend more years as a continuing student (if their program is more than three years long or they study part-time and take longer to complete their program). On the other hand, some students might spend less than two years as a continuing student if they drop out of a course after the first or second year or they change universities mid course. These cases appear to be approximately balanced, leaving about one-third of students commencing and two-thirds continuing.

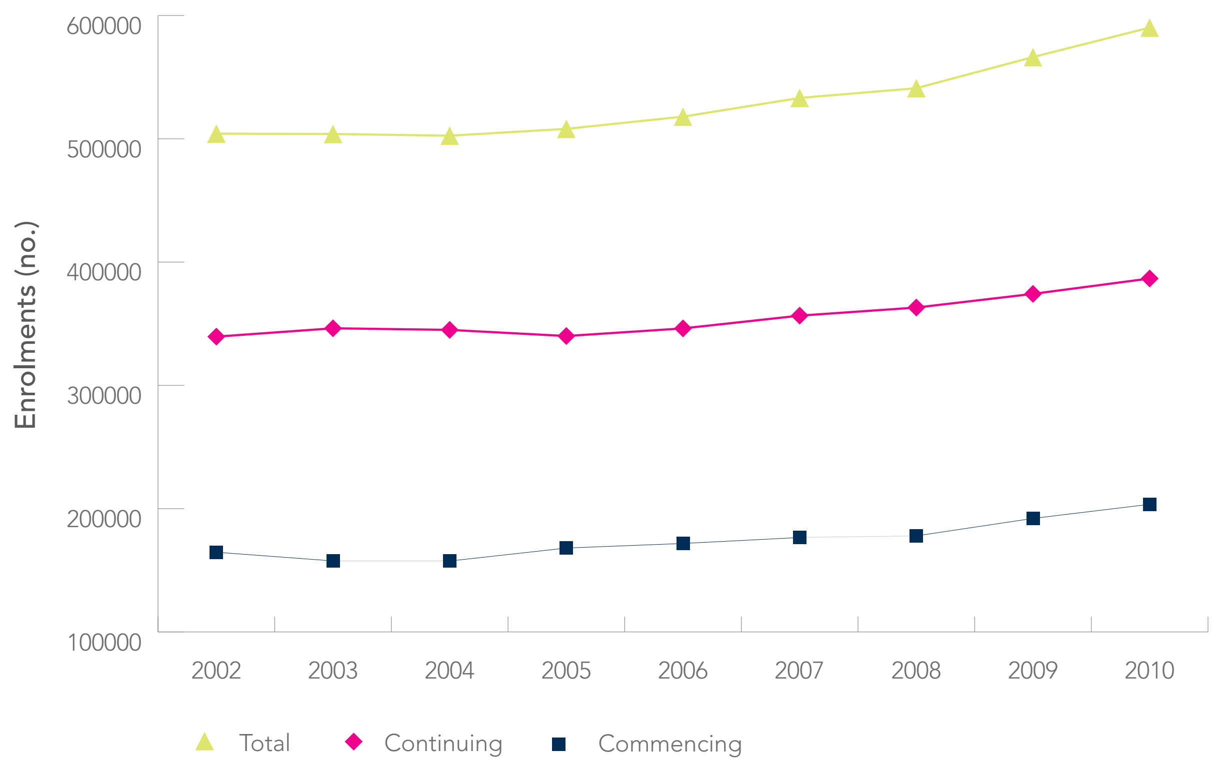


Figure 4.3.1 Domestic bachelor's (pass and graduate entry) enrolments: all FoEs

Table 4.3.1 Domestic enrolments, load and completions: all FoEs

Students/EFTSL (000s)	2002	2003	2004	2005	2006	2007	2008	2009	2010
Bachelor's									
Commencing	164.6	157.6	157.5	168.0	171.8	176.6	177.9	192.1	203.5
Total	504.2	503.9	502.5	508.1	518.0	533.1	541.0	566.3	590.2
Commencing %	33%	31%	31%	33%	33%	33%	33%	34%	34%
Total load	397.9	398.6	395.3	399.6	407.1	419.5	427.7	449.9	470.8
Load per student	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.80
Completions	93.2	96.3	97.4	98.6	98.5	97.7	98.5	101.5	101.1
Honours									
Total enrolments	11.7	11.7	11.5	10.9	10.6	10.8	10.8	11.1	15.1
Completions	8.5	8.6	9.3	9.2	9.3	9.1	8.8	9.0	11.0
Bachelor's + Honours									
Completions	101.7	104.9	106.7	107.7	107.7	106.8	107.2	110.4	112.1
Undergrad. indicative completion rate (*t*-3) (%)	n/a	n/a	n/a	65%	68%	68%	64%	64%	63%
Postgraduate by coursework									
Commencing	65.0	68.1	65.0	64.4	67.4	71.4	74.4	83.2	85.7
Total	122.4	131.8	133.5	133.2	136.6	141.2	146.3	158.0	167.4
Commencing %	53%	52%	49%	48%	49%	51%	51%	53%	51%
Total load	24.6	27.6	29.0	29.3	29.3	30.7	34.7	39.3	44.3
Load per student	0.20	0.21	0.22	0.22	0.21	0.22	0.24	0.25	0.26
Completions	40.5	42.5	45.4	46.4	47.7	48.9	51.8	54.3	57.2
Postgraduate indicative completion rate (*t*-1) (%)	n/a	66%	67%	71%	74%	72%	72%	73%	69%
HDR									
Commencing	8.9	9.2	9.3	8.7	8.8	8.8	8.2	8.6	9.1
Total	37.6	38.7	39.7	39.9	40.5	40.4	39.6	39.7	40.9
Commencing %	24%	24%	23%	22%	22%	22%	21%	22%	22%
Completions	4.9	5.3	5.2	5.5	5.6	5.5	5.6	5.4	5.5
HDR indicative completion rate (*t*-3) (%)	n/a	n/a	n/a	62%	61%	60%	64%	62%	63%

Notes: n/a is not applicable
Bachelor's includes bachelor's pass and bachelor's graduate entry.
The unit for commencing/total enrolments and completions is individual students.
Total enrolments are commencing plus continuing enrolments.
Total load is for commencing and continuing students and is measured in EFTSL.
Load per student is total load in EFTSL divided by total number of enrolments.
Undergraduate indicative completion rate is bachelor's pass, graduate entry and honours completions divided by bachelor's (pass and grad. entry) commencing enrolments from three years previously.
Indicative completion rate is the ratio of completions in year *t* to commencing enrolments from some earlier year—for example, year *t*–3. See text for further explanation.
The postgraduate (coursework) indicative completion rate would be higher than shown if a greater time shift is used—for example, completions year (*t*)/commencements year (*t*–2)—since commencing enrolments grew strongly each year from 2005 to 2010.

Across all FoEs the attrition rate after an undergraduate's commencing year was 18.1 per cent in 2009 (see Table 4.3.2). This means that, of all domestic undergraduates who began in 2009, 18.1 per cent neither completed their course that year nor returned to study that course in 2010.

Table 4.3.2 Attrition rates: domestic commencing bachelor students

	2002	2003	2004	2005	2006	2007	2008	2009
Attrition %	19.8	19.0	18.8	18.9	18.5	19.0	17.9	18.1

Note: Attrition rate for year *t* is the proportion of students who began a bachelor's course in year *t* who neither completed nor returned in year *t*+1.

Between 2002 and 2010 domestic bachelor's (pass and grad. entry) completions grew by about 8 per cent, from 93 198 to 101 140 (see Table 4.3.1 and Figure 4.3.2). This is less than the growth in total enrolments and much less than the growth in commencing enrolments. One would expect completions growth to lag behind commencements growth. Two of the strongest growth years for commencing enrolments were 2009 and 2010. If this growth in enrolments were to translate into higher completions it would first be evident in the data for 2011 (for students starting a three-year program in 2009): 2011 data were not available for this exercise.

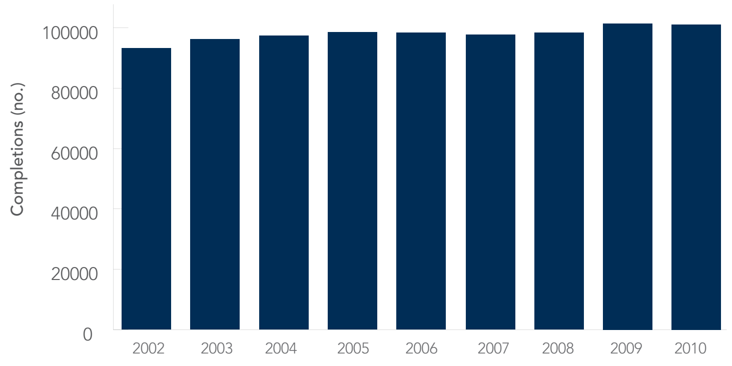


Figure 4.3.2 Domestic bachelor's (pass and graduate entry) completions: all FoEs

For many undergraduates studying full time, completion at the bachelor's pass level would occur two or three years after they began. For example, if a student began a three-year program in 2002 and studied full time, they would expect to complete (that is, be eligible to graduate) in 2004. If the student undertook a four-year program or took an extra year to finish a three-year program, they would complete in 2005 after starting in 2002. Studying for a double degree, taking leave from study, studying part time, failing to pass subjects at the first attempt, and changing course can all delay a student's completion beyond the standard program length.

Consideration of both commencement and completions data allows an estimation of the 'indicative completion rate'—that is, how many students who start a bachelor's degree go on to complete the requirements of their course. This is estimated by comparing completions with commencements from two or three years previously (see 'Undergraduate indicative completion rate' in Table 4.3.1). Such an estimate should be taken as a rough guide only, considering the variability in the time each student spends studying for their degree and the difficulty this poses for choosing a suitable time shift. The estimation shown in Table 4.3.1 takes into account students who complete either the pass degree or an honours degree (further discussion of this shortly). Using a three-year break between commencing and completing (for example, commencing in 2002 and completing in 2005), the 'indicative completion rate' appears to be about two thirds, with variation of a few per cent between years.

Caution is warranted when interpreting the completion rate. Some students might graduate first from their pass degree then graduate again with honours: these students might be counted in both sets of completions data. On the other hand, some students who go on to do an honours year after they have satisfied the requirements of the bachelor's (pass) degree might not be counted at all as a bachelor's (pass) completion. This would also be the case if a student is awarded honours on the basis of their performance during their bachelor's degree, without studying for an extra year. These students would only be counted as completing a bachelor's (honours) program in the DEEWR data. It is for this reason that both honours and bachelor's (pass and graduate entry) completions are added together here, then the total compared to bachelor's (pass and grad. entry) commencing enrolments. As noted, there could be some double counting of students who completed both a pass and an honours degree and thus an overestimation of the completion rate. Another difficulty can arise from students changing universities mid-program: they would show up twice as a commencing enrolment but would only graduate (complete) once. This could result in an underestimation of the completion rate.

Between 2002 and 2010 total load for bachelor's (pass and grad. entry) students grew 18 per cent, from about 400 000 EFTSL to nearly 471 000. Commencing load grew by nearly 26 per cent, the greatest increases occurring in 2009 and 2010. Commencing load makes up about one-third of all domestic bachelor's (pass and grad. entry) load. This means that for each class or subject being taken by an individual commencing student, two classes are being taken by continuing students. This largely follows the enrolment pattern just described.

As Table 4.3.1 shows, in 2010 a total of 590 000 individual domestic students had been enrolled at some stage. These students took a combined subject load of about 471 000 EFTSL, the average load being about 0.8 EFTSL per student. To put this in context, load for a student enrolled in three subjects per semester (instead of the standard four) over two semesters in a calendar year would be 0.75 EFTSL. There is, of course, much variation between individual students in how many subjects are taken in a calendar year—from a student studying part time for one semester in the year only (their EFTSL might be only 0.25 or less for the year) to a student who takes five subjects for each of the two semesters (an EFTSL of 1.25 for the year).

Honours

Total domestic honours enrolments dropped slightly between 2002 and 2009, then grew by 4000, or 36 per cent, in 2010 (see Table 4.3.1). This large growth in honours enrolments is mostly accounted for by strong growth in a handful of FoEs—Society and Culture, Health, Education and Engineering—plus a smaller contribution from Natural and Physical Sciences. The reasons honours enrolments simultaneously increased in so many FoEs are unknown but are probably related to a change in enrolment or coding arrangements at some of the larger institutions. The honours increase in 2010 is not related to an earlier surge in bachelor's enrolments.

Between 2002 and 2010 honours completions grew slightly; they then jumped 22 per cent, to 10 954 in 2010 (see Figure 4.3.3), consistent with the jump in honours enrolments just described. This large increase in honours completions is examined state-by-state in Section 4.3.2.

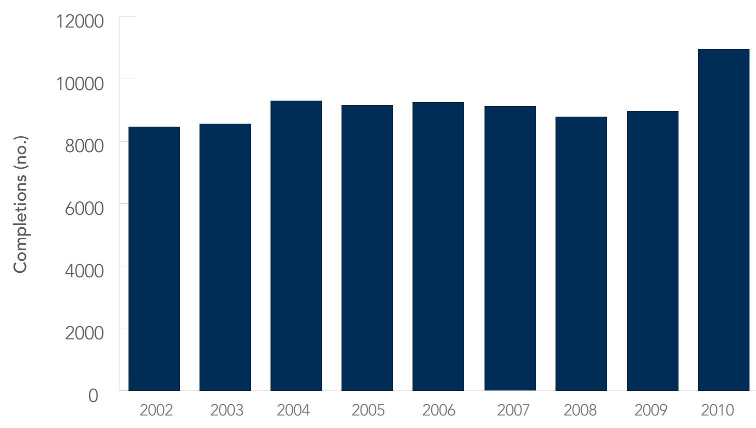


Figure 4.3.3 Domestic honours completions: all FoEs

Postgraduate (coursework)

Total domestic enrolments in postgraduate (coursework) courses grew by 37 per cent between 2002 and 2010, from 122 401 students to 167 389 (see Table 4.3.1). Commencing enrolments grew by nearly 32 per cent, from 65 029 to 85 733. The growth in commencing enrolments was concentrated in the period 2006 to 2010. Commencing enrolments for postgraduate (coursework) students make up about half of total enrolments. So, on average, for each enrolled commencing postgraduate (coursework) student there is one enrolled continuing student.

Completions in postgraduate (coursework) courses grew strongly, from 40 462 in 2002 to 56 971 in 2010 (see Figure 4.3.4)—growth of 40.8 per cent.

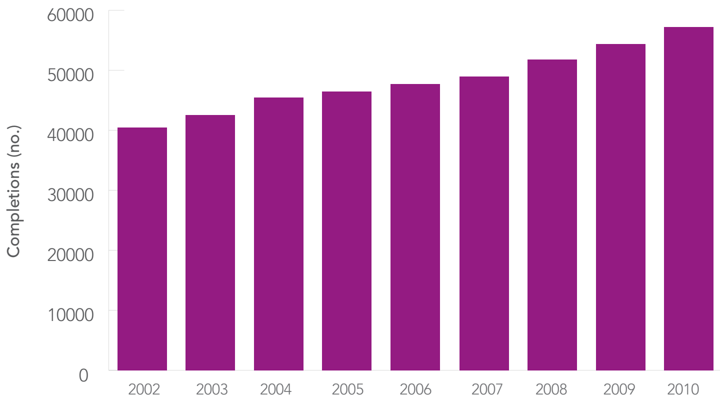


Figure 4.3.4 Domestic postgraduate (coursework) completions: all FoEs

Higher degree by research

Commencing domestic enrolments in HDR courses were quite steady between 2002 and 2010, at about 9000 a year (see Figure 4.3.5). There were 37 578 domestic HDR enrolments in 2002 (see Table 4.3.1). Enrolments rose to about 40 000 in 2004 and remained reasonably steady until 2010. Commencing enrolments made up about 24 per cent of all HDR enrolments in 2002 and 2003; they dropped to 22 per cent in 2005 and remained at that level until 2010. This means that in each year just over three continuing HDR students were enrolled for each commencing HDR student.

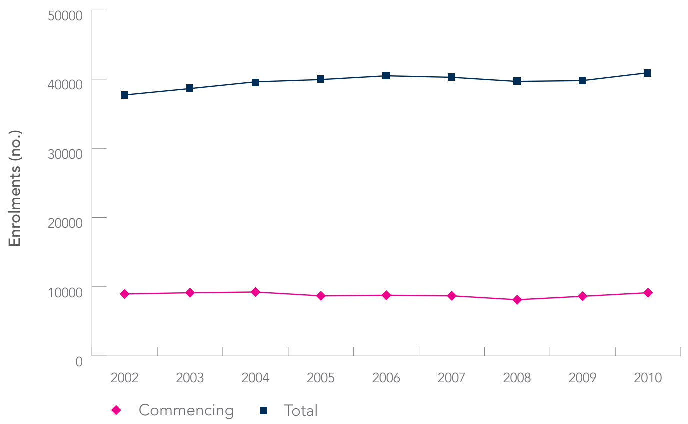


Figure 4.3.5 Domestic HDR enrolments: all FoEs

Domestic HDR completions followed the pattern of continuing enrolments, growing between 2002 and 2005 then remaining fairly steady, at about 5500 a year (see Table 4.3.1). An estimation of the HDR 'indicative completion rate' suggests that about three-fifths of students starting an HDR course go on to complete it.

4.3.2 Selected science-related fields of education: a summary

This section compares the growth in domestic commencing enrolments and completions for science-related FoEs at various course levels. The FoEs and their two-digit codes are Natural and Physical Sciences, 01; Information Technology, 02; Engineering, 03; Agriculture and Environment, 05; and Health, 06.

Bachelor's pass and graduate entry: commencing enrolments and course completions

All science-related FoEs experienced growth in 2009 and 2010, but the patterns in 2002 to 2008 were unique to each FoE (see Figure 4.3.6). Health had the strongest growth among the science-related FoEs: commencing domestic bachelor's (pass and grad. entry) enrolments increased by 73 per cent (whereas, as noted, total growth for all FoEs was just 23.6 per cent). This strong growth meant Health increased its share of commencing enrolments from 13 per cent to 18 per cent (see Figure 4.3.7), a situation underpinned by strong growth in nursing studies (see Section 4.8). The Natural and Physical Sciences field was flat from 2002 to 2008, then grew strongly in 2009 and 2010. As a share of commencing enrolments, N&PS dropped from 10.9 per cent in 2004 to 9.3 per cent in 2008 before recovering to 10.5 per cent in 2010.

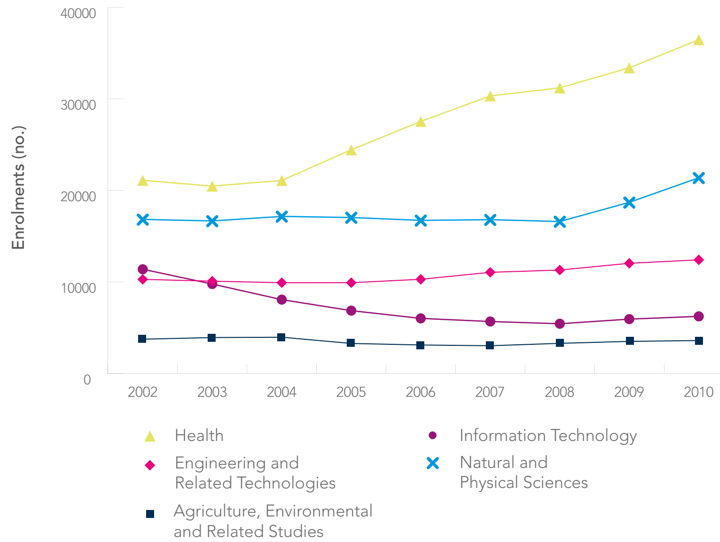


Figure 4.3.6 Commencing domestic bachelor's (pass and grad.entry) enrolments: science-related FoEs

Commencing enrolments in Engineering were about 10 000 from 2002 to 2006, then rose to 12 400 in 2010; the increase for the entire period was almost 21 per cent. Engineering's share of commencing enrolments was fairly consistent, at about 6 per cent (see Figure 4.3.7). Commencing IT enrolments nearly halved between 2002 and 2010, and IT's share dropped from 7 to 3 per cent. Agriculture and Environment had a peak in commencing enrolments in 2004 at 3951, then declined slightly to finish in 2010 on 3581; its share dropped from 2.2 to 1.7 per cent.

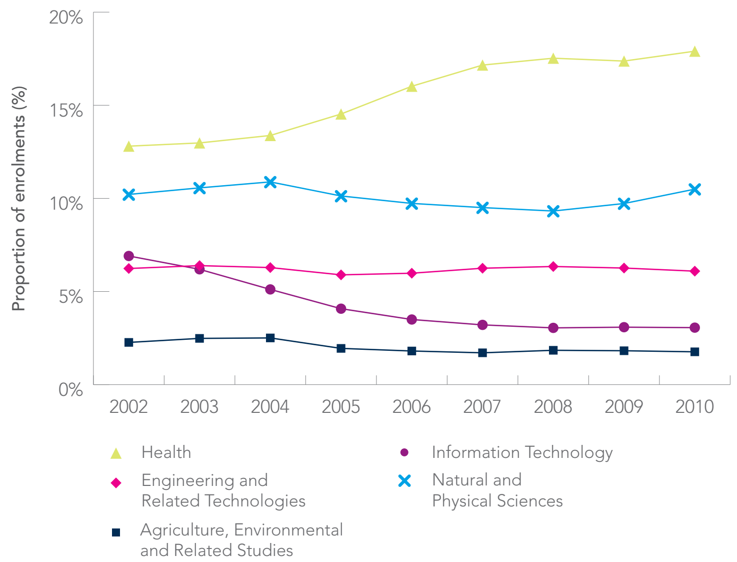


Figure 4.3.7 Commencing domestic bachelor's (pass and grad.entry) enrolments in science-related FoEs proportions of all commencing enrolments

Completions were largely consistent with enrolment patterns (see Figure 4.3.8) and are characterised by strong growth in Health and declines in IT and Agriculture and Environment. These completions have been used to estimate an undergraduate 'indicative completion rate' for each FoE. As is discussed in Section 4.3.1, this completion rate is calculated using combined bachelor's (pass and grad. entry) and honours completions and comparing them with bachelor's enrolments from three years previously. The result provides an indication of how each FoE performs on completion rates relative to the other FoEs.

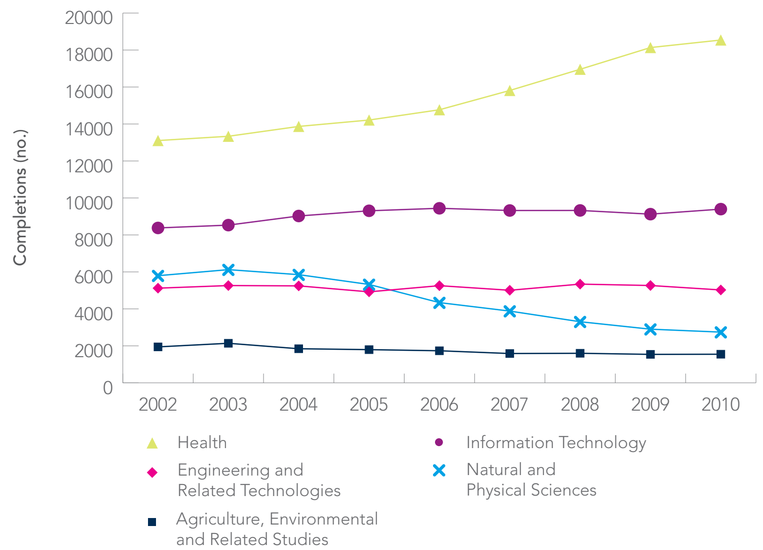


Figure 4.3.8 Domestic bachelor's (pass and grad. entry) completions: science-related FoEs

The indicative completion rates differ between the science-related FoEs (see Table 4.3.3). Health and Natural and Physical Sciences have relatively high completion rates, with an average across the time series of 73 per cent and 69 per cent respectively. Completion rates for the other science-related FoEs are considerably lower: Engineering had an average completion rate for the period of 58 per cent; Agriculture and Environment undergraduates achieved completion rates that varied from 48 per cent to 60 per cent; and IT had the lowest completion rate, an average of only 50 per cent.

Table 4.3.3 Domestic undergraduate indicative completion rates: science-related FoEs (per cent)

Field of education	2005	2006	2007	2008	2009	2010	2005–10 average
Agriculture and Environment	58	53	48	56	60	60	56
Engineering	55	60	58	61	59	57	58
Health	72	77	80	74	70	66	73
Information Technology	49	47	50	51	50	51	50
Natural and Physical Sciences	69	71	68	68	67	71	69
All FoEs	65	68	68	64	64	63	66

Note: Indicative completion rates are the ratio of bachelor's (pass and grad. entry) and Honours completions in year *t* to commencing bachelor's (pass and grad. entry) enrolments in year *t*-3.

Such estimates of indicative completion rates do not explain why some FoEs have a particularly high or low completion rate. It seems logical that, with strong declines in IT enrolments caused by, presumably, a concurrent decline in the attractiveness of IT as a profession, completion rates would be low. If students who enrol see more opportunity in other professions, they might well be switching mid-course, dragging the completion rate lower. As for Engineering courses, enrolments were steady or growing over the period, so the field does not seem to be losing attractiveness in the way IT has. A possible explanation for low completion rates in any FoE could be that courses do not meet students' expectations—including expectations about the content of the course and the interest it holds, and expectations about the difficulty of fulfilling the academic requirements of the course. Among other reasons students fail to complete could be inadequate high school preparation in enabling skills such as mathematics and chemistry.

Gender balance: domestic undergraduates

The distribution of enrolments between the genders is approximately balanced when the science-related FoEs are considered as a group (see Figure 4.3.9). In 2010 female students made up 54 per cent of domestic commencing undergraduate enrolments in the five science-related FoEs.

The gender balance at this broad level does, however, mask more pronounced differences in some individual FoEs and some of the Natural and Physical Sciences discipline groups. These are examined in Sections 4.5 through to 4.8 and also in Chapter 7.

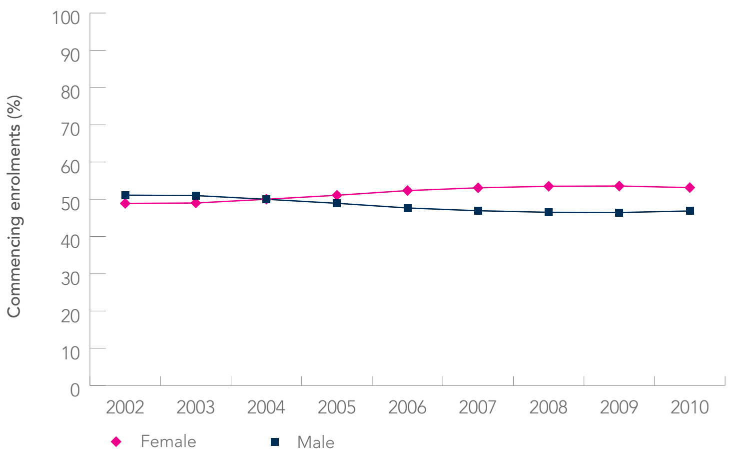


Figure 4.3.9 Proportion of domestic commencing undergraduate enrolments, by gender: science-related FoEs

Honours completions

As noted, the increase in honours enrolments in 2010 has largely been concentrated in a handful of FoEs, among them Engineering, Health, and Natural and Physical Sciences. This section examines the concurrent increase in 2010 completions in these science-related FoEs (see Figure 4.3.10).

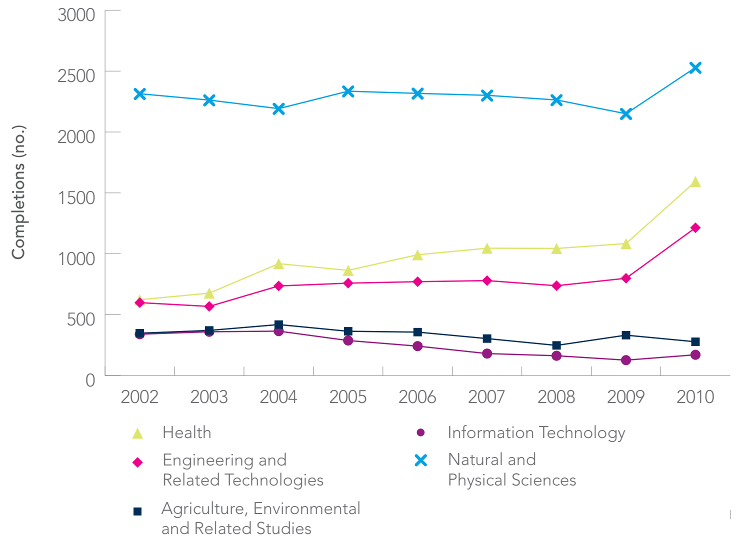


Figure 4.3.10 Domestic honours completions: science-related FoEs

A state-by-state analysis of honours completions in the science-related FoEs shows that the 2010 increase was largely confined to Victorian institutions. As Figures 4.3.11 and 4.3.12 show, the big increases in Engineering and Health can be largely attributed to just one institution for each of those FoEs, rather than an across-the-sector pattern. This shows clearly how a change in the degree arrangements or coding practices at only a couple of institutions can have a major impact on national enrolment patterns.

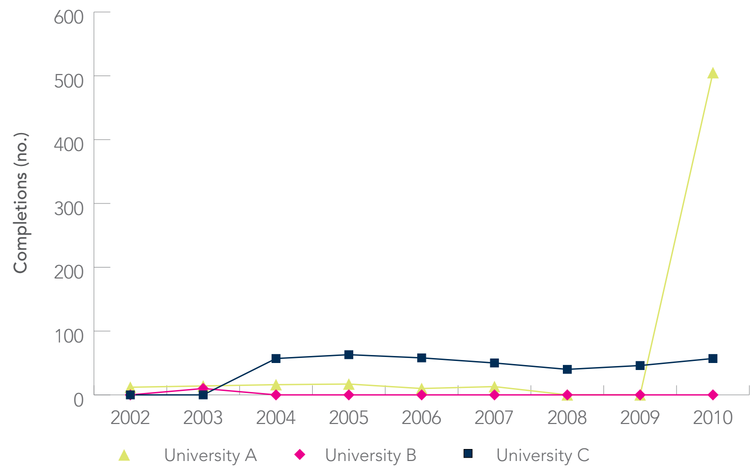


Figure 4.3.11 Domestic honours completions in Engineering, selected Victorian institutions

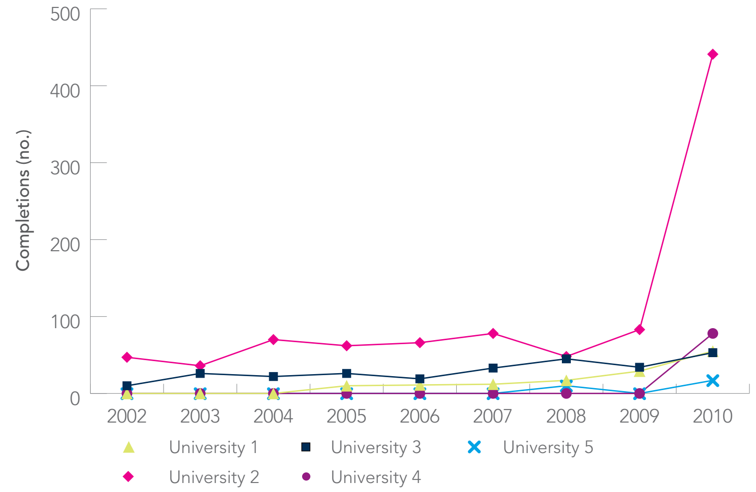


Figure 4.3.12 Domestic honours completions in Health, selected Victorian institutions

The story in Natural and Physical Sciences seems to be different: the jump in N&PS honours completions is spread across the states and the ACT and is not confined just to one or two institutions (see Figure 4.3.13). As noted, commencing enrolments in N&PS bachelor's courses were steady from 2002 to 2008, so the jump in honours completions did not arise from a surge in bachelor's enrolments.

In summary, Natural and Physical Sciences seems to have experienced genuine growth in honours completions at numerous universities, while the apparent growth in completions in Engineering and Health was largely confined to just one institution in each case.

Note: The Northern Territory had fewer than 10 N&PS honours completions in most years and is not shown here.

Figure 4.3.13 Domestic honors completions in N&PS courses, by state and territory

Postgraduate

Health had by far the greatest number of commencing enrolments in postgraduate (coursework) courses between 2002 and 2010 (see right axis of Figure 4.3.14). Health courses at this course level are dominated by nursing studies (see Section 4.8). Health also grew strongly, from less than 9 000 commencing enrolments in 2002 to nearly 15 000 in 2010. This was more than five times the number in Engineering, which had about 2700 commencing students in 2010. The other science-related FoEs did experience growth in 2008 to 2010 but from low bases. As with other course levels, postgraduate IT suffered a sharp decline in the early 2000s.

Looking more closely at Engineering, IT, N&PS, and Agriculture and Environment, postgraduate (coursework) qualifications are gaining popularity, even though these FoEs have not traditionally had this as a common qualification.

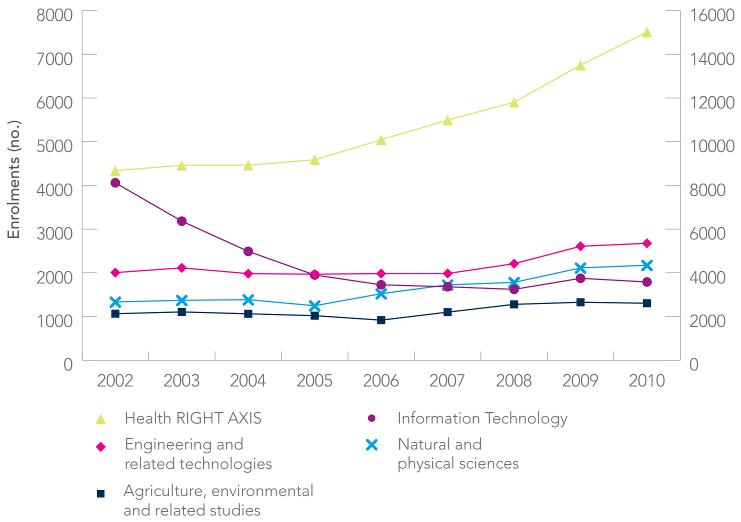


Figure 4.3.14 Domestic commencing postgraduate (coursework) enrolments: science-related FoEs

Postgraduate completions largely follow the commencing enrolment patterns, there being very strong growth in Health, a decline in IT and some growth off low bases in the other FoEs.

Higher degree by research

Domestic HDR commencements for most of the science-related FoEs changed little between 2002 and 2010 (see Figure 4.3.15). In 2002 N&PS had about 1500 commencing students, then it rose and fell before finishing at just above 1600 in 2010. Health had the strongest growth of the science-related FoEs, from 1168 in 2002 to 1410 in 2010 (21 per cent growth). Engineering dropped from about 1000 commencing HDR enrolments in 2002 to 685 in 2008 before recovering to about 1000 in 2010. Agriculture and Environment was fairly constant, at about 350 commencements a year, while IT dropped from 370 to 230.

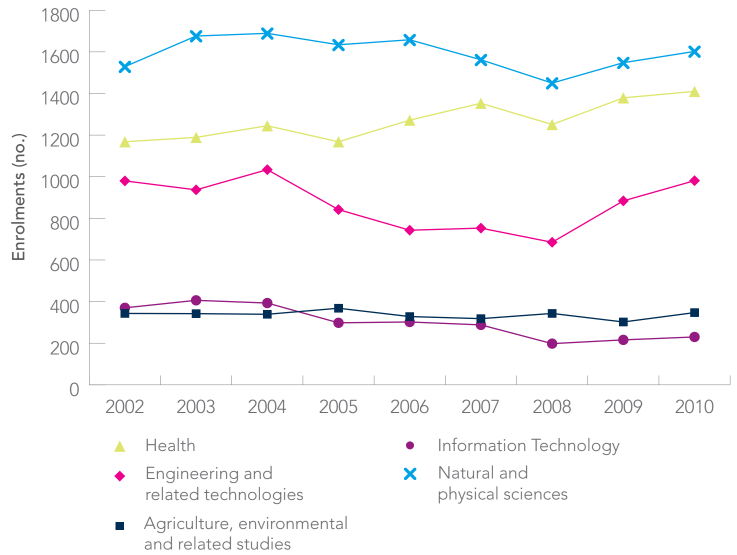


Figure 4.3.15 Domestic commencing HDR enrolments: science-related FoEs

Most science-related FoEs experienced some growth in HDR completions between 2002 and 2010 (see Figure 4.3.16). The growth largely occurred early in the time series, so it cannot be determined whether this was prompted by earlier increases in enrolments because comparable data from before 2002 are not available. Individual institutions' changes in coding practices can also affect the national figures, as is the case with honours. Dobson (2012) presents results suggesting that from 2002 to 2003 Monash University changed its coding of medical science HDRs (in the Health FoE) to biological sciences (in the N&PS FoE). This could result in apparent growth in N&PS HDR completions. Interestingly, IT maintained a fairly steady, although low, number of graduations from 2006 to 2010, despite falls in commencing enrolments from 2003 to 2007.

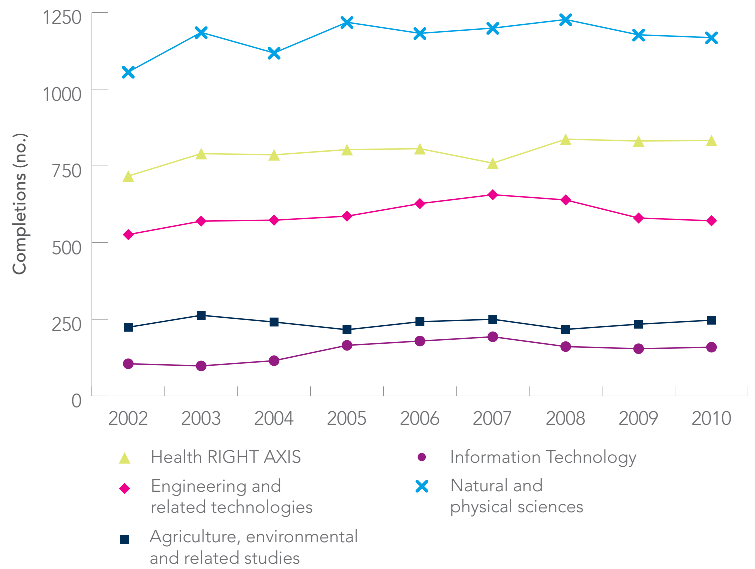


Figure 4.3.16 Domestic HDR completions: science-related FoEs

Table 4.3.4 shows estimates of 'indicative completion rates' for domestic HDR students. It compares completions in one year with the size of the commencing cohort from three years previously. This is consistent with the situation in which a student begins, say, in 2002, submits their thesis after three or three-and-a-half years, and then graduates at the end of 2005. This is a rough guide only, given the variability in completion times among students.

The average 'indicative completion rate' for all FoEs at the HDR course level was about 62 per cent. With the exception of IT, all the science-related FoEs had apparent completion rates above this sector-wide average. N&PS and Engineering had the highest average completion rates during the period, at 73 per cent and 72 per cent respectively; IT had by far the lowest rate, at an average of 51 per cent.

Table 4.3.4 HDR indicative completion rates: science-related FoEs (per cent)

FoE	2005	2006	2007	2008	2009	2010	2005–10 average
Agriculture and Environment	63	71	74	59	71	78	70
Engineering	60	67	63	76	78	76	72
Health	69	68	56	72	65	62	65
Information Technology	45	44	49	54	51	55	51
Natural and Physical Sciences	79	70	76	75	71	75	73
All FoEs	62	61	60	64	62	63	62

Note: The rates shown are completions at year *t*, divided by commencements at year *t*-3.

4.4 NATURAL AND PHYSICAL SCIENCES

This section looks more closely at higher education courses in the broad field of education referred to as Natural and Physical Sciences, as well as the teaching of subjects in the broad discipline group Natural and Physical Sciences. It then examines the teaching of narrow science disciplines (biology, chemistry, and so on) to students enrolled in Natural and Physical Sciences courses. The final two parts of the section present the results of a detailed analysis of the narrow science disciplines: each discipline is looked at through the 'pipeline' of bachelor's – honours – higher degree by research; and the section concludes with an analysis of participation in narrow science disciplines from 1989 to 2010.

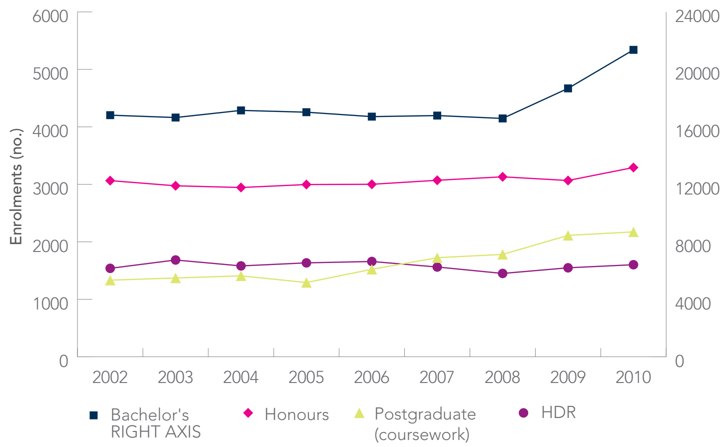
In brief, the findings are as follows:

- Commencing domestic enrolments in N&PS bachelor's courses (pass and graduate entry) were steady from 2002 to 2008, at just under 17 000 a year. They then grew by 29 per cent in 2009 and 2010, reaching 21 360.
- Fifty-two per cent of undergraduate N&PS enrolments in 2010 were of female students.
- The only other course level to experience growth in N&PS commencing enrolments was postgraduate (coursework), which expanded from 1292 in 2005 to 2173 in 2010. Commencing HDR enrolments were steady, at about 1600 each year; honours enrolments (commencing and continuing combined) were also steady, at 3000 a year for most years, but increased in 2010 to 3293.
- There were about 2200 N&PS honours completions each year and 1700 N&PS HDR commencing enrolments, suggesting that for this FoE many science honours graduates are attracted into a higher research degree.
- N&PS HDR students have a relatively high completion rate, accounting for 22 per cent of completions but only 17 per cent of commencing enrolments.
- Teaching of science subjects in N&PS disciplines to domestic bachelor's students grew from 2006 to 2010 as a result of both growth in demand for service teaching and growth in demand from N&PS-enrolled students.
- About half of all science teaching is service teaching. The most popular disciplines for service teaching are mathematics and biology.
- The bulk of service teaching is provided to Health or Engineering students, although Management, Agriculture and Environment, Society and Culture, and Education students also receive a considerable amount of service teaching in science disciplines. Most service teaching load is taken by students in their commencing, or first, year.
- Of all the science subjects taken by first-year science undergraduates, biology contributes 40 per cent of load, chemistry and mathematics about 20 per cent each, physics 9 per cent and earth sciences 5 per cent.
- For continuing students, biology rises to more than 50 per cent of science load, chemistry drops to 10 per cent and mathematics to 13 per cent.
- The distribution of honours load between the science disciplines is largely consistent with that of continuing bachelor's students.
- Mathematics and physics honours both grew between 2002 and 2010, albeit from low bases.
- Biology load taken by commencing HDR students declined by 22 per cent, from a peak of 603 in 2004 to 468 in 2010. This is the only course level in which the biology discipline group suffered a decline in load during the period.
- Mathematics and earth sciences suffered declines in commencing HDR load between 2002 and 2010; chemistry and physics were steady.
- The enabling sciences of mathematics, chemistry and physics all suffered declines in popularity among undergraduate science students in the 1990s, especially at the continuing level. These losses have not been recovered in the 2000s: the disciplines have remained at their late-1990s lows.

4.4.1 Enrolments and completions in N&PS courses

Commencing enrolments and completions

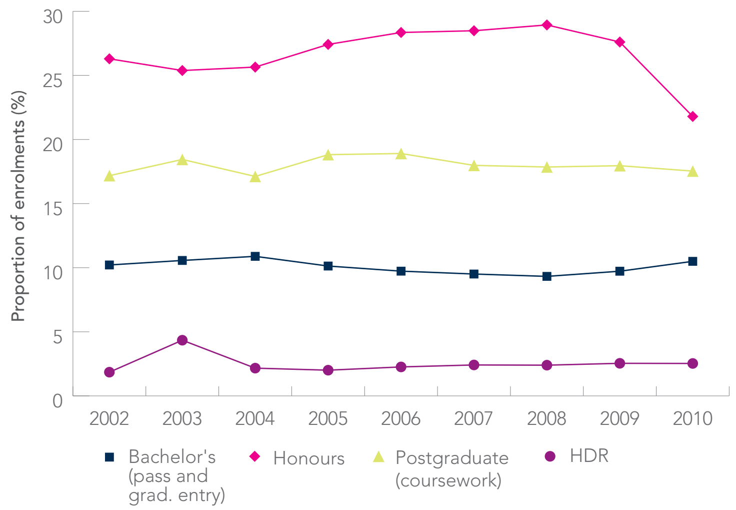
Each of the course levels had a different pattern of commencing enrolments between 2002 and 2010 (see Figure 4.4.1). Commencing domestic enrolments in N&PS bachelor's courses (pass and grad. entry; right axis) were steady from 2002 to 2008, at just under 17 000 a year; they then increased, reaching 21 360 in 2010—nearly 29 per cent growth on 2008. This outstripped growth across all FoEs, which, as shown in Table 4.3.1, was 14 per cent for the same period. The only other course level to experience growth in N&PS commencing enrolments was postgraduate (coursework), which increased from 1292 in 2005 to 2173 in 2010. Commencing HDR enrolments were steady, at about 1600 each year; honours enrolments (commencing and continuing combined) were also steady, at 3000 for most years, but increased to 3293 in 2010.



Note: Honours enrolments are for both commencing and continuing students (see note for Figure 4.3.13)

Figure 4.4.1 Domestic commencing enrolments in N&PS, by course level

Another way of examining enrolments in N&PS courses is to look at their share of all domestic enrolments. Starting with bachelor's (pass and grad. entry), N&PS commencing enrolments accounted for about 10 per cent of all commencing enrolments at that course level. The low point was 2008, when N&PS accounted for 9.3 per cent. The strong growth after 2008 increased N&PS's share to 10.5 per cent in 2010. N&PS's share of honours and HDR enrolments is considerably higher than for bachelor's courses: for most of the period about 25 to 30 per cent of honours enrolments were in N&PS, but this dropped in 2010 because of a sharp increase in honours enrolments in a number of FoEs (as opposed to a drop in N&PS; see Section 4.3). About 17 to 19 per cent of domestic commencing HDR enrolments were in N&PS; this changed little between 2002 and 2010. N&PS postgraduate (coursework) enrolments accounted for about 2 to 3 per cent of all commencing enrolments at that level.



Note: Honours enrolments are for both commencing and continuing students (see note for Figure 4.3.13)

Figure 4.4.2 N&PS share all commencing domestic enrolments

Domestic completions of bachelor's (pass and grad. entry) N&PS courses grew from 2002 to 2005 (see right axis of Figure 4.4.3). It is difficult to determine whether this growth came from increased enrolments or an increasing completion rate: many students who completed in these years would have commenced their programs before 2002, the first year considered in the enrolment analysis. Honours completions were in keeping with honours enrolments, both being steady from 2002 to 2009 then jumping 17 per cent in 2010 to 2529. As noted, this jump in honours occurred in a number of states and thus institutions. It is not clear why there was such an increase in honours completions after so many years of fairly consistent enrolments and completions. There was no corresponding jump in commencing bachelor's enrolments during the years when many 2010 honours students probably began their studies (2006 and 2007).

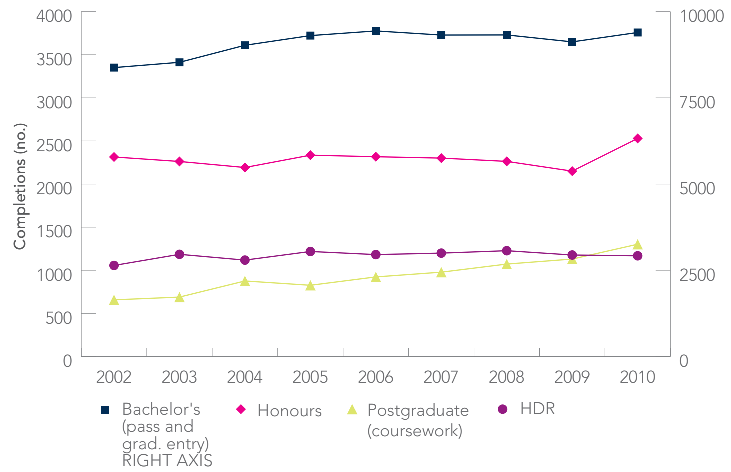


Figure 4.4.3 Domestic completions in N&PS, by course level

It is interesting to compare honours completions with HDR commencements since an honours degree is the standard pathway to obtaining a PhD scholarship. Honours completions were quite consistent, at about 2200 to 2300 a year. HDR commencements were similarly steady—about 1700 a year. This might suggest that a high proportion of N&PS honours graduates start a PhD at some stage. Perhaps this provides an insight into students' motivations in doing an honours year: the extra year might well be considered something that is useful only if one wants to pursue a research degree. Similarly, the relatively high enrolments in N&PS honours (over 25 per cent share) compared with bachelor's enrolments (about 10 per cent share) might cast light on what some students see as the purpose of a science degree.

Another way to examine N&PS completions is to look at them as a share of all completions for each course level (see Figure 4.4.4). The share of completions at the bachelor's (pass and grad. entry) and postgraduate (coursework) levels is broadly similar to the corresponding share of commencing enrolments. HDR completions in N&PS were about 21 to 22 per cent of all HDR completions; consistently above the commencing enrolment share of about 17 to 18 per cent. This suggests a relatively higher completion rate for N&PS HDRs than for other FoEs.

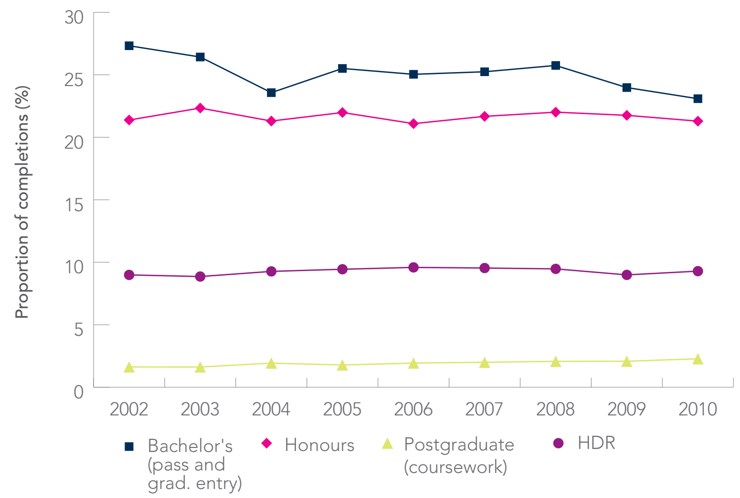


Figure 4.4.4 Domestic completions in N&PS: proportion of all completions

Enrolments by commencing status and gender

Following is an examination of the composition of all N&PS enrolments, looking at what proportion are commencing students at each course level and at the gender profile of N&PS students at the bachelor's level. Figure 4.4.5 shows that total domestic N&PS bachelor's enrolments were fairly steady, at about 53 000 a year, from 2002 to 2008 before rising as a result of the increased commencing enrolments in 2009 and 2010. As noted, commencing enrolments make up just under one-third of all enrolments, meaning that commencing students are outnumbered two to one by continuing students. This balance is broadly similar in all FoEs, including N&PS. The genders are reasonably balanced across all N&PS bachelor's enrolments, about 55 per cent of enrolments being for women in 2002 and about 52 per cent in 2010 (see Figure 4.4.6). Both genders experienced growth in enrolments in 2009 and 2010 and hence retained their respective shares of enrolments.

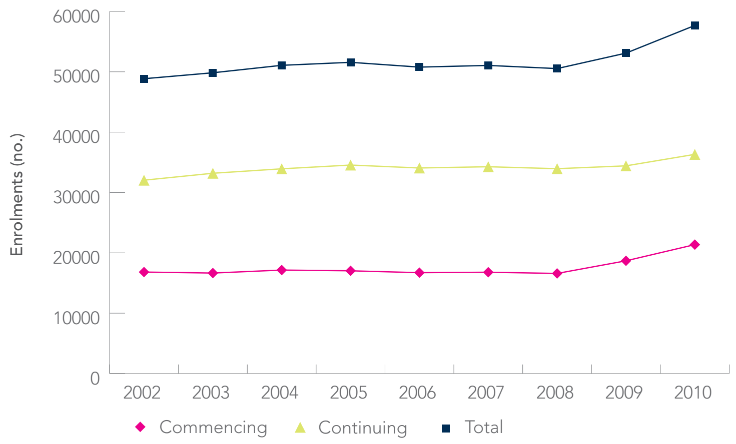
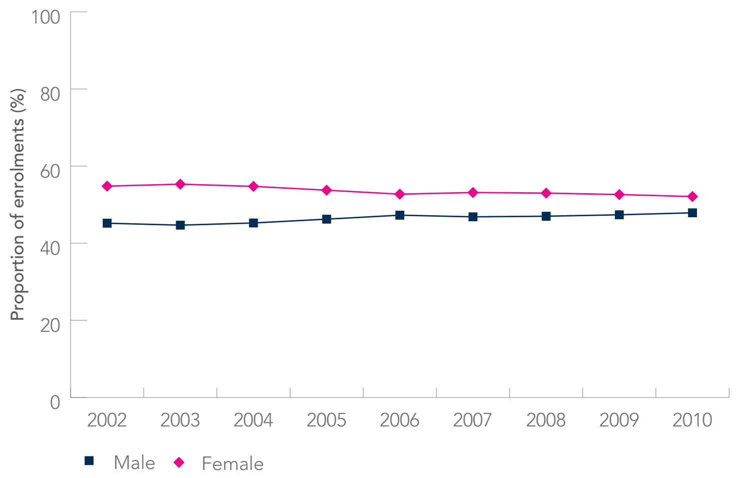


Figure 4.4.5 Domestic bachelor's (pass and grad. entry) enrolments in N&PS, by commencing status



Note: Data are for bachelor's pass, graduate entry and honours combined (see Figure 4.3.13).

Figure 4.4.6 N&PS domestic enrolments: commencing undergraduates, by gender

Postgraduate (coursework) courses experienced strong growth in total enrolment numbers between 2002 and 2010 (see Figure 4.4.7). Just over half of these enrolments each year were for commencing students—53 per cent in 2010. This would suggest that, on average, students at this course level are enrolled in their courses over two calendar years. There will, naturally, be variation, some students not returning at all after their initial enrolment (dropping out or moving on to another course or to another university), some students completing a postgraduate course in one calendar year (a graduate certificate or master's, for example, can be completed in a year) and other students studying part time and being enrolled for more than two years.

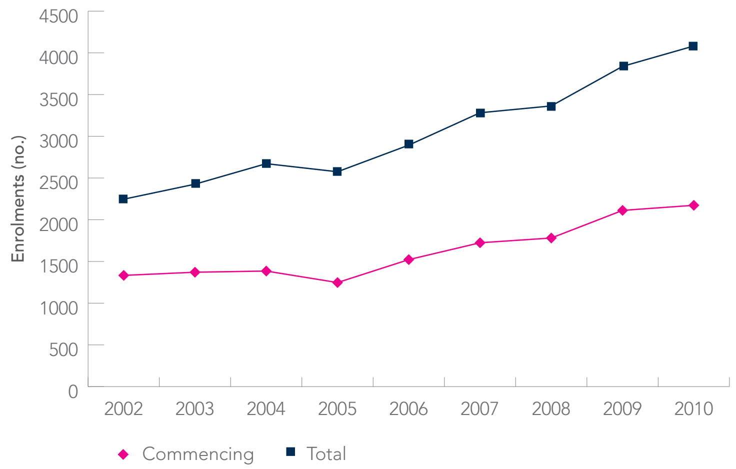


Figure 4.4.7 Domestic postgraduate (coursework) enrolments in N&PS

Total N&PS HDR enrolments grew from 2002 to 2005 and then were quite steady at about 7500 to 2010 (see Figure 4.4.8). The increase was primarily a result of growth in the number of continuing students: commencing student enrolments were reasonably steady during the entire period. It is not clear whether the growth in continuing HDR enrolments in the early 2000s is a lagging indicator of growth in commencing enrolments before 2002 or an indication that the students were taking longer to complete their programs and hence staying enrolled as continuing students for longer. Another explanation could be a higher attrition rate later in the series, whereby students might commence an HDR but then discontinue their enrolment.

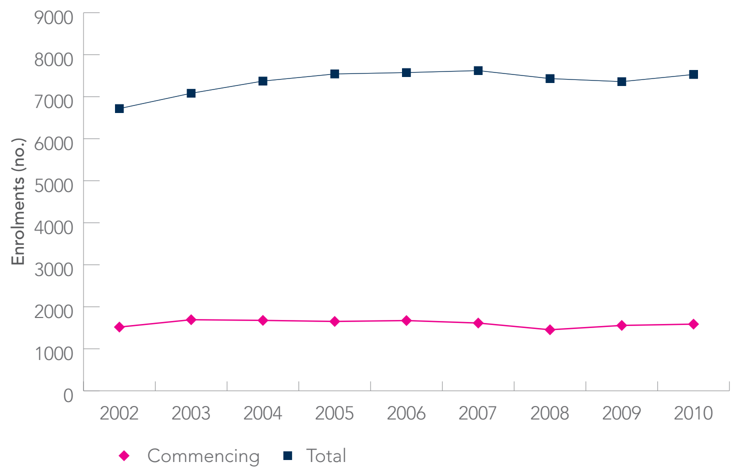


Figure 4.4.8 Domestic HDR enrolments in N&PS

The proportion of all N&PS HDR enrolments that were for commencing students in the years 2006 to 2010 (before which commencing enrolments had been quite steady for several years) was about 22 per cent. This is very similar to the situation for HDR enrolments in all FoEs and suggests that there are, on average, about three continuing students enrolled in an N&PS HDR for each commencing student. This is consistent with an HDR student spending a year as a commencing student and then three years (on average) as a continuing student. As noted, there are various reasons for individual students to spend less or more time as a continuing student after their commencing year.

4.4.2 Teaching in broad discipline group 01, N&PS

This section presents the results of a student load analysis for all teaching of subjects in broad discipline group 01, N&PS, with a particular focus on the bachelor's level. It is important to remember that N&PS subjects are studied by students enrolled in all the different FoEs, not just by students enrolled in N&PS courses. (Section 4.4.3 provides an analysis of the narrow science disciplines.)

BDG 01, N&PS, load for bachelor's students

Teaching of science subjects to domestic bachelor's (pass and graduate entry) students in all FoEs was steady from 2002 to 2004, at about 53 000 equivalent full-time student load, or EFTSL (see Figure 4.4.9). It then grew by 22 per cent, to be about 65 000 in 2010. All students are included in these figures, regardless of which FoE their course is in. These figures for total science load do not show how many individual students have taken a science subject each year; rather, they provide an indication of how many individual subject enrolments there were in total, with individual students taking one or more science subjects each. A typical EFTSL for a single student enrolled in one semester-long subject might be 0.125 (for example, Maths 1A in semester one of first-year study). This could vary from institution to institution, especially if the academic year is organised in a different way, such as trimesters rather than semesters. A student taking a science subject in both semesters (say, Maths 1A in semester one and Maths 1B in semester two) might have an N&PS EFTSL of 0.25 for the year; a student taking a standard full-time load that comprises science subjects only for the entire year would have an N&PS EFTSL of 1.

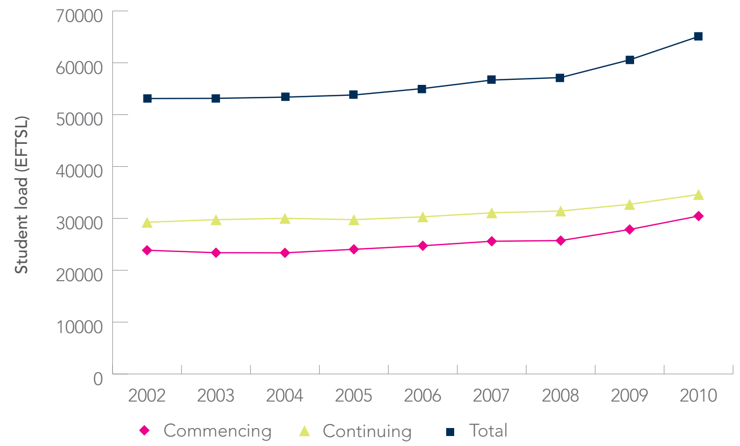


Figure 4.4.9 All student load for subjects in N&PS: domestic, bachelor's (pass and grad. entry), by commencing status

Figure 4.4.9 shows that the N&PS load taken by commencing students is only a little less than that taken by continuing students: the respective shares of all N&PS load are about 45 per cent for commencing students and 55 per cent for continuing students. To put this in context, as noted in Section 4.3, continuing bachelor's students outnumber commencing students by two to one; similarly, total load to continuing bachelor's students outweighs load to commencing students by about two to one. This means science subjects are not being taken evenly across an average student's program; rather, they are concentrated more in an average student's commencing year.

Another way to illustrate this characteristic of N&PS load is to compare N&PS disciplines' share of all load (across all disciplines) at the commencing and continuing levels (see Figure 4.4.10). About 18 per cent of all subjects taken by commencing students were in the N&PS disciplines. For continuing students, the proportion drops to only 11 per cent.

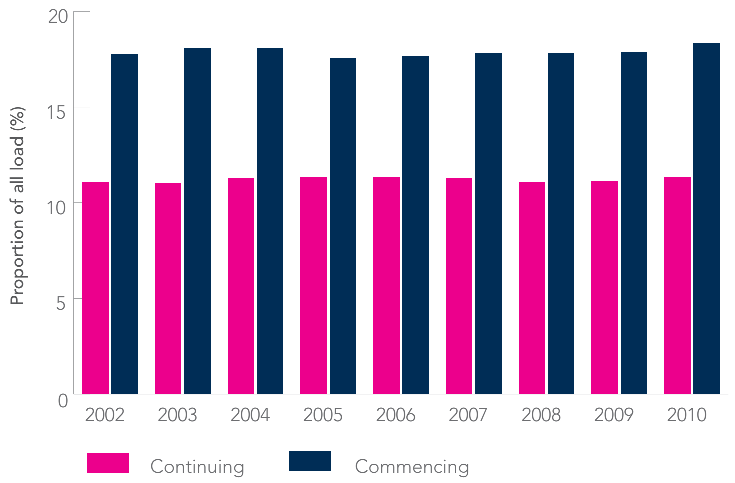


Figure 4.4.10 Proportion of all domestic bachelor's (pass and grad. entry) student load for N&PS

Following is an examination of how science teaching is distributed between students enrolled in N&PS courses (FoE 01; primary or supplementary course) and students not enrolled in N&PS courses (other FoEs). Here the two groups are referred to as 'science students' and 'non-science', or 'other', students respectively.

Figure 4.4.11 shows the contribution to total domestic N&PS load (bachelor's level) from science students and non-science students. It shows that about half of science teaching is to science students and half to other students (here this science load to other students is referred to as 'service teaching'). Towards the end of this section is an analysis of which FoEs receive this service teaching, while Section 4.4.4 examines in more detail which individual narrow disciplines (at the four-digit level) are taken by science students.

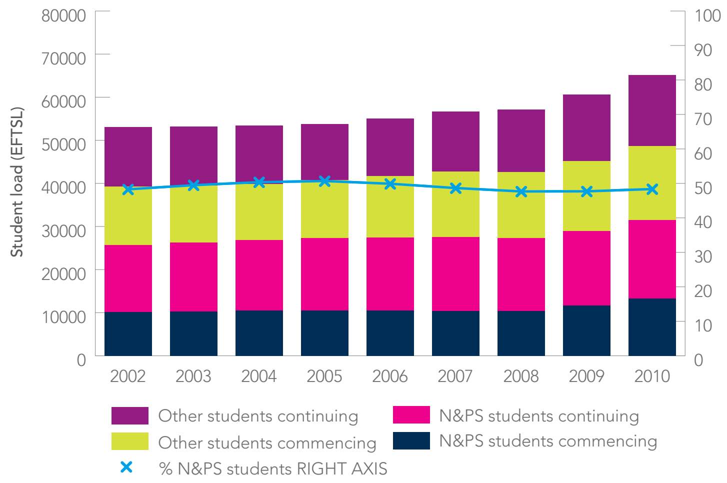


Figure 4.4.11 Teaching of N&PS disciplines to science and non-science domestic bachelor's students

An examination of just the N&PS load taken by science students (see Figure 4.4.12) reveals that about 40 per cent of science load taken by science students is taken by commencing students. Since commencing students constitute about a third of all science students, it would seem that science students are taking slightly more science subjects in their first year than in each of their continuing years. One explanation for this could be that students taking a double degree might spread their continuing science subjects over a number of years; another explanation could be that some students study full time in first year then less than full time (less than 1 EFTSL for the year) in subsequent years.

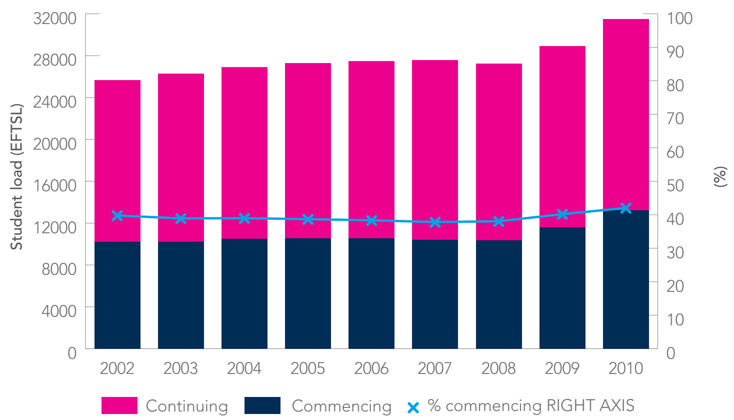


Figure 4.4.12 Teaching of N&PS disciplines to domestic bachelor's (pass and grad. entry) science students

Next, we look at non-science students taking subjects in the science disciplines (see Figure 4.4.13). This service teaching demand grew by about one-third from 2002 to 2010, the growth occurring between 2006 and 2010. About half the load is taught to commencing students, even though they are outnumbered two to one by continuing students. Non-science students therefore take twice as much science in first year as they do in each of their second or subsequent years

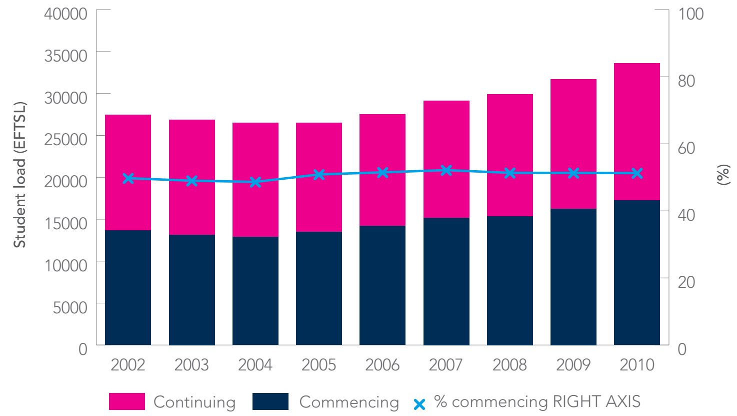


Figure 4.4.13 Teaching of N&PS disciplines to domestic bachelor's (pass and grad. entry) non-science students

If the foregoing analysis is pieced together, a picture emerges of what an 'average' science class might look like, for both commencing and non-commencing students. This is, however, only an indication of the average composition of all science classes in the entire higher education sector, not an indication of what individual classes might look like in individual institutions. Of all the science teaching delivered to domestic commencing bachelor's students, about 40 per cent goes to science students (see Figure 4.4.14), leaving about 60 per cent for non-science students. Another way to think of this is to imagine that in all first-year science classes non-science students outnumber science students by a factor of three to two. In the case of continuing science load the situation is reversed somewhat: about 55 per cent of science load is taught to science students. This is not to say that all science classes contain a mix of science and non-science students. It might be that in many institutions individual science subjects are open only to students enrolled in specific non-N&PS degrees. An example would be a biology subject that it is deliberately designed for nursing students: such a class would not contain a mix of students; it would contain only non-science (nursing) students..

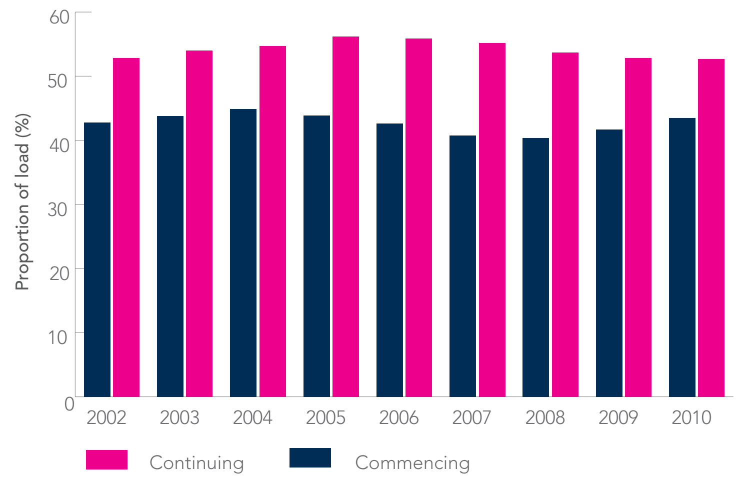


Figure 4.4.14 Proportion of domestic bachelor's student load in the science disciplines taught to science students

Service teaching in the broad discipline group 01, N&PS

The following data show the fields of education that received the most service teaching in Natural and Physical Sciences disciplines from 2002 to 2010 (see Figure 4.4.15). Health students received the most—16 335 EFTSL in 2010—and this demand increased strongly between 2004 and 2010 (nearly 60 per cent growth). Engineering was a clear second in demand for science service teaching, at about 5000 EFTSL in 2002 and increasing to about 6000 in 2010 (20 per cent growth). Various other FoEs received service teaching in the science disciplines of between 1000 and 3000 EFTSL a year. Of note is the drop in demand from IT students and Agriculture and Environment students: although this was more than offset by the growth in demand from Health students, the overall growth could mask a change in the types of science disciplines being taught. For example, a change in load from IT students to Health students might result in a decline in maths service teaching in favour of biology service teaching (see the discussion of Figure 4.4.16).

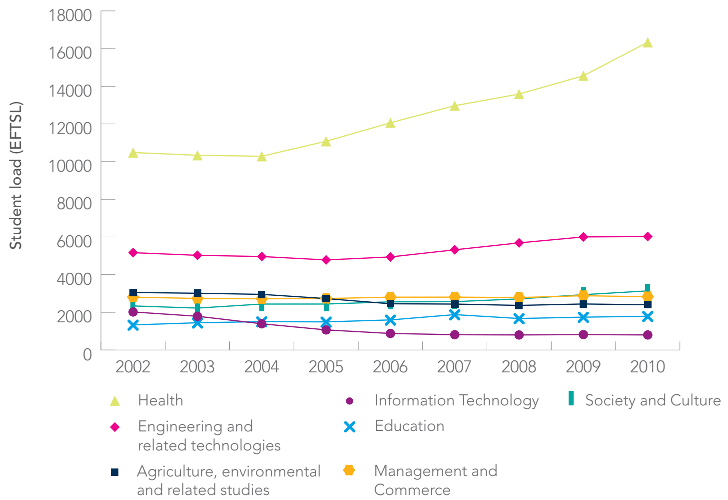


Figure 4.4.15 Domestic undergraduates and N&PS service teaching: load of science service teaching received by students, selected FoEs

Finally, a look at which narrow (four-digit) disciplines are taught to non-science undergraduates is warranted (included here are a selection of FoEs only—IT, Engineering, Agriculture and Environment, Health, Society and Culture, and Management). Mathematics and biology account for the greatest amount of service teaching to this group of students (Figure 4.4.16). The growth in biology service teaching largely follows the growth in service teaching to Health students. One would expect much of the mathematics service teaching to go to FoEs such as Engineering, Management and Commerce, and IT. Mathematics service teaching demand declined from 2002 to 2005, and this corresponds with the declining enrolments and demand for service teaching from IT students in those years. After 2005, however, demand for mathematics service teaching grew, corresponding to the growth in demand from Engineering and Management and Commerce, as well as a stabilisation in demand from IT students.

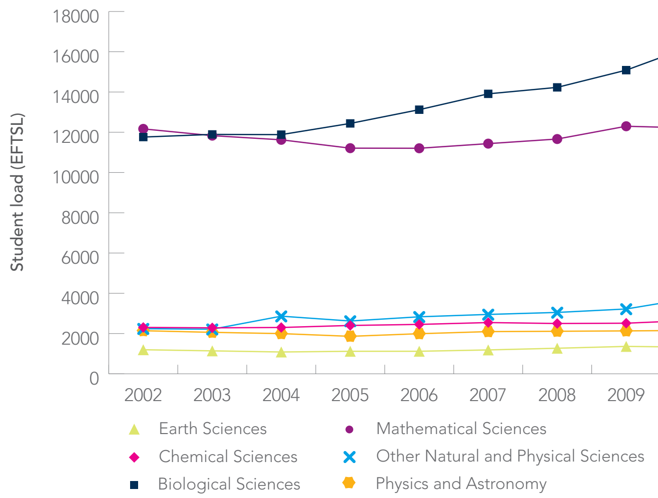


Figure 4.4.16 Undergraduate science service teaching: narrow disciplines

4.4.3 Science teaching to science students: narrow disciplines

Following is an in-depth look at which narrow (four-digit) science disciplines are being studied by domestic students enrolled in science courses (FoE 01) at different course levels. It should be borne in mind that the analysis is for science students only—those who are enrolled in an N&PS course as either their primary or their supplementary course (that is, as a single or a double degree). Further, only load taken by science students in the science disciplines (broad discipline group N&PS, 01) is considered. Students at any course level might be taking subject load in disciplines other than that which corresponds to their course FoE, but this is usually just a small proportion of their load. Dobson (2012) found that about a quarter of student load taken by science undergraduates is in disciplines other than science; an example would be a science undergraduate studying subjects in the broad discipline group of Agriculture and Environment.

N&PS bachelor's (pass and graduate entry)

First we look at N&PS subjects taken by domestic commencing students enrolled in bachelor's degrees in the N&PS FoE (primary or supplementary course). In other words, we examine which narrow disciplines are being studied by science undergraduates in their first year. Included are students who are taking a double degree, such as Bachelor of Arts – Bachelor of Science. Total science load

to commencing science students followed the enrolment patterns shown in Section 4.4.1, load being fairly steady from 2002 to 2008 then growing strongly in 2009 and 2010.

In order to see what has happened to the individual disciplines, their load can be compared over the time series (see Figure 4.4.17). Subjects in the Biological Sciences narrow discipline group were the most popular for commencing science students (right axis, Figure 4.4.17). Mathematics and chemistry were very similar in load over the whole period: each had lower load than biology but more than any of the other discipline groups. Physics and Astronomy was the next most popular first-year discipline group.

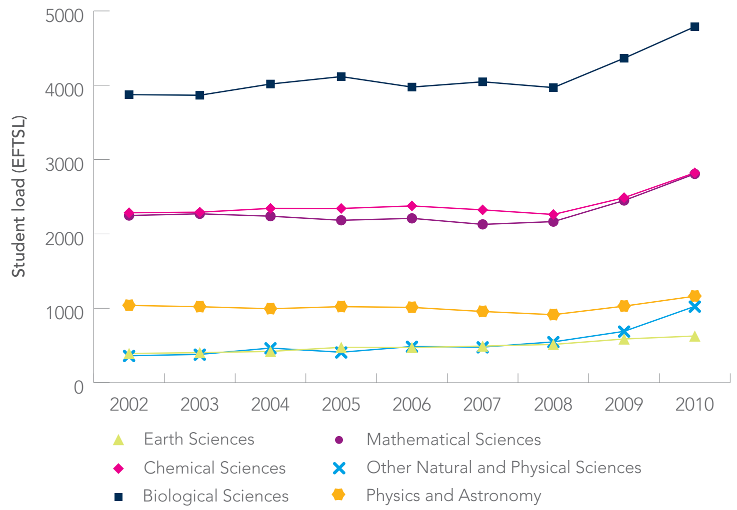


Figure 4.4.17 Commencing narrow discipline science load: domestic bachelor's (pass and grad. entry) enrolled in FoE N&PS

It is striking that in 2009 and 2010, when there was a surge in science enrolments, there was concurrent growth in all the discipline groups. It seems that the extra students attracted into a science degree in those years largely took up the same disciplines the previous cohorts had taken. This is confirmed by examining the proportion of science load in each discipline for commencing students (see Figure 4.4.18): the proportions changed little from 2008 to 2010. The exception is for narrow discipline group 0199, Other N&PS, where strong growth in 2009 and 2010 led to an increased share of the total science load. The disciplines that make up Other N&PS are medical, forensic and food sciences, laboratory technology, pharmacology, and natural and physical science subjects that are not further defined or not elsewhere classified. The growth shown here in Other N&PS is entirely the result of growth in medical science, pharmacology, forensic science and N&PS not elsewhere classified (data not shown).

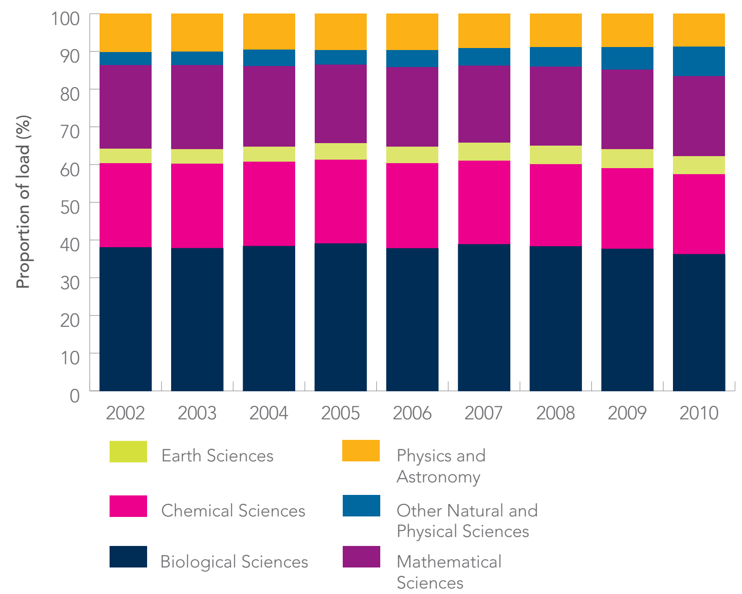


Figure 4.4.18 Proportion of commencing narrow discipline science load: domestic bachelor's (pass and grad. entry) enrolled in FoE N&PS

Next we can examine the distribution across the four-digit science disciplines for continuing science bachelor's students (see Figure 4.4.19). It is evident that biology's popularity persists (right axis). All the other disciplines are now clustered together, with relatively low load in comparison with biology. Mathematics, chemistry and 'Other N&PS' are the most popular disciplines for continuing students after biology. The figure also shows that loads for the enabling sciences of mathematics, physics and chemistry changed little from 2002 to 2010.

Now we look at each discipline as a proportion of all science teaching to continuing science bachelor's students (see Figure 4.4.20). As noted, for commencing science students biology accounts for about 40 per cent of commencing science load and mathematics and chemistry about 20 per cent each. As a proportion, mathematics and chemistry drop significantly at the continuing level: mathematics accounts for about 13 per cent and chemistry for about 10 per cent. Biology rises to over 50 per cent at the continuing level. It will take another year or two of data to see clearly what the 2009 and 2010 cohorts (where there was strong growth in enrolments) are studying in their continuing years.

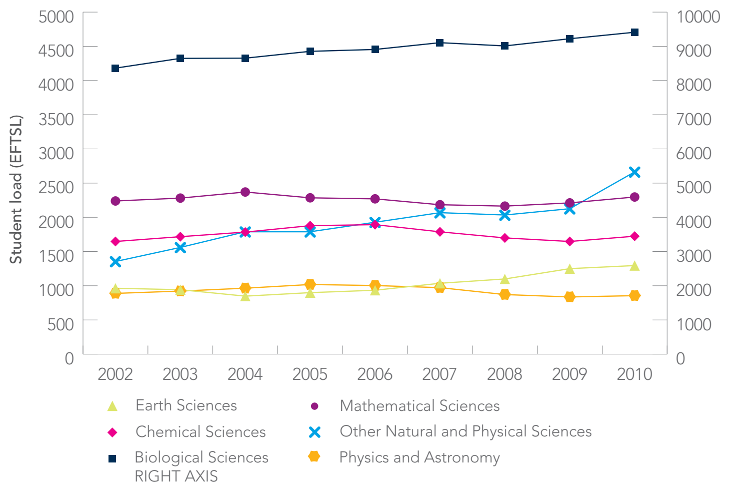


Figure 4.4.19 Continuing narrow discipline science load: domestic bachelor's (pass and grad. entry) enrolled in FoE N&PS

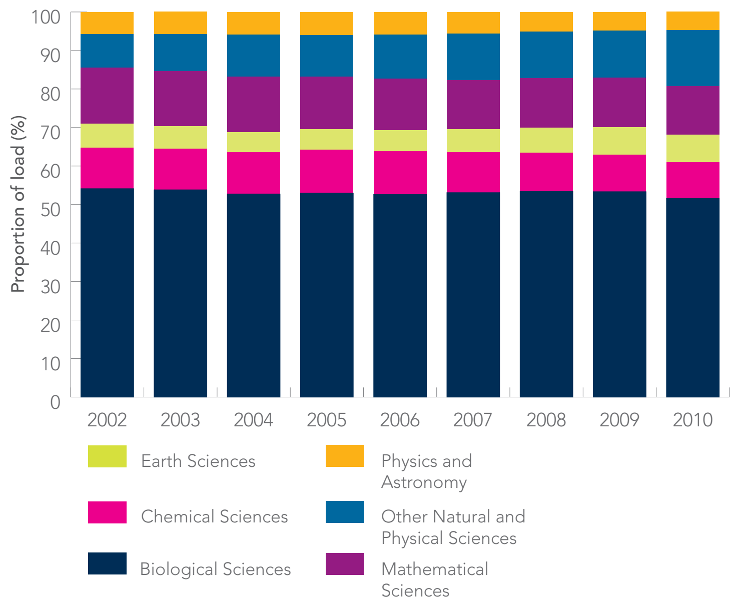


Figure 4.4.20 Proportion of continuing narrow discipline science load: domestic bachelor's (pass and grad. entry) enrolled in FoE N&PS

A load analysis can tell us only the relative share each discipline has of all the subjects taken by science students: it cannot tell us what the distribution is between second- and third- or final-year subjects or how many students are taking each discipline and how much they are taking. For example, the continuing mathematics load shown in Figure 4.4.19 could be taken by a small group of students who are majoring in mathematics and are therefore taking a heavy load in mathematics subjects in their continuing years. On the other hand, the mathematics load could be spread among many more students who take only one or two mathematics subjects at the second-year level but go on to major in other disciplines. The answer is probably a mix of these two scenarios, and others: the point is the data do not reveal this balance.

N&PS honours

A load analysis can be used to obtain an estimate of the balance between the disciplines for domestic N&PS honours students. As with any load analysis, however, there are limits to its usefulness. It tells us the relative status of each discipline but does not tell us how many students are attempting, say, honours in mathematics. It also does not tell us which disciplines were studied by students who went on to complete their honours.

Figure 4.4.21 shows that the distribution of honours load between the disciplines is largely consistent with that of continuing students. Biology (right axis) has by far the largest share of N&PS honours load and has about four to five times more than most of the other disciplines. Honours loads in mathematics and physics grew consistently from 2002 to 2010: mathematics load grew 50 per cent, from 146 EFTSL in 2002 to 219 in 2010; physics grew nearly 60 per cent from 129 to 204 EFTSL. Chemistry honours load fluctuated before finishing at about 250 EFTSL in 2010, which is just a little under where it was in 2002. Earth sciences declined from 238 EFTSL in 2002 to 151 in 2007, then recovered to 265 EFTSL in 2010. 'Other N&PS' outperformed most of the non-biology disciplines, with about 300 EFTSL in most years.

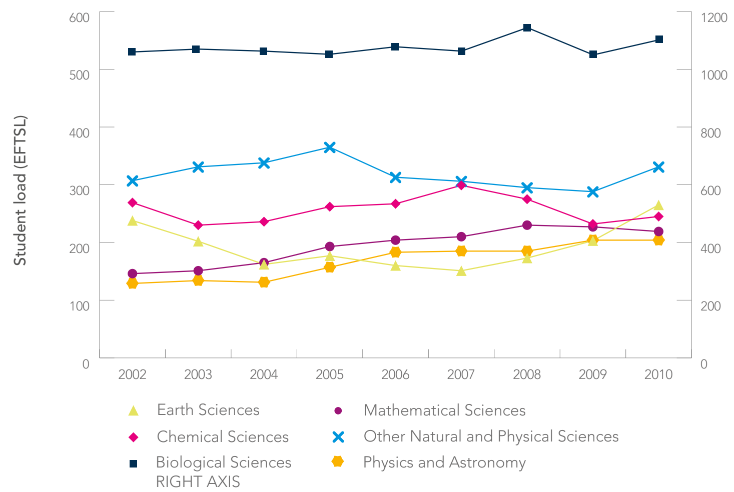


Figure 4.4.21 Student load in narrow science disciplines: domestic students enrolled in N&PS honours

The different patterns of load growth between the disciplines led to small shifts in the proportion held by each discipline (see Figure 4.4.22). Mathematics and physics increased their share of honours load between 2002 and 2010. Earth sciences dropped its share then recovered between 2008 and 2010. Chemistry and biology shares reduced slightly in 2008 to 2010 as other discipline shares increased. Biology had 45–50 per cent of the honours load.

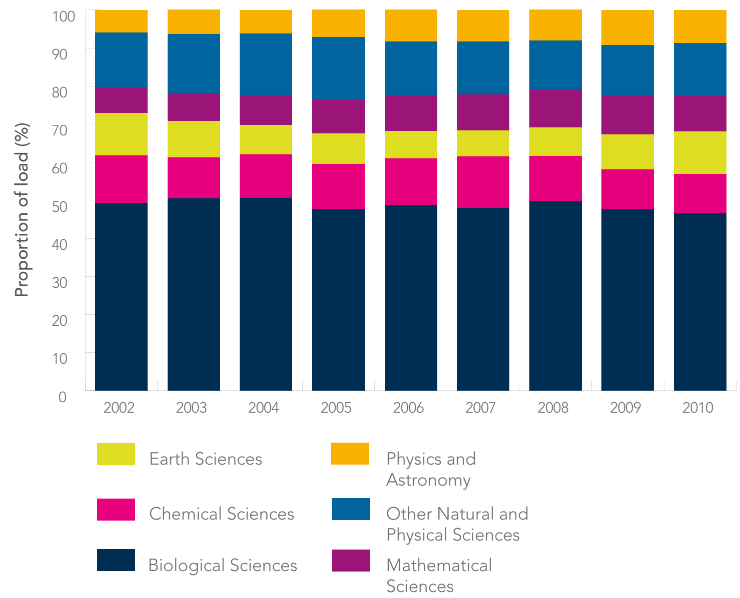


Figure 4.4.22 Proportion of student load in narrow science disciplines: domestic students enrolled in N&PS honours

N&PS postgraduate (coursework)

The N&PS postgraduate (coursework) course levels are becoming more popular in all disciplines other than chemistry, although the growth is from a low base (see Figure 4.4.23). This growth from a low base reflects similar growth in enrolments at this level in most of the science-related FoEs.

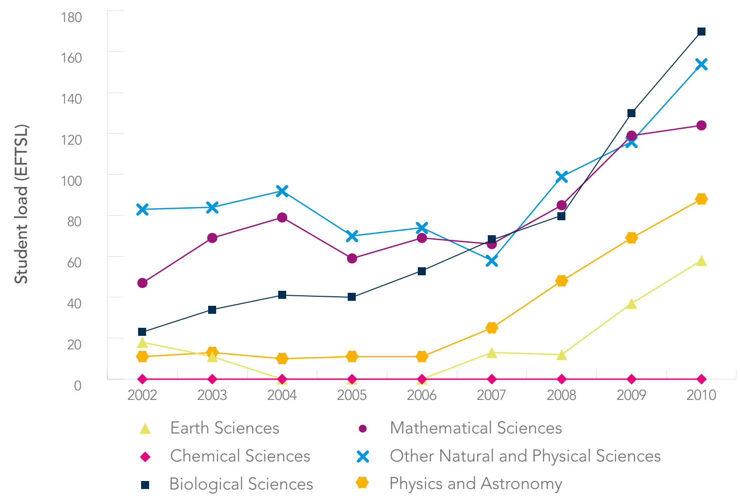


Figure 4.4.23 Narrow discipline science load: domestic postgraduate (coursework) students enrolled in FoE N&PS

N&PS higher degree by research

In the case of N&PS HDR, each narrow discipline had its own load pattern from 2002 to 2010 (see Figure 4.4.24). Biology (right axis) is again the most studied discipline. With the exception of earth sciences, which experienced a 45 per cent decline, all the disciplines showed some growth in load.

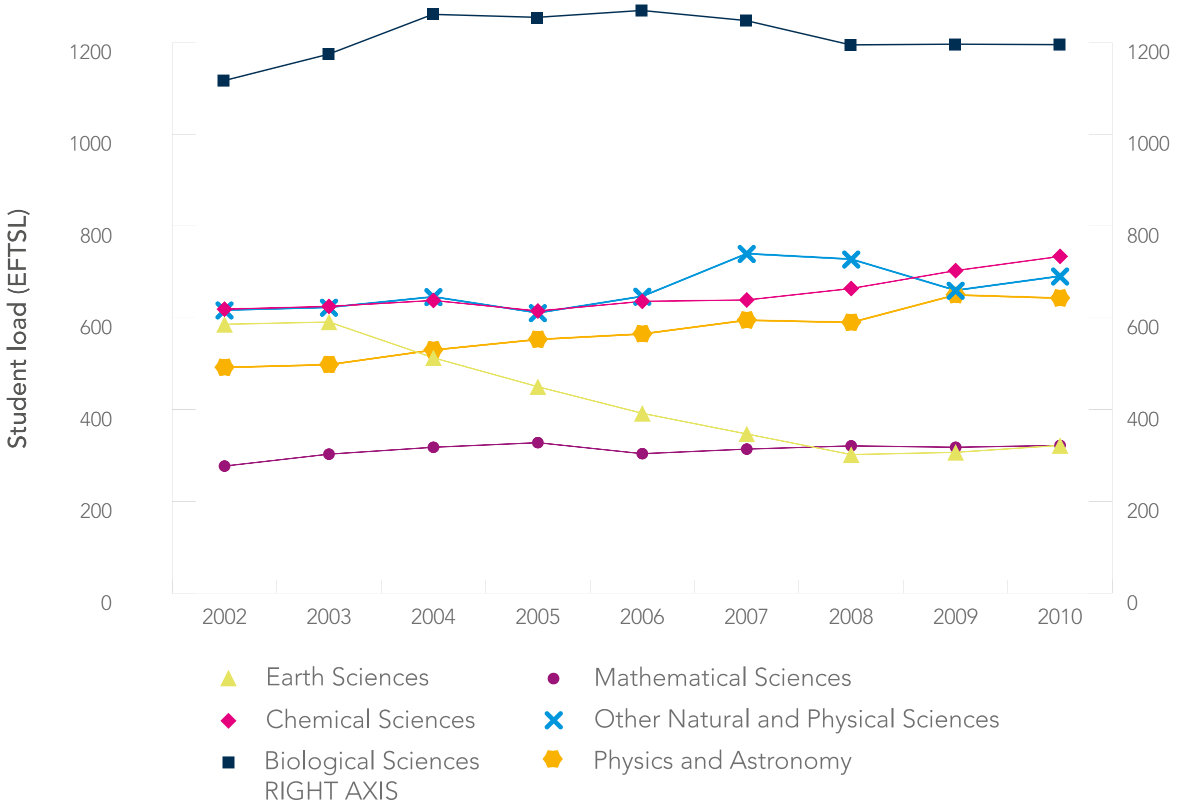


Figure 4.4.24 Narrow discipline science load: domestic HDR students enrolled in FoE N&PS

Some of the disciplines experienced a change in their share of N&PS HDR load (see Figure 4.4.25). Physics, chemistry and 'Other N&PS' all increased their share from 2005 to 2010. Earth sciences had a declining share of HDR load, and biology finished in 2010 much where it had been in 2002, at 47 per cent.

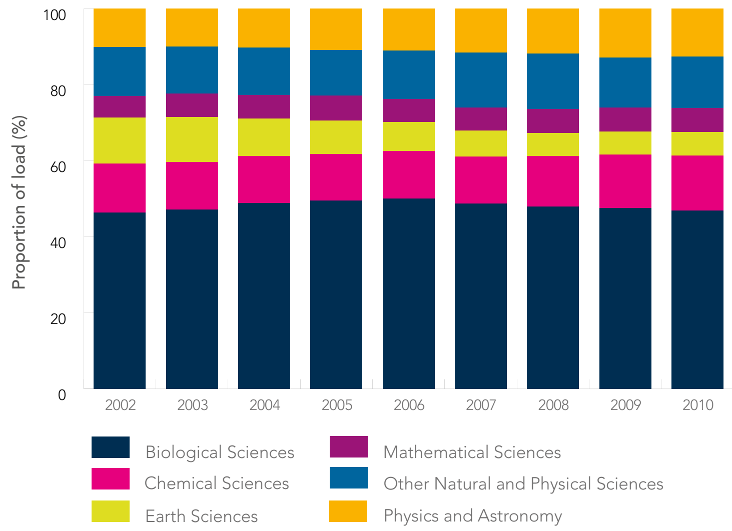


Figure 4.4.25 Proportion of narrow discipline science load: domestic HDR students enrolled in FoE N&PS

The total load combines students at all stages of their HDR and might hide trends in the disciplines being taken up by new HDR students. This is because any change year on year would be diluted by the load from students who had started one, two or more years previously. An analysis of commencing HDR load is therefore included here to highlight the narrow disciplines being taken up by new N&PS HDR students.

Biology load taken by commencing HDR students declined by 22 per cent, from a peak of 603 in 2004 to 468 in 2010 (see Figure 4.4.26). This is the only course level where the biology discipline group suffered a decline in load over the period. Mathematics declined from 86 commencing EFTSL in 2003 to 61 in 2010. Earth sciences also declined, with its load shrinking from 2002 to 2008 before some recovery in 2009 and 2010. Physics and chemistry ended in 2010 much where they started in 2002.

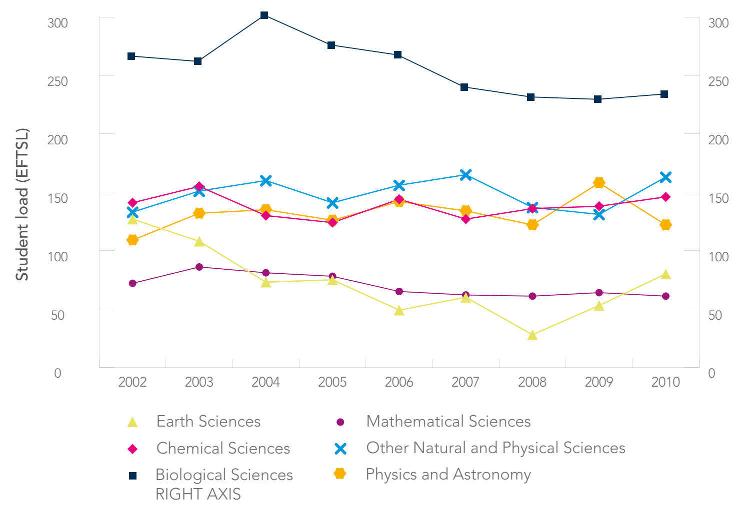


Figure 4.4.26 Commencing narrow discipline science load: domestic HDR students enrolled in FoE N&PS

4.4.4 Bachelor's–honours–HDR narrow discipline load ratios

This section examines the tertiary science 'pipeline'—what the relationship is for each narrow discipline between bachelor's load and honours load and what it is between honours load and commencing HDR.

Bachelor's–honours

The 'conversion rate' into honours for students studying the science disciplines at the bachelor's continuing level is simply the ratio of a discipline's honours load in one year to the continuing bachelor's load from the previous year (see Figure 4.4.27). On this measure, physics and earth sciences have the highest conversion between later year bachelor's and honours; mathematics has the lowest. Physics and mathematics load ratios grew between 2002 and 2010 because of the growth in honours load over a period when their respective continuing bachelor's loads were relatively steady. Chemistry maintained a fairly steady conversion rate, honours load variations matching more closely those in bachelor's load. Earth sciences honours load grew at a faster pace than the corresponding bachelor's load from 2007 to 2010, but the ratio is much the same in 2010 as it was in 2003. The four digit discipline 'Other N&PS' is not included in this analysis.

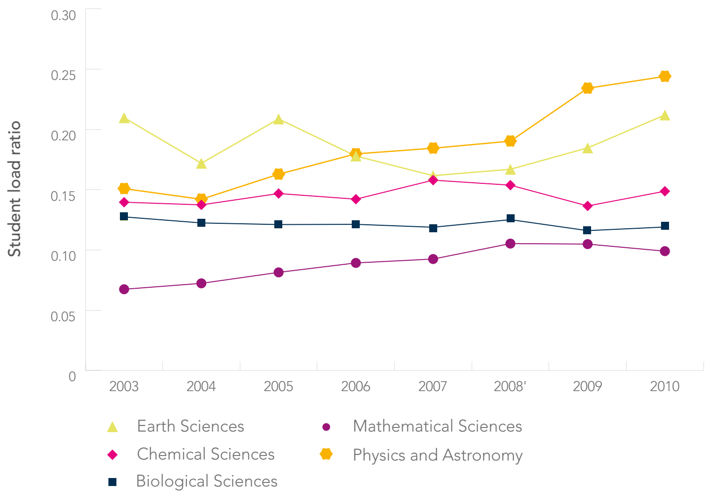


Figure 4.4.27 Narrow discipline load ratios for science students (domestic): honours (*t*) / bacherlor's continuing (*t*-1)

HDR–honours

The HDR to honours load ratios were calculated by dividing the commencing HDR load for each discipline by its honours load from the previous year. The ratio for most disciplines dropped from 2003 to 2008 (see Figure 4.4.28). Physics started in 2002 with the highest 'conversion factor' by far. In 2003 the load in physics taken by commencing HDR students was the same as the physics load to honours students in the previous year. This suggests that about as many students began an HDR in physics in 2003 as had taken honours in 2002. (There are confounders, though—students doing a mixed honours, where their load is split between disciplines; students taking time off between honours and their HDR; and students doing honours part time.) The drop in the physics honours conversion rate during the period is explained by strong growth in physics honours without concurrent growth in physics HDR load. A similar story applies to mathematics: honours increased but commencing HDR load did not. Biology commencing HDR dropped while honours remained steady, resulting a declining HDR–honours ratio.

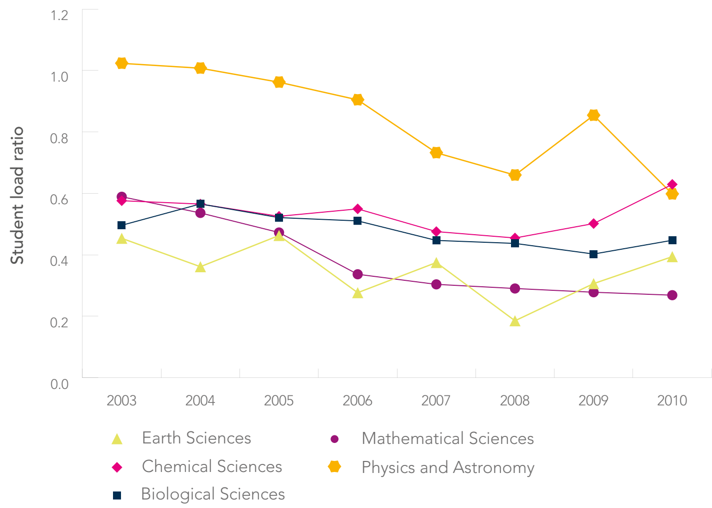


Figure 4.4.28 Narrow discipline load ratios for science students (domestic): HDR commencing (*t*) / honours (*t*-1)

Piecing together the honours–bachelor's and honours–HDR ratios, it seems that mathematics and physics honours have been growing independently of growth in bachelor's load, but this has not resulted in growth in HDR load for these disciplines. Biology HDR commencing load has been declining despite growth in bachelor's biology and steady honours biology. Continuing study in physics seems to be more indicative of an intention to go on to honours and an HDR than is the case for disciplines such as mathematics and biology (physics has a high honours–bachelor's ratio and a high, albeit declining, HDR–honours ratio). Continuing bachelor's study of earth sciences seems to convert well into honours in earth sciences (a relatively high honours–bachelor's ratio), but that does not then convert into high HDR rates (a relatively low HDR–honours ratio).

This analysis might offer some insight into the motivations of students taking the different disciplines at various course levels. For mathematics and biology, it seems the students that take these subjects in the later years of their bachelor's degree are less likely to continue to honours than those who major in other science disciplines, especially physics and earth sciences. For biology, this might be explained in part by the role of a biology degree as a precursor to medicine or other health studies. For mathematics, it could be that some students study mathematics at the continuing level as

an enabling subject for their true focus in another discipline. The independent growth in physics and mathematics honours could be evidence of students responding to the demands of the workforce or perhaps part of the general move towards increasing qualifications throughout the workforce—a trend illustrated by the strong growth in postgraduate (coursework) programs.

4.4.5 Undergraduate science and IT, 1989 to 2010

The change of fields of education and broad discipline groups in 2001 (Dobson 2012) makes longer time-series analysis problematic. Following is a discussion of what happened in the enabling disciplines—mathematics, chemistry and physics—from 1989 to 2010. A crucial difference between the years before 2001 and those after is the removal of computer science and information technologies from the former field of study 09, Science. This is particularly important when comparing mathematics load from the 1990s with mathematics load in 2001 and beyond: much of the drop in load from the late 90s to 2002 is explained by the loss of IT students from field of study 09, Science (pre-2001), to FoE 01, N&PS (post-2001). Figure 4.4.29 shows the contribution of IT students to mathematics load in 2002 and beyond[1].

The series appearing from 1989 to 2000 (left half of Figure 4.4.29) show student load in the science disciplines for subjects taken by domestic bachelor's students enrolled in the former field of study 09, Science (scale is on left axis). Note that one of the narrow disciplines is computer science, formerly part of Science but now in the IT FoE. Also shown is the total load, in all disciplines, for all domestic bachelor's students (green line; scale on right axis). This gives an idea of the expansion of the higher education system over the period. Of particular interest is the strong growth in the biology discipline group and in computer science. The other science disciplines were mostly flat or declining in the 1990s.

The series appearing from 2002 to 2010 (right half of Figure 4.4.29) are for loads in N&PS disciplines of students enrolled in N&PS courses (the post-2001 classification system; scale is on left axis). The series 'Total load in all disciplines to all domestic bachelor's pass' is continued for 2002 to 2010 (scale on right axis). The computer science series is the load in the broad discipline group IT taken by students enrolled in courses in the IT FoE. A new series is added for 2002 to 2010, showing mathematics load taken by IT students. The mathematics series for 1989 to 2000 represents load for mathematics subjects taken by both science and computer science students. Mathematics is then shown as two series after 2001.

It is clear from Figure 4.4.29 that computer science/IT has experienced considerable decline in popularity throughout the 2000s, after very steep growth in the 1990s. Biology also stands out with steep growth in popularity in the 1990s. As noted, however, biology maintained its popularity during the 2000s.

Figure 4.4.30 is similar in concept to Figure 4.4.29, except it shows just a selection of science disciplines and is for continuing bachelor's students only. The figure highlights the decline, in absolute terms, in the popularity of the enabling science disciplines of mathematics, chemistry and physics for continuing bachelor's students in the 1990s. Since then popularity for these disciplines has remained flat. All this has occurred at a time of massive expansion in the higher education system.

[1] 2001 data is not included in this analysis as the counting methodology for enrolments used in 2001 was different to that used in 2002 (Dobson 2012).

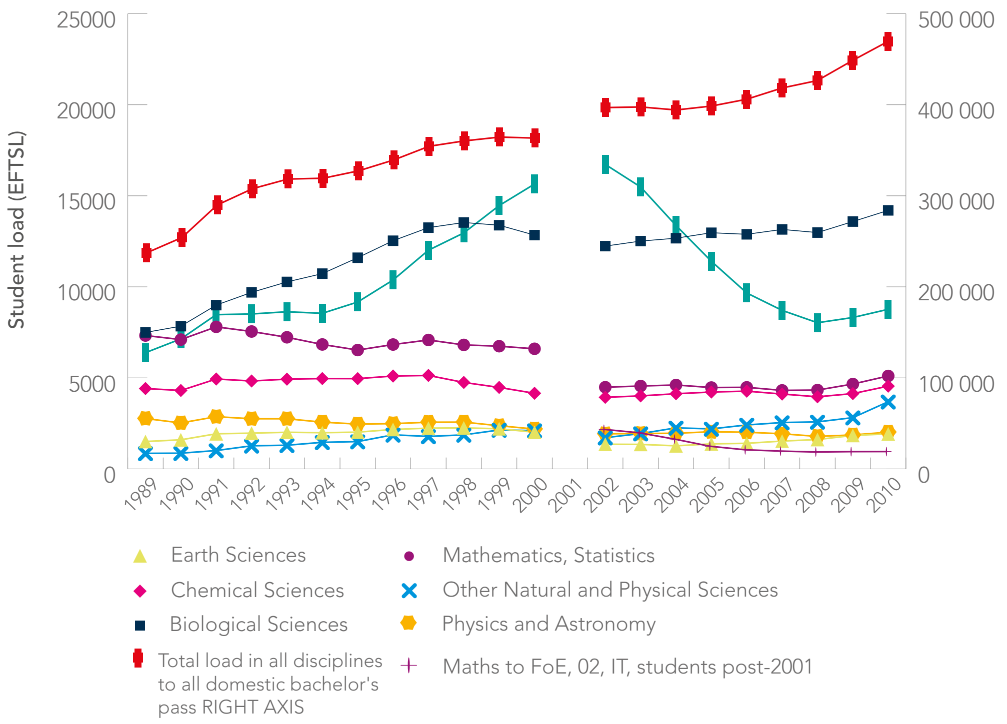


Figure 4.4.29 Science and IT load to science and IT undergraduates, 1989 to 2010

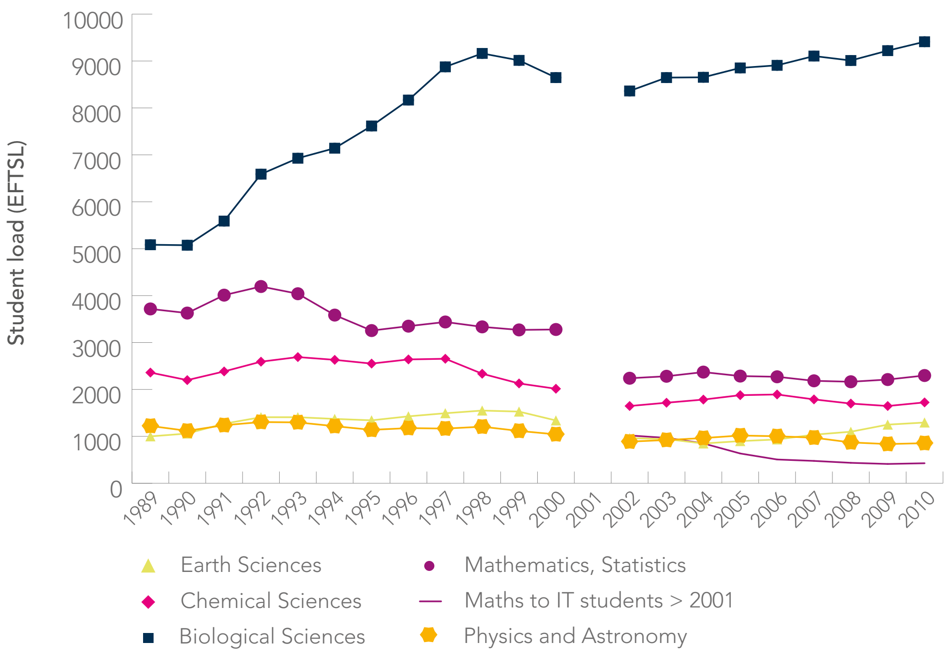


Figure 4.4.30 Continuing science load, domestic undergraduates enrolled in science courses

4.5 INFORMATION TECHNOLOGY

This section examines enrolments and completions in field of education 02, Information Technology. It also provides an analysis of subjects taught in broad discipline group 02, Information Technology. IT study and teaching experienced a decline for most of the analysis period, 2002 to 2010. This is reflected throughout the various IT-related Higher Education Statistics analysed here.

In brief, the findings are as follows:

- Commencing enrolments and completions at the undergraduate level in IT fell by about 50 per cent for most of 2002 to 2010.
- Male students were overrepresented in commencing enrolments in IT at the undergraduate course level.
- In contrast with completions for other course levels in IT, higher degree by research completions increased between 2002 and 2010, albeit from a low base.
- Despite the general decline in IT enrolments, completions and teaching, the proportion of IT service teaching at the undergraduate level remained stable between 2002 and 2010.
- About 45 per cent of IT teaching to undergraduate students was delivered as service teaching or to undergraduate students enrolled in non-IT fields of education.
- Undergraduate students in Management and Commerce, Engineering, Natural and Physical Sciences, and Society and Culture received almost all of the IT service teaching.

4.5.1 Enrolments and completions

Commencing enrolments in undergraduate degrees (including honours) in IT decreased by 52.3 per cent from 2002 to 2008 (see Figure 4.5.1). There was a recovery between 2008 and 2010: undergraduate enrolments increased by 15.2 per cent, to 6302 in 2010.

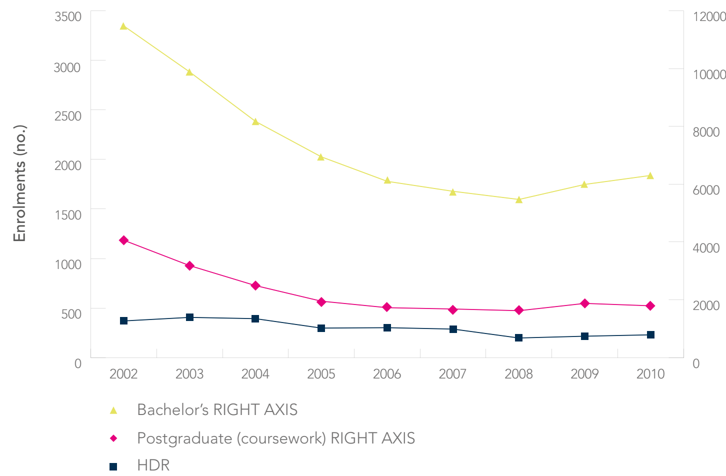


Figure 4.5.1 Domestic commencing enrolments in IT, by course level

The trend in commencing enrolments in undergraduate degrees is broadly mirrored in commencing enrolments at the postgraduate (coursework) level, there being a 60.1 per cent decrease over the period 2002-08. This was also followed by a recovery, to 1874 enrolments in 2009 and 1790 in 2010.

Similarly, commencing enrolments for higher degree by research students decreased from 370 in 2002 to 230 in 2010.

As might be expected, the trend in completions for most course levels in IT broadly reflects what is evident for IT enrolments. Course completions form a lagging indicator. Following an initial increase from 2002 to 2003, undergraduate completions in IT declined by 53 per cent from 2004 to 2010; consistent with the decrease in commencing enrolments (see Figure 4.5.2).

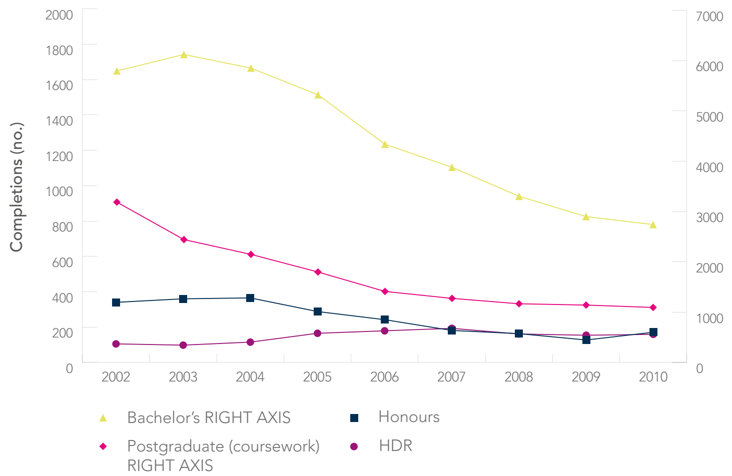


Figure 4.5.2 Domestic completions in IT, by course level

Study at honours level is not uniform across fields of education or even institutions. For example, eligible undergraduate students in science might enrol separately and commence at honours level in Natural and Physical Sciences. Alternatively, students completing a bachelor's degree in IT may be awarded honours as a reward for academic excellence. As a potential gateway to a higher degree by research, completions provide a reasonable indicator for honours students. Completions in bachelor's honours degrees in IT fell by 65.3 per cent from a peak in 2004. A small recovery yielded 171 completions in 2010.

Completions in postgraduate (coursework) degrees also declined, although to a greater extent than undergraduate completions. They fell by 65.6 per cent from 2002 to 2010.

In contrast with completions for other IT course levels, higher degree by research completions increased 54.3 per cent (from a low base) between 2002 and 2010.

With the exception of HDR completions, completions for every other course level in IT declined as a proportion of that course level in all fields of education. For example, as a proportion of postgraduate (coursework) degree completions in all FoEs, postgraduate (coursework) completions in IT declined from 7.9 per cent in 2002 to 1.9 per cent in 2010 (see Figure 4.5.3). This encapsulates the contraction of IT as an FoE during 2002 to 2010, and growth in other areas.

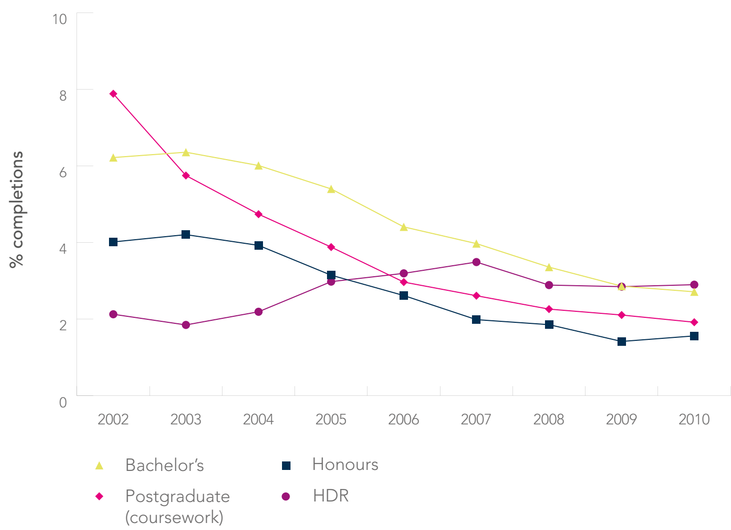


Figure 4.5.3 Domestic course completions in IT, by course level, as a proportion of completions in all FoEs

Enrolments by commencing status and gender

Total undergraduate enrolments in IT declined by 50 per cent between 2002 and 2010 (see Figure 4.5.4). Unlike commencing undergraduate enrolments, continuing undergraduate enrolments remained in decline throughout the period.

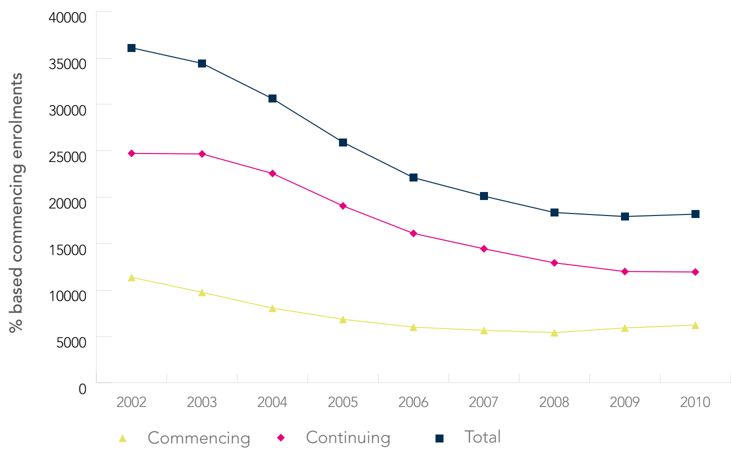


Figure 4.5.4 Domestic IT undergraduate enrolments, by student status

Sector-wide enrolment data show that female students were in the majority from 2002 to 2010 (Dobson 2012). In 2010 females accounted for 55.6 per cent of all enrolments at Australian higher education institutions. Male students are, however, overrepresented in commencing domestic enrolments in undergraduate IT courses. There was a gradual increase in the proportion of male students from 77.2 per cent to 85.9 per cent during 2002 to 2010 (see Figure 4.5.5).

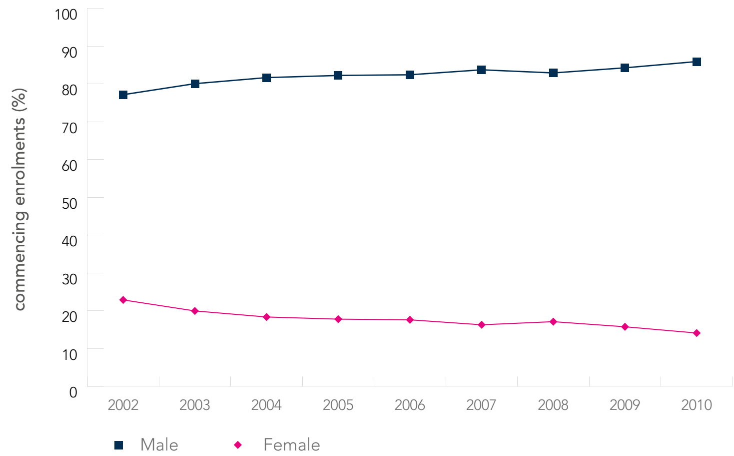


Figure 4.5.5 Domestic commencing undergraduate enrolments in IT, by gender

Domestic postgraduate (coursework) enrolments in IT decreased by 56.6 per cent from 2002 to 2010 (see Figure 4.5.6). This was underpinned by a comparable decline of 55.9 per cent in commencing enrolments over the same period.

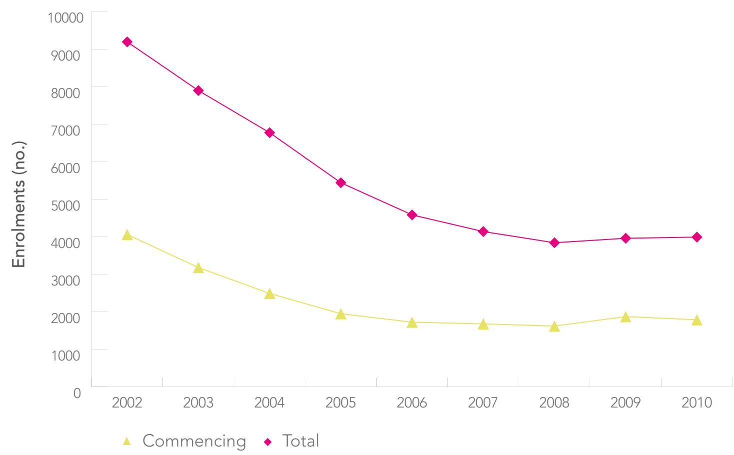


Figure 4.5.6 Domestic postgraduate (coursework) enrolments in IT

In contrast with enrolments in all the other IT course levels, total HDR enrolments increased 35.9 per cent during the initial part of the analysis period from 2002 to 2006 (see Figure 4.5.7). There was then a decline of 23.9 per cent from the peak in 2006 to the level in 2009. A small recovery, 4.2 per cent, in total IT HDR enrolments occurred in 2010.

Overall, commencing HDR enrolments fell 37.8 per cent between 2002 and 2010.

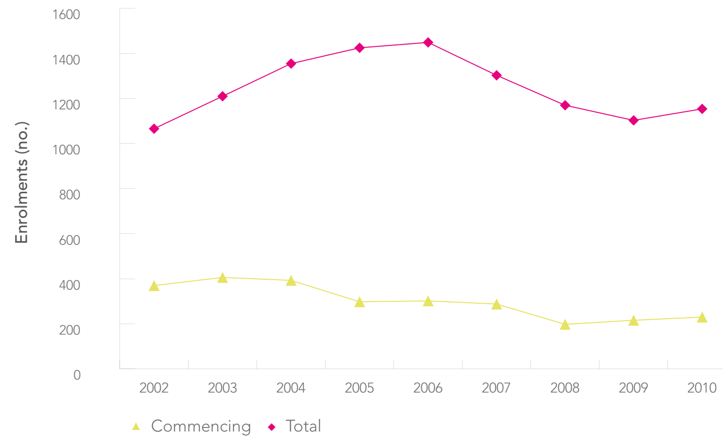


Figure 4.5.7 Domestic HDR enrolments in IT

4.5.2 Teaching in broad discipline group 02, Information Technology

The subjects taught in broad discipline group 02, Information Technology are analysed here in order to cast light on what students study as part of their course. The analysis of student load in IT is performed at the broad (two-digit) and narrow (four-digit) discipline levels for selected course levels.

Teaching of subjects in IT disciplines to all domestic undergraduate students

The general decline in IT enrolment numbers at almost all course levels resulted in a concomitant decline in teaching of IT to domestic students enrolled in all fields of education during 2002 to 2010. IT teaching to all undergraduate students decreased by 67.7 per cent (see Figure 4.5.8).

This decline is underpinned by a greater fall in teaching to continuing students compared with commencing students: teaching to continuing students fell by 51 per cent from 2002 to 2010; teaching to commencing students decreased by 30.3 per cent during the same period.

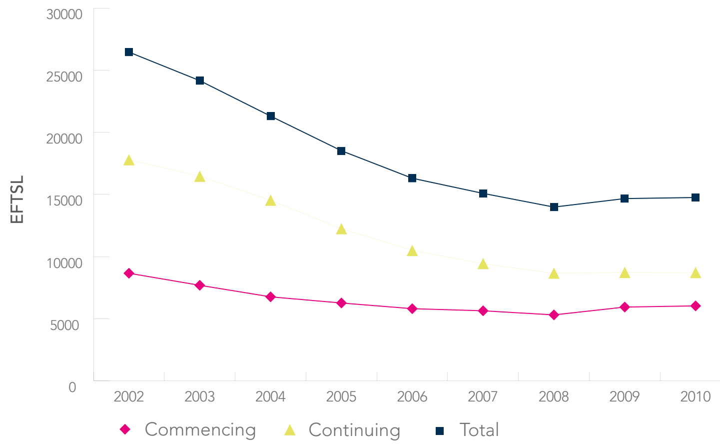


Figure 4.5.8 Teaching of IT to domestic undergraduate students in all fields of education

Teaching of IT to non-IT undergraduates

Teaching of IT to non-IT undergraduate students decreased 41.5 per cent from 2002 to 2010 (see Figure 4.5.9a).

About 45 per cent of IT teaching was delivered to commencing and continuing undergraduate students enrolled in non-IT fields of education (Figure 4.5.9b). Despite the general decline in IT enrolments, completions and teaching, the proportion of IT service teaching at the undergraduate level remained stable between 2002 and 2010.

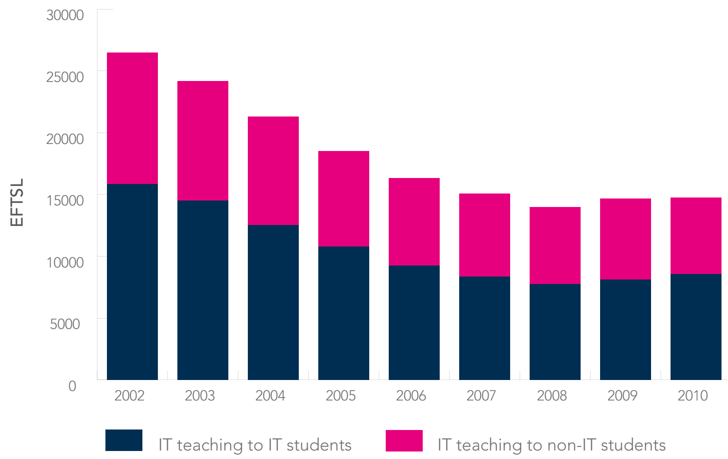


Figure 4.5.9a Teaching of IT to non-IT undergraduates: EFTSL

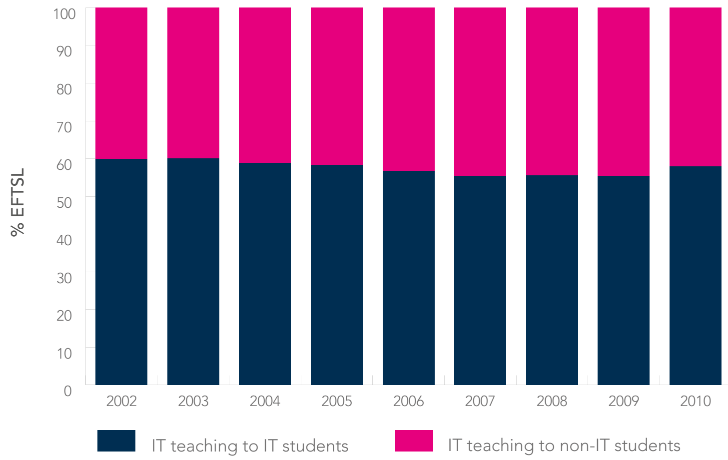


Figure 4.5.9b Teaching of IT to non-IT domestic undergraduates: proportion of EFTSL

Teaching of IT disciplines to IT undergraduates

The trend in IT teaching to IT undergraduate students is consistent with IT teaching to all domestic undergraduate students: teaching IT undergraduate students decreased by 46.1 per cent from 2002 to 2010 (see Figure 4.5.10). A slight recovery is, however, evident with growth of 10.2 per cent from 2008 to 2010.

As can be generally expected on the basis of the proportion of continuing to commencing undergraduate students enrolled in any field of education, the bulk of IT teaching (60–70 per cent) is to continuing IT students. The share of teaching to commencing IT undergraduate students increased, however, from 30 per cent in 2002 to 37 per cent in 2010 (see Figure 4.5.10; right axis).

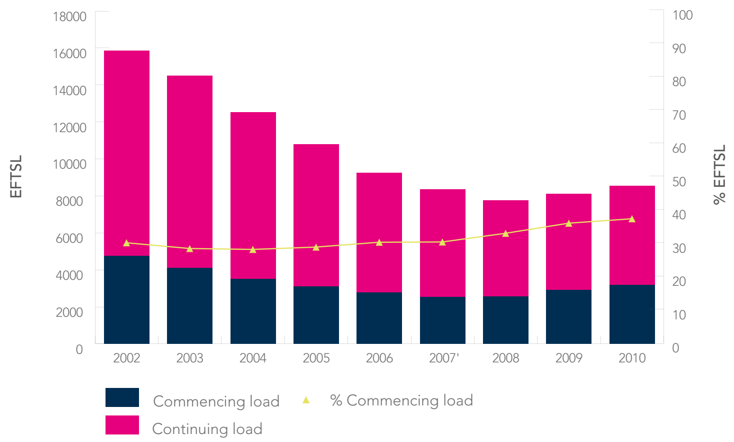


Figure 4.5.10 Teaching of IT to domestic IT undergraduates

Service teaching in broad discipline group 02, Information Technology

In 2010 Management and Commerce, Engineering, Natural and Physical Sciences, and Society and Culture were the main recipients of service teaching in IT (see Figure 4.5.11). These fields of education received 6120 EFTSL out of a total of 6206 EFTSL committed to service teaching. Teaching to students enrolled in Health and Agriculture and Environment (not shown) accounts for the remainder of this service teaching.

Management and Commerce received the greatest amount of service teaching, at about 45 per cent, followed by Engineering at about 30 per cent, Natural and Physical Sciences at about 10 per cent, and Society and Commerce at 10 per cent. The share of IT service teaching received by each of these fields of education has remained largely stable between 2002 and 2010.

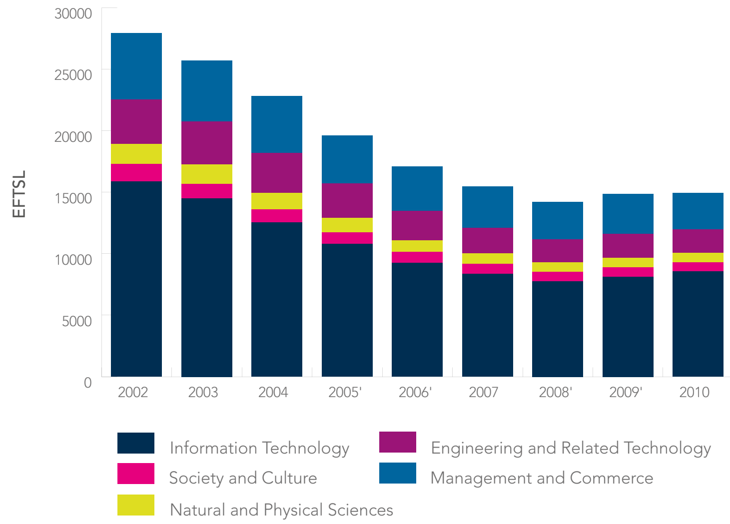


Figure 4.5.11 Distribution of IT service teaching, by field of education

4.5.3 IT teaching to students enrolled in IT: narrow disciplines

A deeper examination of student load allows the determination of what IT narrow disciplines are being taken by and taught to domestic IT students. This is done by analysing student load at the four-digit level for IT students enrolled in selected course levels.

Although subjects studied as part of a degree can be defined specifically, there are constraints on how study load can be interpreted (Dobson 2012). Caution is warranted because course offerings by universities vary, as do practices for coding courses.

Undergraduate: bachelor's pass and graduate entry

Consistent with the decline in domestic IT undergraduate enrolment numbers, teaching of commencing undergraduate students in IT narrow disciplines declined by 33.1 per cent from 2002 to 2010 (see Figure 4.5.12a).

The teaching of Computer Science fell by 50 per cent between 2002 and 2010. The teaching of Information Systems declined during the first part of the analysis period but then recovered ground: it decreased 38.6 per cent from 2002 to 2007 and then increased by 31.7 per cent between 2007 and 2010.

As a proportion of all IT teaching to commencing IT students, Computer Science declined from 59.4 per cent in 2002 to 44.4 per cent in 2010, while Information Systems grew from 29.5 per cent to 35.6 per cent and Other Information Technology grew from 11.2 per cent to 20 per cent (see Figure 4.5.12b). It is difficult to say whether this change in the distribution of these narrow disciplines is indicative of the changing mix of subjects studied by undergraduate students as part of their undergraduate degree in IT or reflects the way universities code subjects to narrow discipline groups (Dobson 2012).

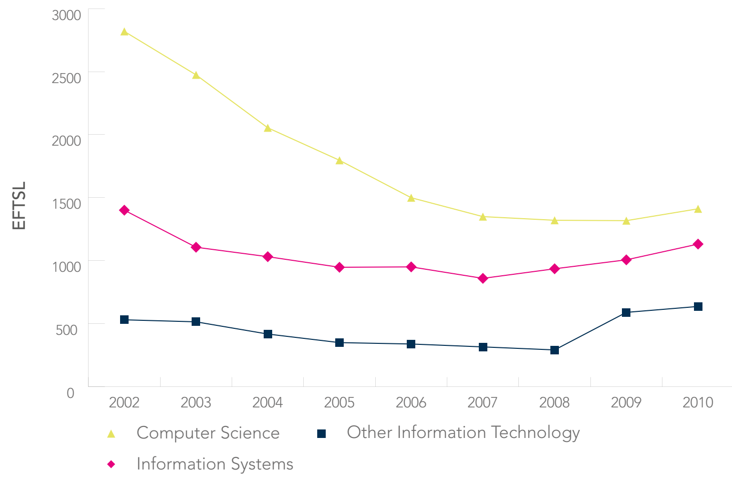


Figure 4.5.12a Teaching in IT narrow disciplines to domestic commencing undergraduate IT students: EFTSL

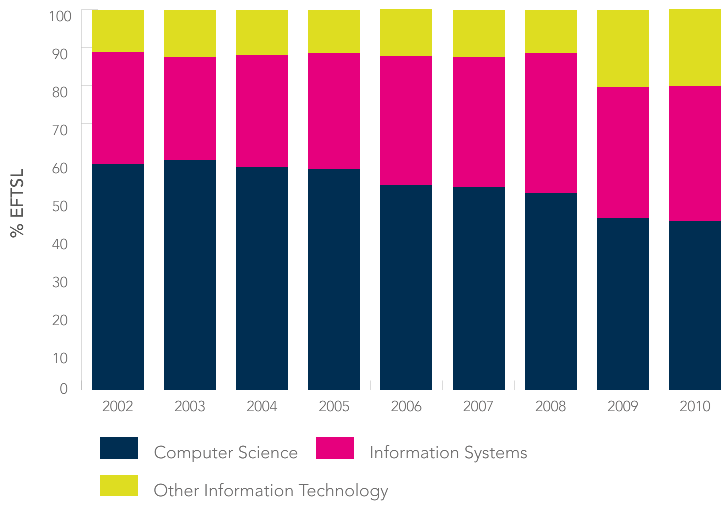


Figure 4.5.12b Teaching in IT narrow disciplines to domestic commencing undergraduate IT students: proportion of EFTSL

The trends in teaching of IT narrow disciplines to domestic commencing students are broadly reflected in the trends for domestic continuing students: teaching of all IT narrow disciplines to the latter group decreased 51.6 per cent from 2002 to 2010 (see Figure 4.5.13a).

Teaching of Computer Science experienced the greatest decline: 63.5 per cent from 2002 to 2010. Similarly teaching in Information Systems fell by 44.8 per cent during the period. The decline in the teaching of Other Information Technology was comparatively modest at 17.5 per cent.

As a proportion of all IT teaching to domestic continuing IT students, Computer Science declined from 56.8 per cent in 2002 to 42.9 per cent in 2010, while Information Systems grew from 29.5 per cent in 2002 to 33.6 per cent in 2010 and Other Information Technology grew from 13.8 per cent in 2002 to 23.5 per cent in 2010 (see Figure 4.5.13b).

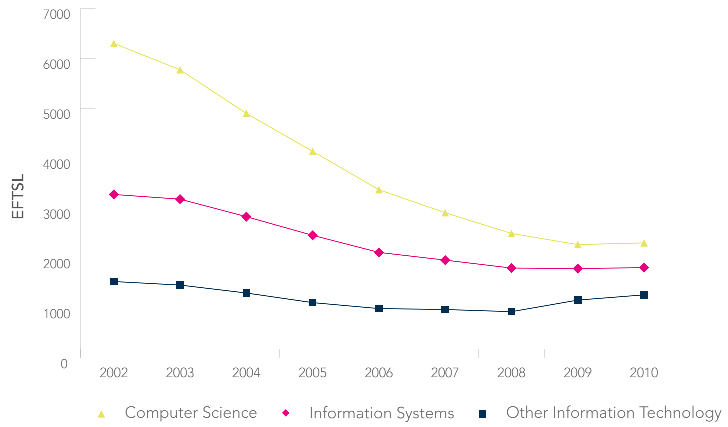


Figure 4.5.13a Teaching in IT narrow disciplines to domestic continuing undergraduate IT students: EFTSL

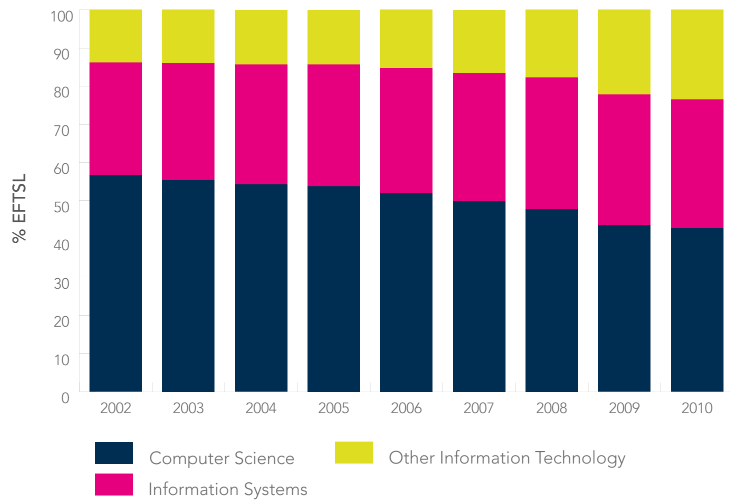


Figure 4.5.13b Teaching in IT narrow disciplines to domestic continuing undergraduate IT students: proportion of EFTSL

Postgraduate (coursework) in IT

Consistent with the teaching trends in course levels examined for IT thus far, teaching in all IT narrow disciplines at the postgraduate (coursework) level decreased 54.6 per cent from 2002 to 2010 (see Figure 4.5.14). This decline is underpinned by a fall largely in the teaching of Computer Science and Information Systems; teaching in Other Information Technology remained stable.

More than 80 per cent of subjects studied by postgraduate (coursework) IT students were from the narrow disciplines of Computer Science (about 45 per cent) and Information Systems (39 per cent).

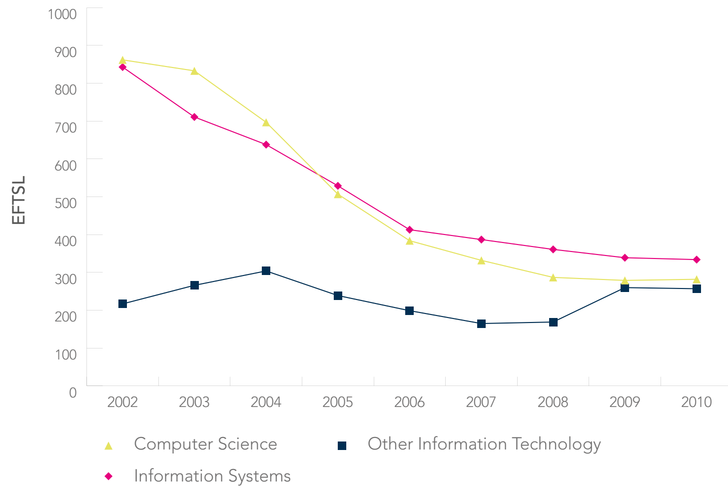


Figure 4.5.14 Teaching of IT narrow disciplines to domestic postgraduate (coursework) IT students

Higher degree by research in IT

The trend in teaching to domestic HDR students opposes the overall trend seen for IT teaching to IT students enrolled in all the other course levels; total HDR load in IT increased by 44.5 per cent between 2002 and 2005 (see Figure 4.5.15a). This was followed by a decline of 28.9 per cent, with the load reaching its lowest level in 2009.

Computer Science was the dominant narrow discipline for HDR students, accounting for bulk of the initial rise and subsequent fall in student load during 2002 to 2010.

The proportion of total load accounted for by each narrow discipline remained relatively stable during the period (see Figure 4.5.15b).

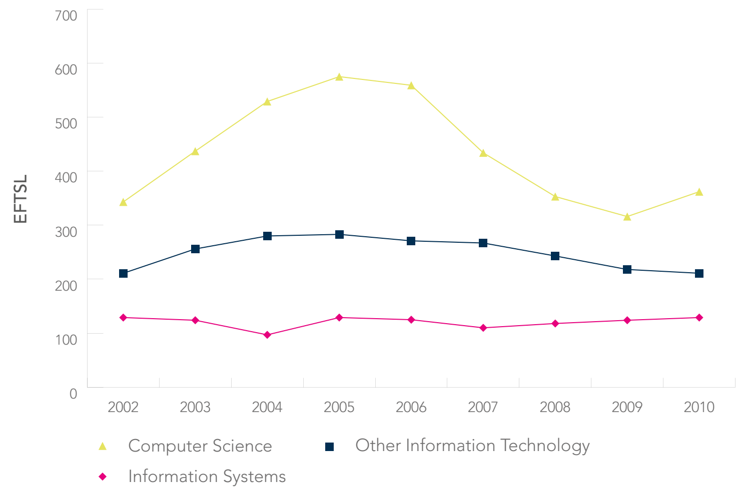


Figure 4.5.15a Teaching of IT narrow disciplines to HDR IT students: EFTSL

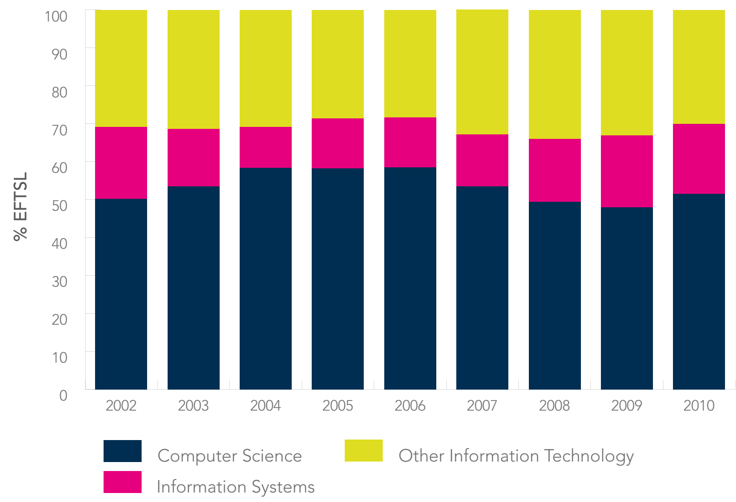


Figure 4.5.15b Teaching of IT narrow disciplines to HDR IT students: proportion of EFTSL

4.6 ENGINEERING AND RELATED TECHNOLOGIES

This section examines enrolments and completions in field of education 03, Engineering and Related Technologies. It also provides an analysis of subjects taught in broad discipline group 03, Engineering and Related Technologies. The field of education 03 and broad discipline group 03 are referred to here as Engineering.

In brief, the findings are as follows:

- Commencing enrolments in Engineering undergraduate degrees increased by 22 per cent between 2002 and 2010.
- Higher degree by research enrolments in Engineering remained steady between 2002 and 2010.
- Completions at the bachelor's and HDR levels remained largely steady during the period.
- As with Information Technology, male students were over-represented in commencing enrolments in undergraduate Engineering degrees.
- Teaching in the narrow discipline of Electrical and Electronic Engineering and Technology to continuing undergraduate students in Engineering fell 40.8 per cent between 2002 and 2010. This coincided with a decline in Electrical and Electronic Engineering and Technology service teaching to IT students.
- In contrast, the teaching of Civil Engineering to continuing students in Engineering more than doubled during the period.

4.6.1 Enrolments and completions

Commencing enrolments in Engineering undergraduate degrees increased by 22 per cent over the period 2002 to 2010 (see Figure 4.6.1). Commencing enrolments in postgraduate (coursework) degrees also grew, by 33.4 per cent. In contrast, HDR enrolments remained steady, there being 980 and 981 commencing enrolments in 2002 and 2010 respectively.

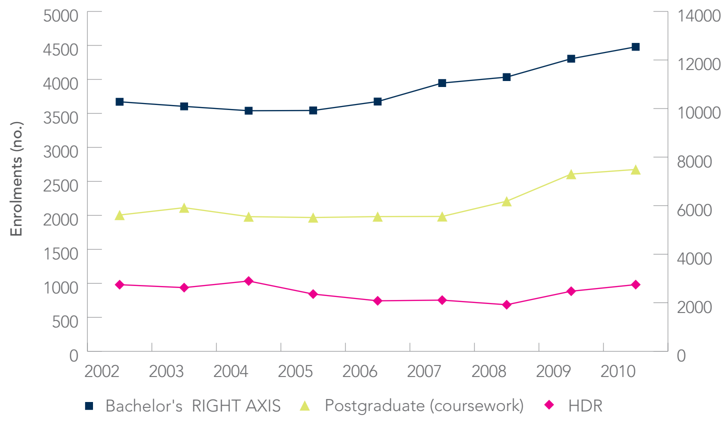


Figure 4.6.1 Domestic commencing enrolments in Engineering, by course level

Completions at the bachelor's and HDR levels remained largely steady during 2002 to 2010. The average number of completions at the undergraduate level was 5159 a year; at the HDR level it was 592 (see Figure 4.6.2).

Completions in postgraduate (coursework) degrees remained steady between 2002 and 2006 then increased by 77.9 per cent to 2010.

Bachelor's honours completions increased by 33.4 per cent over the period 2002 to 2009. Such completions in 2010 are excluded from this analysis because the increase in completions in 2010 is not representative of the higher education sector but is specific to one institution. For a discussion of the increase in honours completions in Engineering in 2010, see Section 4.3.2.

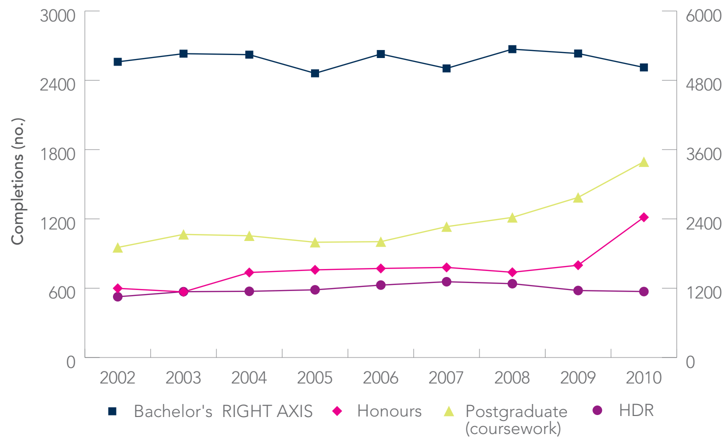


Figure 4.6.2 Domestic completions in Engineering, by course level

As a proportion of all completions, HDR, undergraduate and postgraduate completions in Engineering remained generally steady during 2002 to 2010 (see Figure 4.6.3). HDR completions in Engineering accounted for 10 to 12 per cent of HDR completions in all fields of education from 2002 to 2010. As a proportion of honours completions in all fields of education, honours completions in Engineering grew from 7.1 per cent in 2002 to 8.9 per cent in 2009.

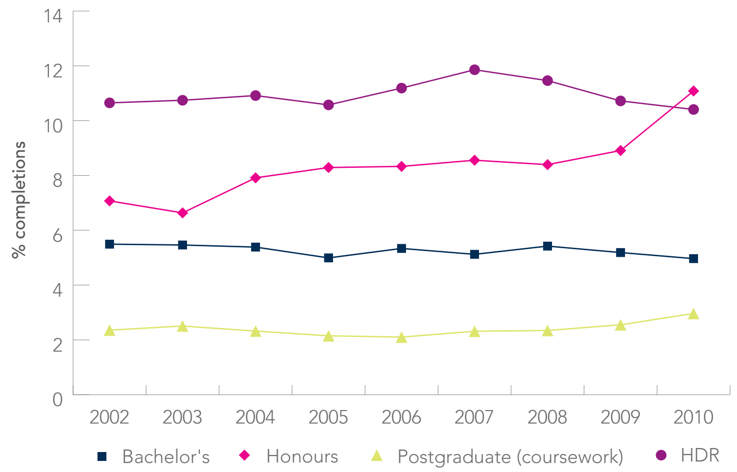


Figure 4.6.3 Domestic completions in Engineering, by course level, as a proportion of completions in all FoEs

Engineering enrolments by commencing status and gender

Total undergraduate enrolments in Engineering increased 15.7 per cent from 2002 to 2010 (see Figure 4.6.4). This trend is reflected in both commencing and continuing enrolments: commencing undergraduate enrolments grew by 22.0 per cent; continuing enrolments increased by 13.8 per cent.

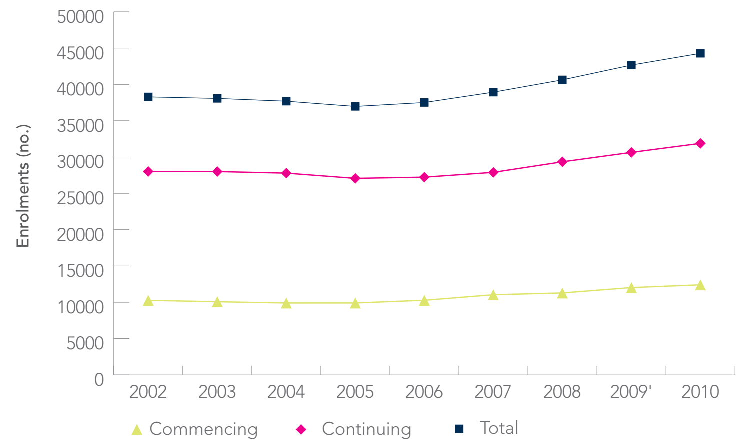


Figure 4.6.4 Domestic undergraduate enrolments in Engineering, by student status

Male students were overrepresented in undergraduate Engineering degrees, accounting for more than 80 per cent of all commencing enrolments between 2002 and 2010 (see Figure 4.6.5). The number of male students starting Engineering increased 17 per cent from 2002 to 2010. In comparison, the number of female students increased by 10 per cent. Thus the gender imbalance in Engineering at the undergraduate course level persisted between 2002 and 2010.

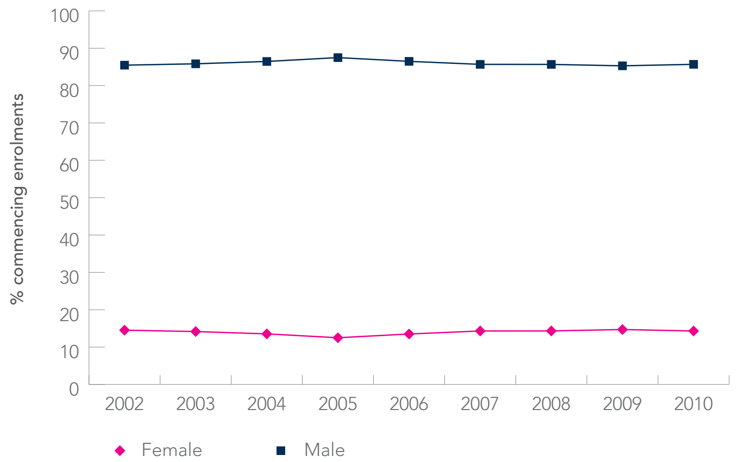


Figure 4.6.5 Domestic commencing enrolments in Engineering, by gender

Total enrolments in postgraduate (coursework) degrees increased by 48.4 per cent over the period 2002 to 2010 (see Figure 4.6.6). The growth was underpinned by an increase in commencing enrolment numbers by 33.4 per cent.

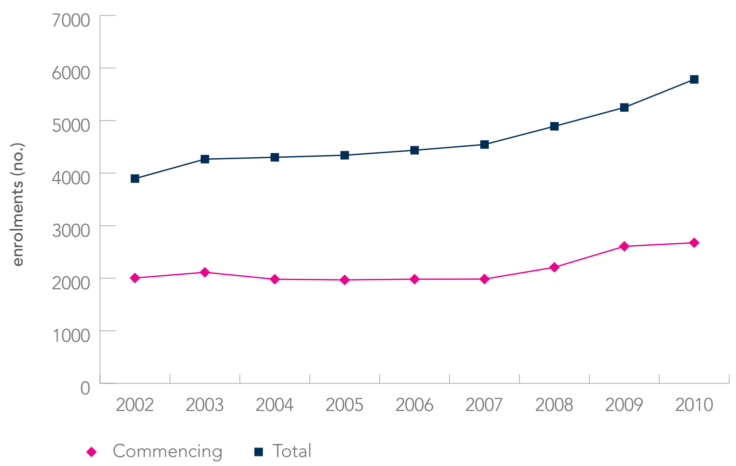


Figure 4.6.6 Domestic postgraduate (coursework) enrolments in Engineering

Unlike enrolments at postgraduate (coursework) level, total HDR enrolments in Engineering increased by only 4.5 per cent between 2002 and 2010 (see Figure 4.6.7). Commencing HDR enrolments were steady over the same period.

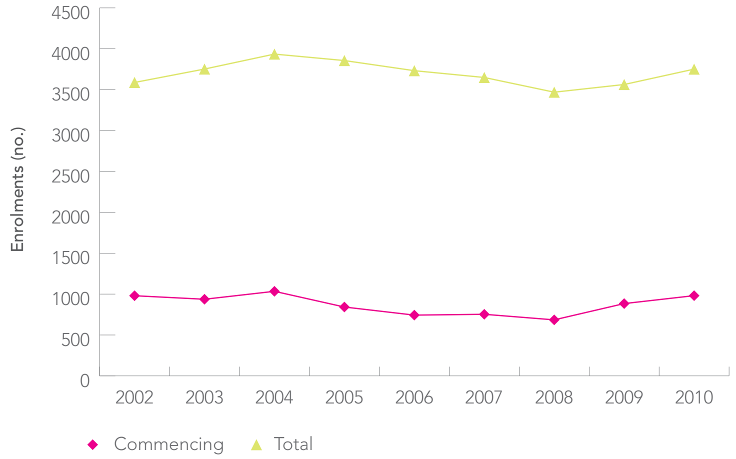


Figure 4.6.7 Domestic HDR enrolments in Engineering

4.6.2 Teaching in broad discipline group 03, Engineering and Related Technologies

The subjects taught in broad discipline group 03, Engineering and Related Technologies, are analysed here in order to cast light on what students study as part of their course. The analysis of student load in Engineering is performed at the broad (two-digit) and narrow (four-digit) discipline levels for selected course levels.

Teaching of subjects in Engineering disciplines to all domestic undergraduate students

Teaching of Engineering to all undergraduate students increased 24.3 per cent from 2002 to 2010 (see Figure 4.6.8). This growth is underpinned by an increase in teaching to both commencing (31.3 per cent) and continuing (22.2 per cent) students.

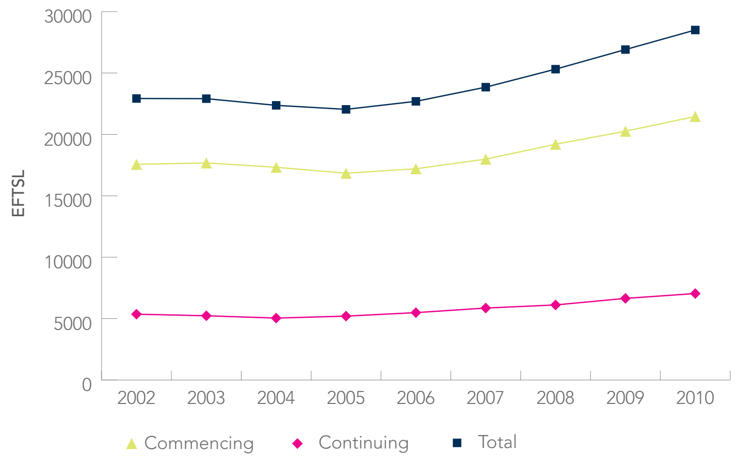


Figure 4.6.8 Teaching of Engineering to domestic undergraduate students in all fields of education

Teaching of Engineering to non-Engineering undergraduates

Almost 90 per cent of Engineering teaching is delivered to Engineering students in all course levels (see Dobson 2012, table 3). Unlike Natural and Physical Sciences and IT, Engineering as a broad discipline group is not a major service teaching discipline.

Much of the small amount of service teaching in Engineering went to undergraduate students in IT and Natural and Physical Sciences. As might be expected, Engineering load to IT students decreased significantly, a decline of 59.4 per cent from 2002 to 2010. As a share of all undergraduate teaching in Engineering, teaching to IT students fell from 7.0 to 2.5 per cent during this period. A large proportion of this decline was in the narrow discipline of Electrical and Electronic Engineering and Technology.

In contrast, teaching of Engineering to Natural and Physical Sciences students increased slightly, 4.3 per cent, during 2002 to 2010. As a share of all undergraduate teaching in Engineering, teaching to students in Natural Physical Sciences fell from 5.7 per cent to 4.8 per cent during this period. Teaching to Natural and Physical Sciences students was again dominated by the narrow discipline of Electrical and Electronic Engineering and Technology, which declined from 2002 to 2010.

Teaching of Engineering disciplines to Engineering undergraduates

Teaching of Engineering to Engineering undergraduate students increased by 25.3 per cent during 2002 to 2010 (see Figure 4.6.9). This increase is evenly distributed between commencing and continuing students. The share of all teaching for commencing students remained steady, at about 25 per cent (see Figure 4.6.9; right axis).

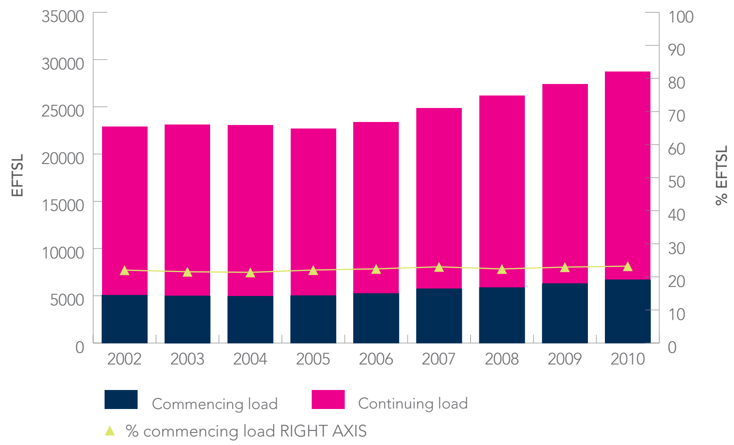


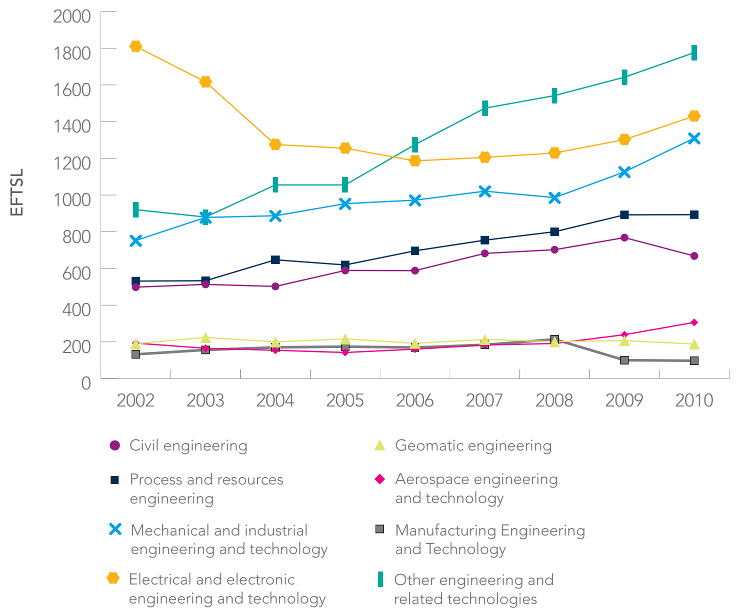
Figure 4.6.9 Teaching of Engineering to domestic undergraduate Engineering students

4.6.3 Engineering teaching to students enrolled in Engineering: narrow disciplines

A deeper examination of student load allows the determination of what Engineering narrow disciplines are being taken by and taught to domestic Engineering students. This is done by analysing student load at the four-digit level for Engineering students enrolled in selected course levels.

Undergraduate: bachelor's pass and graduate entry

Teaching in the narrow discipline of Electrical and Electronic Engineering and Technology to commencing undergraduate students decreased by 21 per cent during 2002 to 2010 (see Figure 4.6.10a). In contrast, teaching in the generic narrow discipline Other Engineering and Related Technologies increased by 93 per cent during the same period. Similarly, teaching in Mechanical and Industrial Engineering grew by 74.2 per cent, Process and Resources Engineering by 68.2 per cent, and Civil Engineering by 34.1 per cent .



Note: The narrow disciplines of Automotive Engineering and Technology and Maritime Engineering and Technology are not shown because of low numbers (EFTSL less than 10) across the time series.

Figure 4.6.10a Teaching in narrow disciplines of Engineering to domestic commencing undergraduate students

Among the remaining narrow disciplines, teaching to commencing undergraduate students shows three distinct trends for 2002 to 2010. Considerable growth, 58.5 per cent, is seen for Aerospace Engineering, while teaching in Geomatic Engineering remained stable, and teaching in Manufacturing Engineering fell by 36.1 per cent. The fall in the teaching of Manufacturing Engineering occurred over a short period, between 2008 and 2010. Given the low absolute number of EFTSL involved, it is possible that the trends in teaching for Aerospace Engineering and Manufacturing Engineering relate to individual institutions, rather than the sector as whole.

As a proportion of teaching in all Engineering narrow disciplines to commencing students, teaching in the narrow discipline Other Engineering increased from 18.2 per cent in 2002 to 26.6 per cent in 2010, while teaching in Electrical and Electronic Engineering and Technology fell from 35.8 per cent to 21.4 per cent during the period (see Figure 4.6.10b). Teaching in Other Engineering now represents the largest proportion of Engineering teaching for commencing undergraduate students.

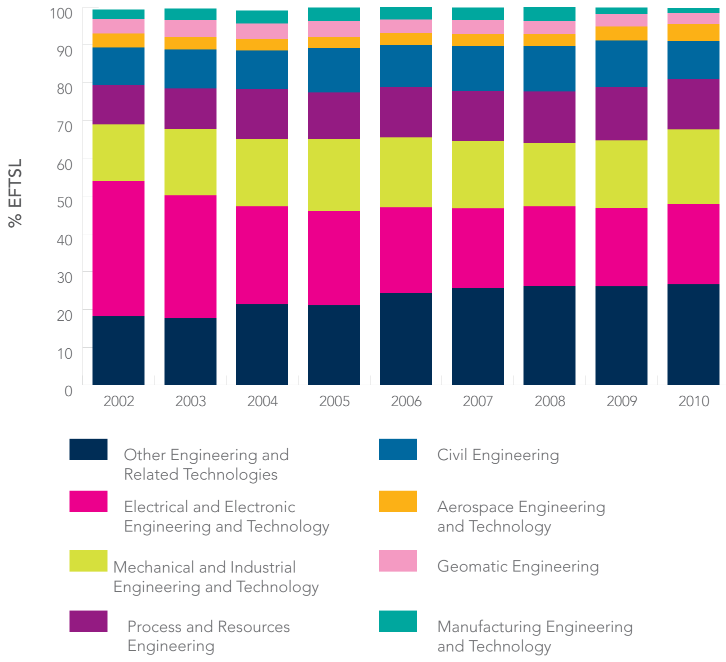


Figure 4.6.10b Teaching in narrow disciplines of Engineering to domestic commencing undergraduate students: proportion of EFTSL

The overall decline in the teaching of Electrical and Electronic Engineering and Technology to commencing undergraduate students is also evident for continuing undergraduate students enrolled in Engineering; a 40.8 per cent decline during 2002 to 2010 for the latter (see Figure 4.6.11a). In contrast, the teaching of Civil Engineering to continuing students more than doubled in that period. Similarly, teaching of Mechanical and Industrial Engineering increased by 52.5 per cent, Other Engineering by 49.6 per cent, and Process and Resources Engineering by 53.5 per cent. Teaching in the remaining narrow disciplines remained relatively stable during the period.

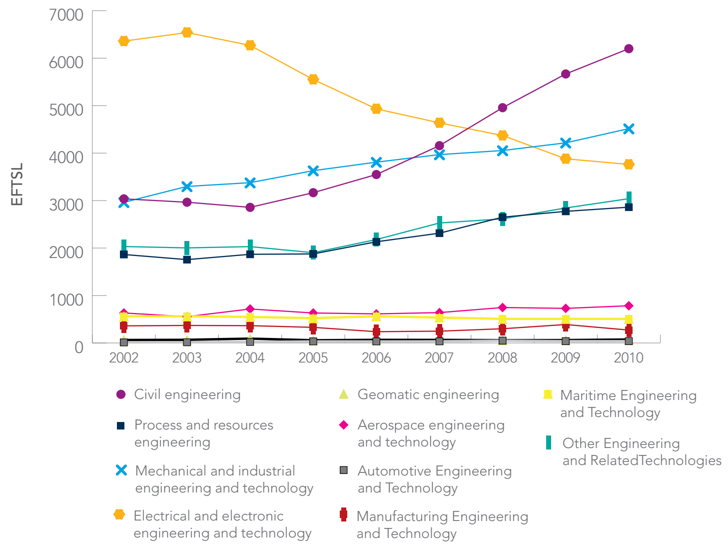


Figure 4.6.11a Teaching in narrow disciplines of Engineering to domestic continuing undergraduate students: EFTSL

As a proportion of teaching in all Engineering narrow disciplines to continuing undergraduate students, teaching in Civil Engineering became dominant; growing from 17 per cent in 2002 to 28.1 per cent in 2010, while teaching in Electrical and Electronic Engineering and Technology fell from 35.6 per cent to 17.1 per cent (see Figure 4.6.11b).

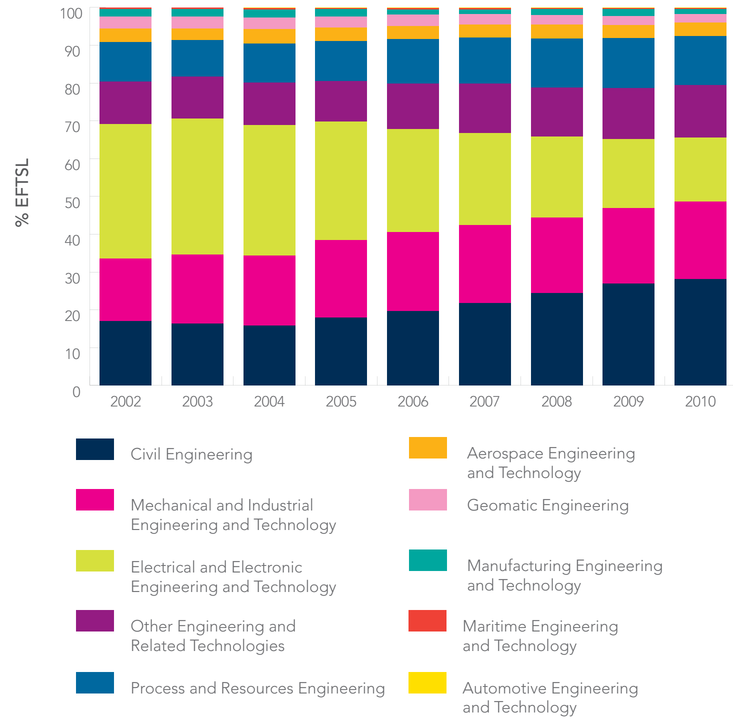
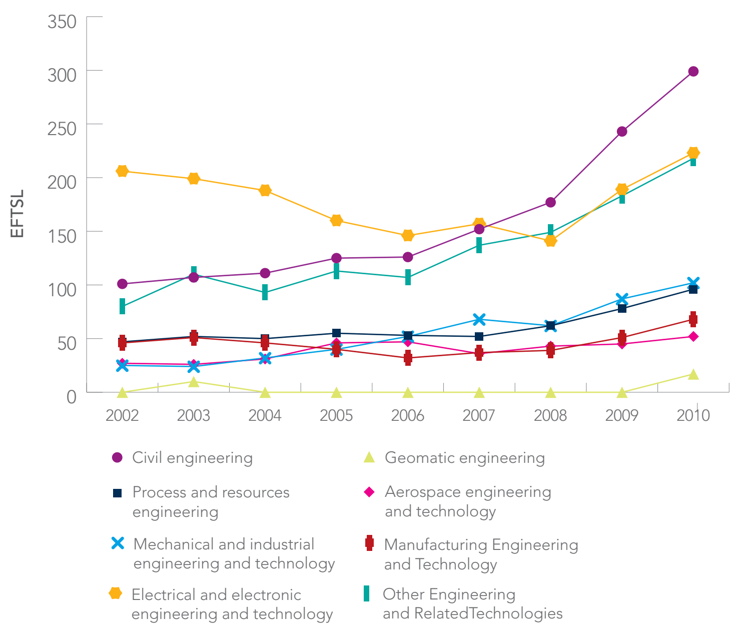


Figure 4.6.11b Teaching in narrow disciplines of Engineering to domestic continuing undergraduate students postgraduate (coursework) in Engineering: proportion EFTSL

Postgraduate (coursework) in Engineering



Note: The narrow disciplines of Automotive Engineering and Technology and Maritime Engineering and Technology are not shown because of low numbers (EFTSL less than 10) across the time series.

Figure 4.6.12 Teaching in narrow disciplines of Engineering to domestic postgraduate (coursework) students.

Teaching in all narrow disciplines to students enrolled at the postgraduate (coursework) course level increased in absolute terms during 2002 to 2010 (see Figure 4.6.12). This growth was, however, from a low base in most cases.

Postgraduate (coursework) teaching in Civil Engineering increased by 196 per cent during 2002 to 2010. Teaching in the generic Other Engineering discipline grew by 172.5 per cent. Teaching in Electrical and Electronic Engineering and Technology experienced relatively modest growth of 8.3 per cent.

Higher degree by research in Engineering

Total load for Engineering HDR students decreased by 4 per cent between 2002 and 2010.

Student load in most narrow disciplines of Engineering broadly showed a decline, a slight increase or no change from 2002 to 2010 (see Figure 4.6.13). Specifically, load in the narrow disciplines Other Engineering and Process Engineering fell 14.2 per cent and 12 per cent respectively during the period. In contrast, load for Electrical and Electronic Engineering and Technology increased 23.6 per cent. A single large increase in load for Electrical and Electronic Engineering and Technology is evident in 2005. Growth is also evident in load for Mechanical and Industrial Engineering, which increased by 8.8 per cent from 2002 to 2010.

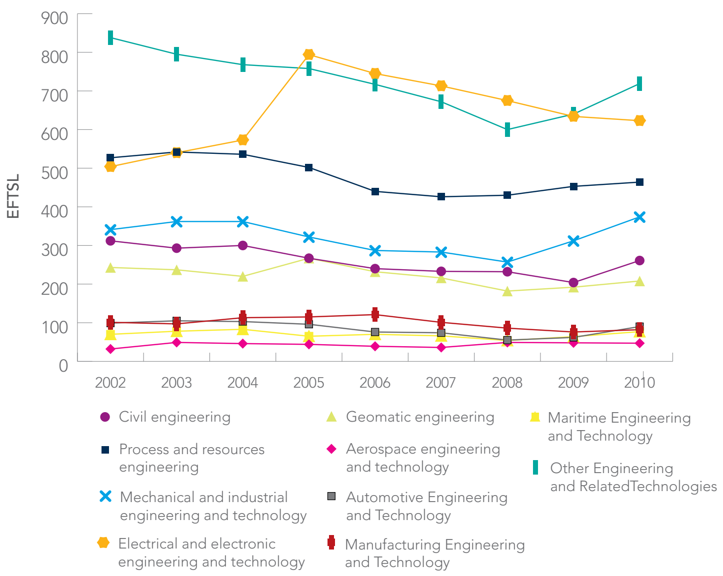


Figure 4.6.13 Teaching in narrow disciplines of Engineering to HDR students.

4.7 AGRICULTURE, ENVIRONMENTAL AND RELATED STUDIES

This section examines enrolments and completions in field of education 05, Agriculture, Environmental and Related Studies. It also provides an analysis of subjects taught in broad discipline group 05, Agriculture, Environmental and Related Studies.

Higher education statistics on enrolments and teaching collected as part of FoE 05 and BDG 05 (referred to here as Agriculture and Environment) are related to disciplines in both agriculture and the environment. In most course levels examined teaching in the narrow disciplines of Agriculture and Environmental Studies accounted for the bulk of the teaching in BDG 05. Trends in teaching at the broad discipline level can therefore mask opposite trends in the teaching of narrow disciplines. Meaningful analysis of teaching in BDG 05 can be performed only by separately considering teaching in agriculture- or environment-specific disciplines.

In brief, the findings are as follows:

- Total undergraduate enrolments in Agriculture and Environment decreased by 11.1 per cent between 2002 and 2010.
- Commencing undergraduate enrolments in Agriculture and Environment declined by 4.1 per cent between 2002 and 2010, while commencing enrolments in higher degrees by research remained steady.
- Completions at the undergraduate course level in Agriculture and Environment declined by 20.4 per cent during the period.
- Male and female students are evenly represented in commencing enrolments at the undergraduate level.
- Total undergraduate teaching in Agriculture and Environment grew by 18.4 per cent during 2002 to 2010.
- The service teaching component of this teaching to undergraduate students nearly doubled.
- In 2010 service teaching in Agriculture and Environment made up for more than 50 per cent of all undergraduate teaching in broad discipline group 05.
- In 2010 undergraduate students in Natural and Physical Sciences received 58 per cent of the service teaching in Agriculture and Environment.
- Teaching in the narrow discipline of Agriculture to commencing and continuing undergraduate students enrolled in Agriculture and Environment declined by 18.3 per cent and 31.1 per cent respectively during 2002 to 2010.
- Teaching in postgraduate (coursework) degrees in Agriculture and Environment is dominated by the narrow discipline Environmental Studies, which accounted for 84 per cent of all teaching at this course level.

4.7.1 Enrolments and completions

The number of commencing undergraduate enrolments in Agriculture and Environment decreased during 2002 to 2010 by 4.1 per cent (see Figure 4.7.1). The details of the trend are: commencing enrolments initially fell by 20.4 per cent from 2002 to 2007; they then recovered by a similar magnitude, growing by 20.5 per cent between 2007 and 2010.

In contrast with the overall decline in commencing undergraduate enrolments, commencing enrolments at postgraduate (coursework) course level increased 22.6 per cent during 2002 to 2010. Commencing enrolments in HDR, on the other hand, remained largely steady, at 340—350, during the period.

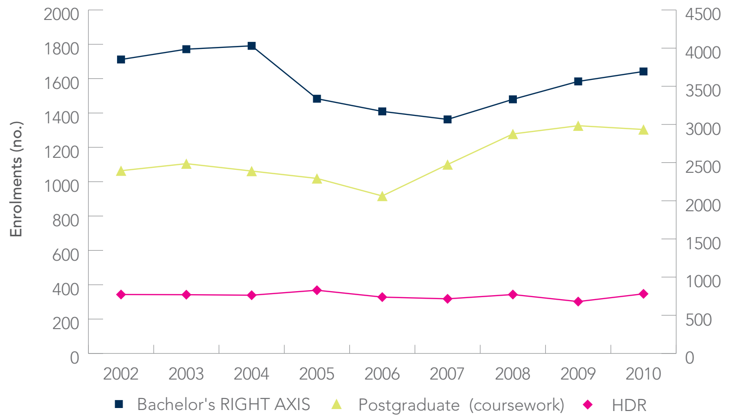


Figure 4.7.1 Domestic commencing enrolments in Agriculture and Environment, by course level

Consistent with the trend in commencing enrolments, completions at the undergraduate course level in Agriculture and Environment decreased by 20.4 per cent (see Figure 4.7.2). Similarly, completions at the bachelor's honours course level declined by 29 per cent during the period. In contrast, postgraduate (coursework) completions increased by 69.3 per cent. Consistent with higher degree by research commencements in Agriculture and Environment, HDR completions remained largely steady between 2002 and 2010.

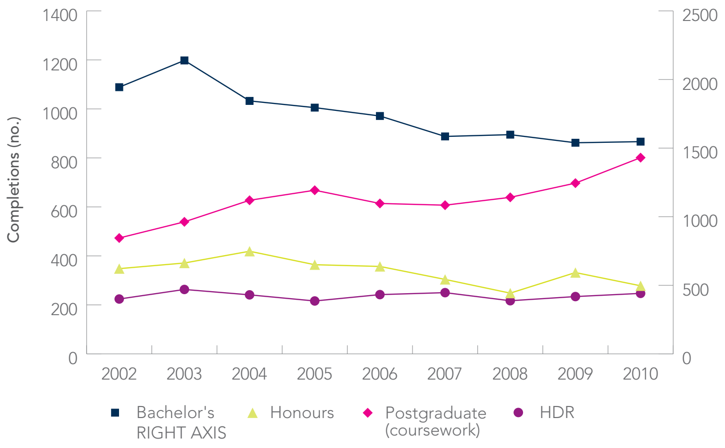


Figure 4.7.2 Domestic course completions in Agriculture and Environment, by course level

Undergraduate completions declined as a proportion of all completions at this course level between 2002 and 2010 (see Figure 4.7.3). In particular, the share of completions at the bachelor's honours course level fell from 4.1 per cent in 2002 to 2.5 per cent in 2010.

Postgraduate (coursework) degrees in Agriculture and Environment increased their relative share of completions between 2002 and 2010 (1.2 per cent to 1.4 per cent) and the share of HDR completions remained static, at 4.5 per cent.

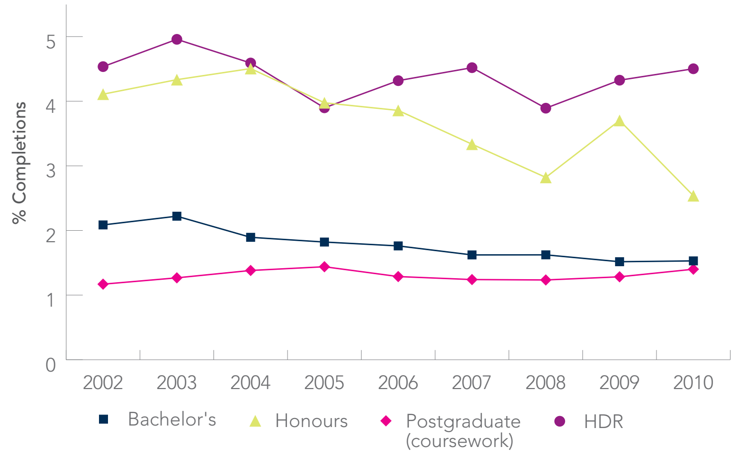


Figure 4.7.3 Domestic course completions in Agriculture and Environment, by course level, as a proportion of completions in all FoEs

Enrolments by commencing status and gender

Total undergraduate enrolments in Agriculture and Environment decreased 11.1 per cent during 2002 to 2010 (see Figure 4.7.4). This is underpinned by a greater decline in continuing students (14.5 per cent) than in commencing students (4.1 per cent). Along with the 20.4 per cent decline in undergraduate completions, this suggests considerable attrition among continuing undergraduate students in Agriculture and Environment.

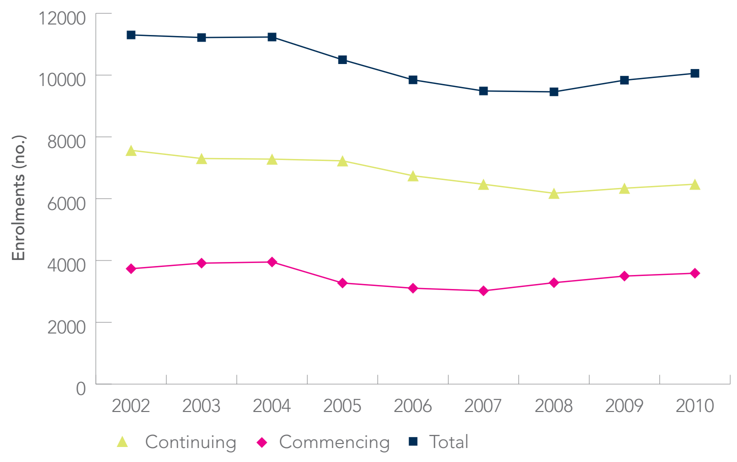


Figure 4.7.4 Domestic undergraduate enrolments in Agriculture and Environment, by student status

Analysis of the gender composition of commencing enrolments in Agriculture and Environment shows that male and female students are evenly represented (see Figure 4.7.5). This contrasts with the gender imbalance noted for IT and Engineering.

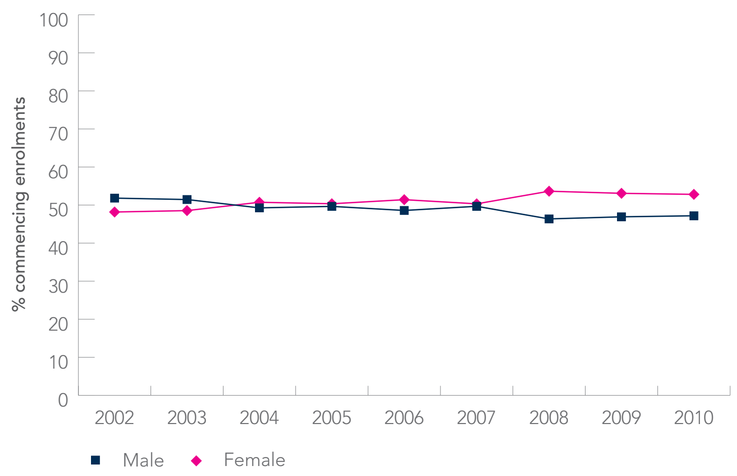


Figure 4.7.5 Domestic commencing undergraduate enrolments in Agriculture and Environment, by gender

Unlike undergraduate enrolments, total postgraduate (coursework) enrolments grew by 48.9 per cent during 2002 to 2010 (see Figure 4.7.6).

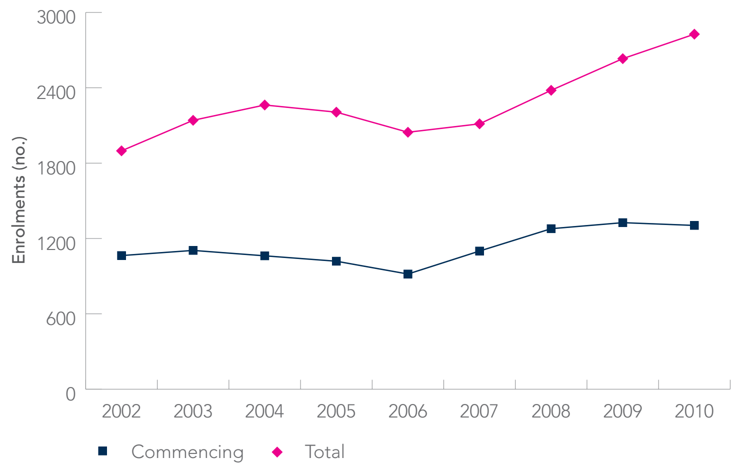


Figure 4.7.6 Postgraduate (coursework) enrolments in Agriculture and Environment

In comparison, growth in total HDR enrolments was relatively modest, at 10.6 per cent, and commencing HDR enrolments remained static during the period (see Figure 4.7.7).

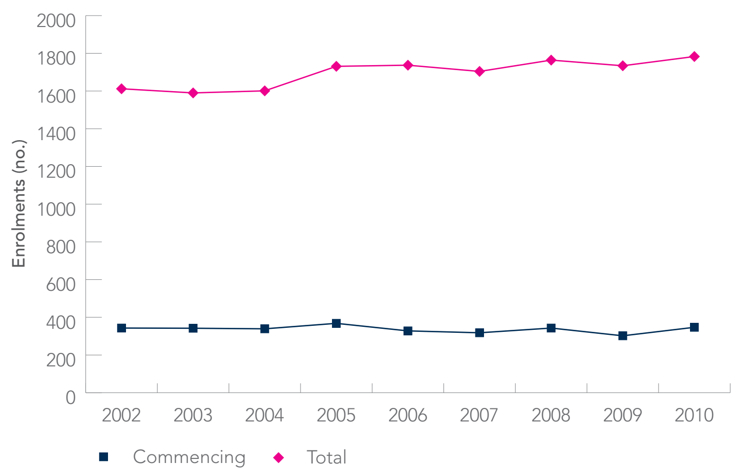


Figure 4.7.7 HDR enrolments in Agriculture and Environment

4.7.2 Teaching in broad discipline group 05, Agriculture, Environmental and Related Studies

The subjects taught in broad discipline group 05, Agriculture, Environmental and Related Studies, are analysed here in order to cast light on what students study as part of their course. The analysis of student load is performed at the broad (two-digit) and narrow (four-digit) discipline levels for selected course levels.

Teaching of subjects in Agriculture and Environment disciplines to all domestic undergraduate students

Total undergraduate teaching in Agriculture and Environment to all fields of education increased 18.4 per cent during 2002 to 2010 (see Figure 4.7.8). This growth is largely the result of an increase in teaching to commencing undergraduate students, which increased by 52.4 per cent during the period. In contrast, teaching to continuing students remained relatively stable, with growth of only 5.7 per cent.

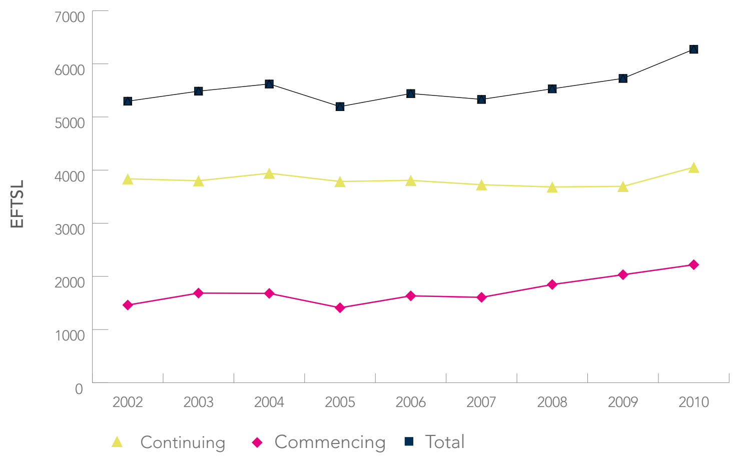


Figure 4.7.8 Teaching of Agriculture and Environment to domestic undergraduate students in all fields of education

Teaching Agriculture and Environment to non-Agriculture and Environment undergraduates

The teaching of students in other FoEs—that is, service teaching—nearly doubled, from 2002 to 2010 (see Figure 4.7.9a). In 2010 service teaching in Agriculture and Environment accounted for more than 50 per cent of all undergraduate teaching in Agriculture and Environment (see Figure 4.7.9b).

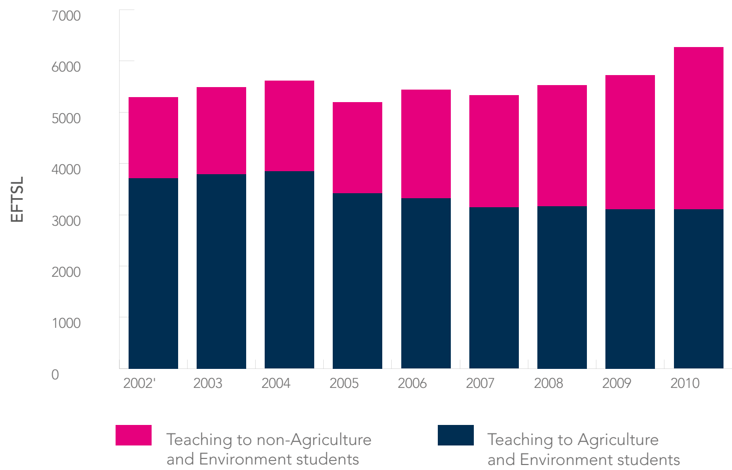


Figure 4.7.9a Teaching of Agriculture and Environment to undergraduate students in other fields of education: EFTSL

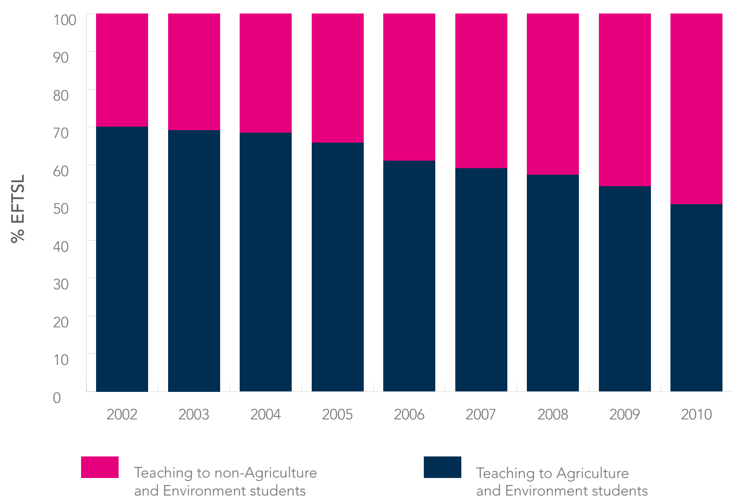


Figure 4.7.9b Teaching of Agriculture and Environment to undergraduate students in other fields of education: proportion of EFTSL

Teaching of Agriculture and Environment disciplines to Agriculture and Environment undergraduates

While teaching in Agriculture and Environment delivered to undergraduates in all fields of education increased, teaching delivered to Agriculture and Environment undergraduate students decreased by 16.4 per cent during 2002 to 2010 (see Figure 4.7.10). This fall was underpinned by a 24.8 per cent decrease in teaching to continuing students during the period.

On the other hand, teaching of commencing students showed modest growth of 7.4 per cent, from 26.2 per cent of total load in 2002 to 33.7 per cent of total load in 2010 (see Figure 4.7.10; right axis).

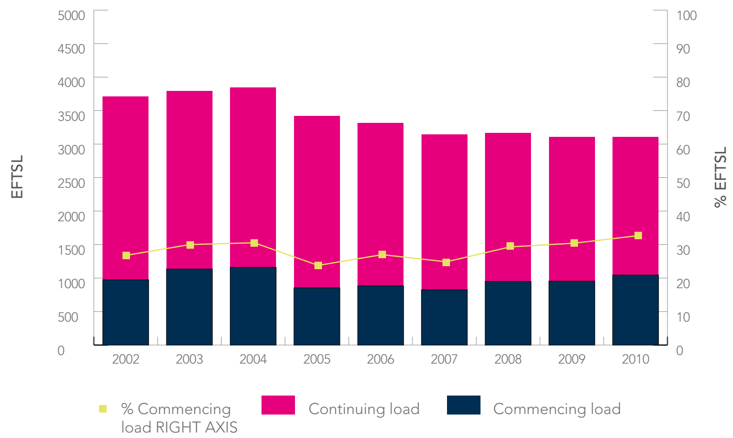


Figure 4.7.10 Teaching of Agriculture and Environment to undergraduate students in Agriculture and Environment

Service teaching in broad discipline group 05, Agriculture and Environment

Between 2002 and 2010 undergraduate students in Natural and Physical Sciences and Society and Culture received most of the service teaching provided by Agriculture and Environment (see Figure 4.7.11). The amount received by students in Natural and Physical Sciences increased by 78.4 per cent, and that received by students in Society and Culture increased by 144.6 per cent during the period.

In 2010 undergraduate students in Natural and Physical Sciences received 58 per cent of all the service teaching provided by Agriculture and Environment. Undergraduates in Society and Culture were the second-largest group of recipients of this service teaching, receiving 21 per cent.

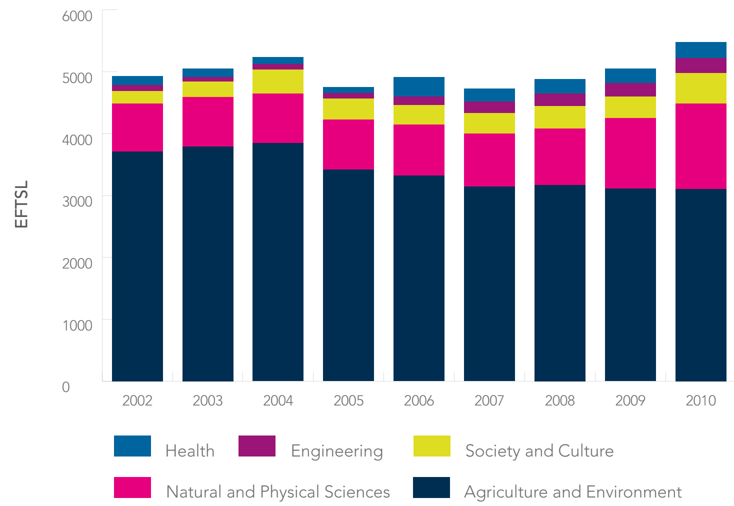


Figure 4.7.11 Distribution of Agriculture and Environment service teaching, by field of education

4.7.3 Teaching of Agriculture and Environment to students enrolled in Agriculture and Environment: narrow disciplines

A deeper examination of student load allows the determination of what Agriculture and Environment narrow disciplines are being taken by and taught to domestic Agriculture and Environment students. This is done by analysing student load at the four-digit level for Agriculture and Environment students enrolled in selected course levels.

Undergraduate: bachelor's pass and graduate entry

Teaching in the narrow discipline of Agriculture to commencing undergraduate students decreased by 18.3 per cent between 2002 and 2010 (see Figure 4.7.12a). In contrast, teaching in Environmental Studies increased by 88.9 per cent, during this period. This level of growth resulted in Environmental Studies surpassing Agriculture as the most commonly taught narrow discipline within broad discipline group 05 in 2009 and 2010.

In 2010 the narrow disciplines of Agriculture and Environmental Studies accounted for almost 90 per cent of all teaching to commencing undergraduate students in Agriculture and Environment (see Figure 4.7.12b). The relative share of teaching in these two narrow disciplines remained largely stable between 2008 and 2010.

Teaching in the other narrow disciplines either declined or remained steady during 2002 to 2010. Teaching in the generic narrow discipline Other Agriculture, Environmental and Related Studies accounted for about 100 EFTSL a year in the same period. Teaching in Horticulture and Viticulture, Forestry Studies and Fisheries Studies each accounted for less than 100 EFTSL a year.

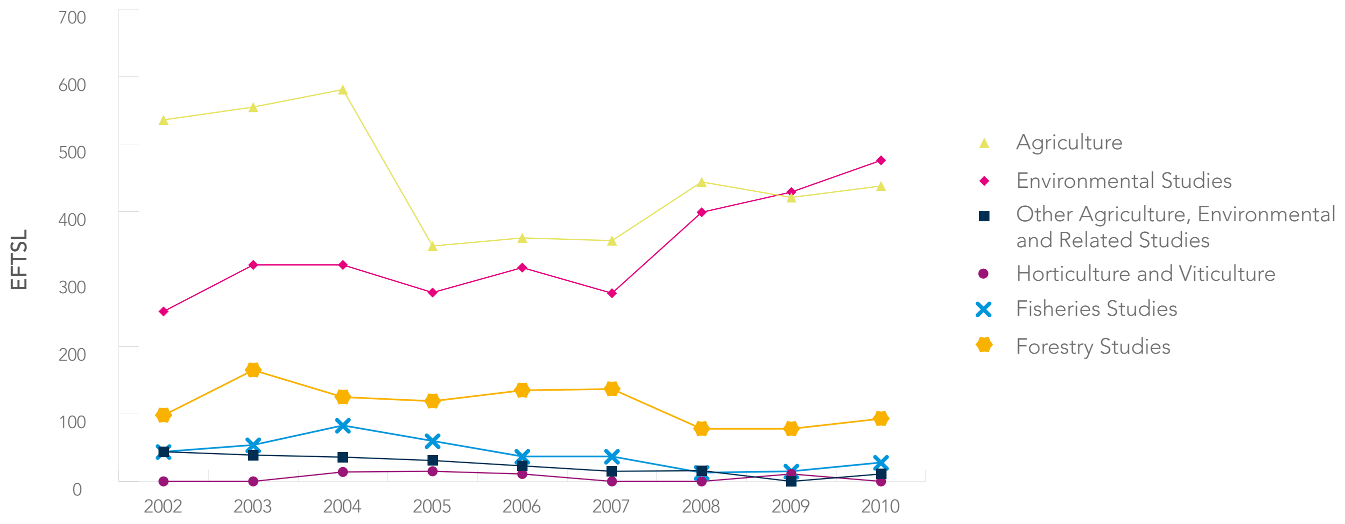


Figure 4.7.12a Teaching in Agriculture and Environment narrow disciplines to commencing undergraduate students: EFTSL

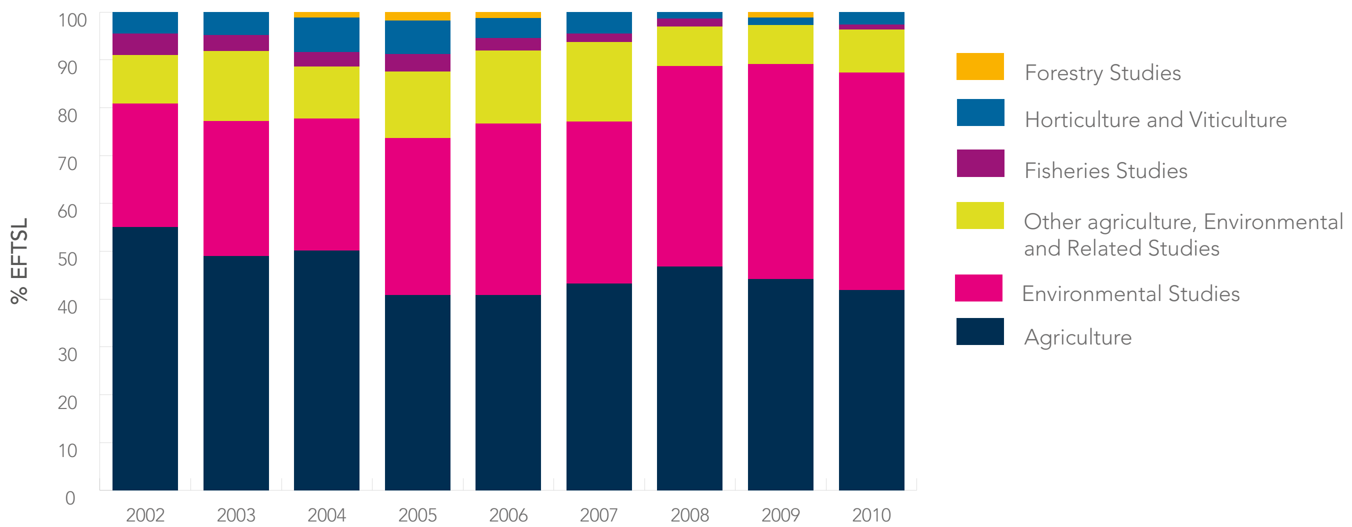


Figure 4.7.12b Teaching in Agriculture and Environment narrow disciplines to commencing undergraduate students: proportion of EFTSL

As with the teaching of commencing undergraduates, the teaching of Agriculture to undergraduates continuing in Agriculture and Environment decreased by 31.1 per cent during 2002 to 2010 (see Figure 4.7.13a). Teaching of Environmental Studies to continuing students, however, remained steady, at about 900 EFTSL.

Again as with commencing students, teaching in the narrow disciplines of Agriculture and Environmental Studies dominated teaching to continuing students, accounting for 81.9 per cent of teaching in all Agriculture and Environment narrow disciplines in 2010 (see Figure 4.7.13b). Teaching in the other narrow disciplines showed an overall downward trend between 2002 and 2010.

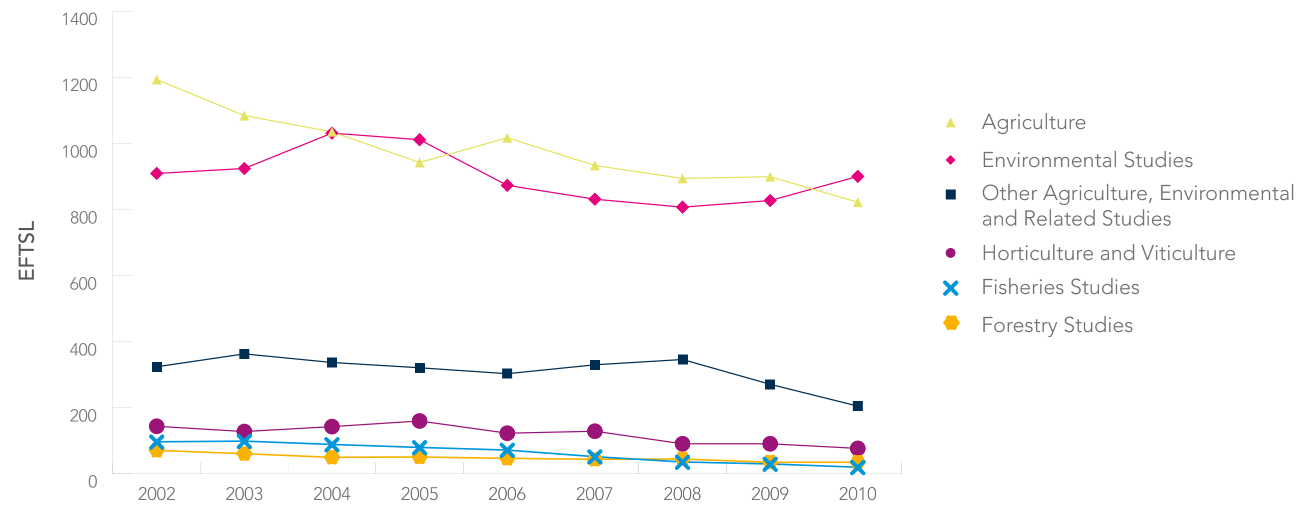


Figure 4.7.13a Teaching in Agriculture and Environment narrow disciplines to continuing undergraduate students: EFTSL

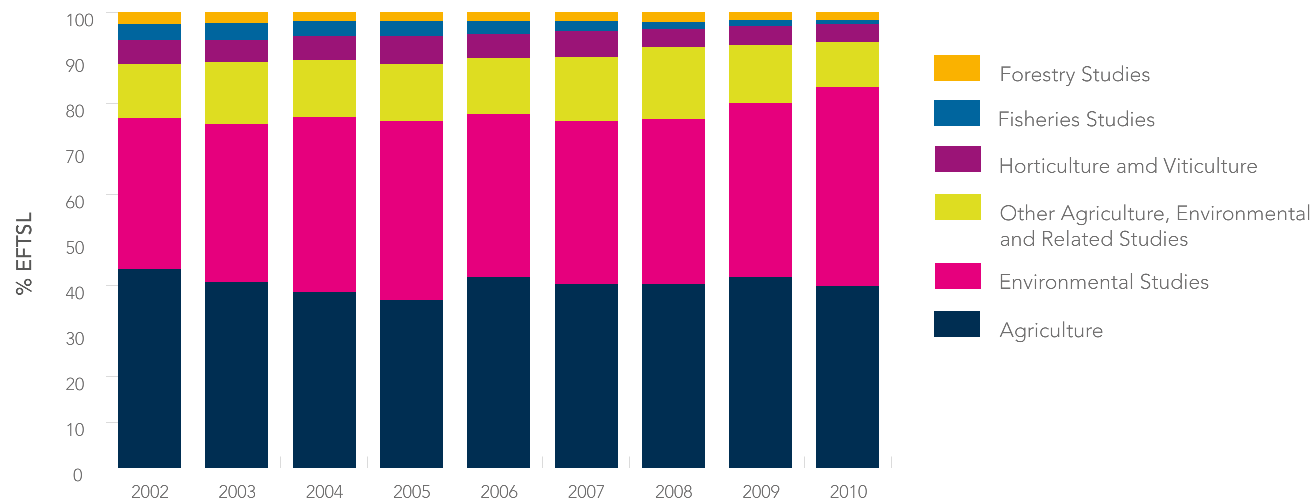


Figure 4.7.13b Teaching in Agriculture and Environment narrow disciplines to continuing undergraduate students: proportion of EFTSL

Postgraduate (coursework) in Agriculture and Environment

Teaching of Environmental Studies to postgraduate (coursework) students in Agriculture and Environment experienced considerable growth, 151.9 per cent, during 2002 to 2010 (see Figure 4.7.14). This growth was, however, from a low base. In 2010 Environmental Studies was the dominant narrow discipline, accounting for 84 per cent of teaching in broad discipline group 05 at the postgraduate (coursework) course level.

The other narrow disciplines individually accounted for a teaching load of below 50 EFTSL between 2002 and 2010. The contributions of these narrow disciplines are likely to be understated because EFTSL below 10 is counted as zero for the purposes of this analysis.

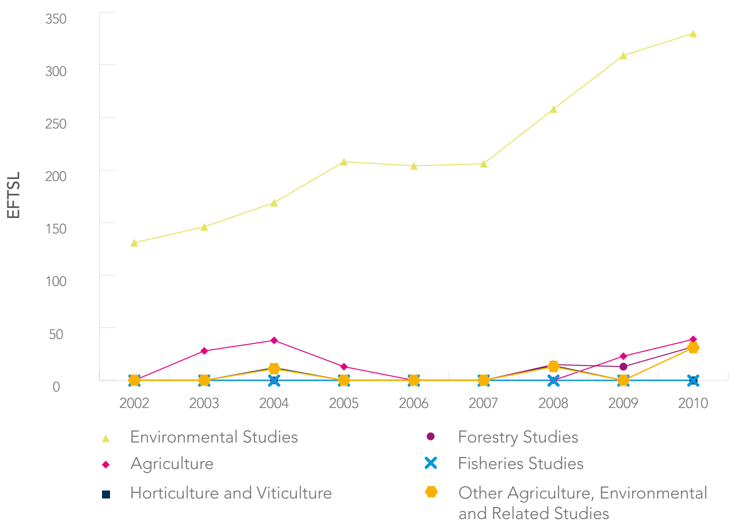


Figure 4.7.14 Teaching in Agriculture and Environment narrow disciplines at the postgraduate (coursework) course level

Higher degree by research in Agriculture and Environment

In the case of HDR teaching load, growth is apparent in the two major narrow disciplines in Agriculture and Environment during 2002 to 2010 (see Figure 4.7.15). Although Agriculture remained the most common narrow discipline at the HDR level, there was considerable growth in Environmental Studies. Student load for Agriculture increased 8.8 per cent during 2002 to 2010. Growth in Environmental Studies, however, was 44.1 per cent.

The other narrow disciplines individually accounted for a teaching load of below 50 EFTSL for most of the period. The contributions of these narrow disciplines are likely to be understated because, as noted, EFTSL below 10 is counted as zero for the purposes of this analysis.

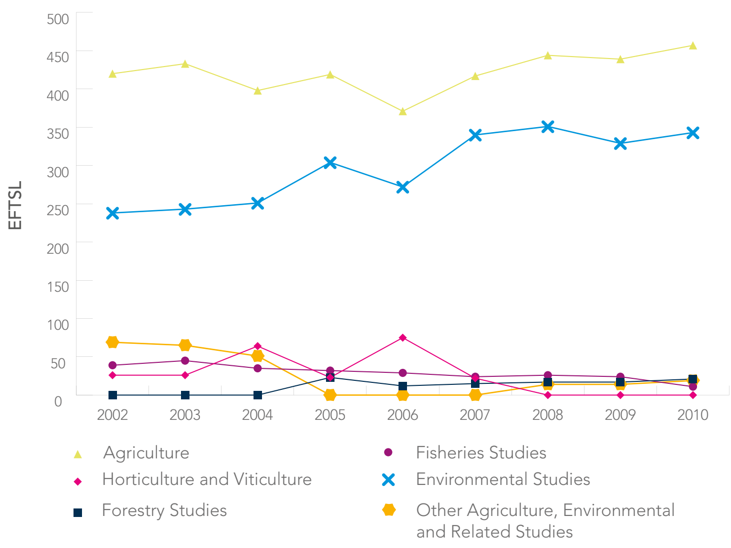


Figure 4.7.15 Teaching in the narrow disciplines of Agriculture and Environment to HDR students

4.8 HEALTH

This section examines enrolments and completions in field of education 06, Health. It also provides an analysis of subjects taught in broad discipline group 06, Health.

The Health FoE covers a broad range of disciplines, from Medical Studies and Nursing to Complementary Therapies. Students who complete their studies in Health can move into a number health professions, among them general practice, dentistry, pharmacy and nursing.

Health experienced considerable expansion between 2002 and 2010. This is reflected throughout the various Health-related Higher Education Statistics analysed as part of this section. As a result, a general increasing trend is seen in enrolments, completions and teaching in all course levels examined. In particular, considerable growth is evident in the teaching of Nursing at the undergraduate and postgraduate (coursework) levels.

In brief, the findings are as follows:

- Commencing enrolments in bachelor's degrees in Health increased by more than 70 per cent between 2002 and 2010.
- Commencing enrolments in postgraduate (coursework) degrees in Health also increased by more than 70 per cent.
- Commencing higher degree by research enrolments grew by 20.7 per cent.
- In contrast with IT and Engineering, female students accounted for almost 80 per cent of all commencing undergraduate enrolments in Health between 2002 and 2010.
- Nursing was the largest narrow discipline taught to commencing undergraduate students enrolled in Health from 2002 to 2010.
- Teaching of Nursing to undergraduate students in Health nearly doubled during this time.
- In 2009 more than of half the teaching in each Health narrow discipline was provided to female undergraduate students enrolled in Health. The proportions of teaching in Health narrow disciplines to female students ranged from 56 per cent for Medical Studies to 89 per cent for Nursing.
- Teaching in the narrow discipline of Nursing at the postgraduate (coursework) level almost quadrupled between 2002 and 2010.
- Unlike teaching of undergraduate and postgraduate (coursework) students, teaching of Health disciplines to higher degree by research students in Health was dominated by the narrow discipline of Medical Studies, which accounted for about 50 per cent of all load to HDR students during 2002 to 2010.

4.8.1 Enrolments and completions

The number of commencing undergraduate enrolments in Health increased by 74 per cent over the period 2002 to 2010 (see Figure 4.8.1). Commencing enrolments in the postgraduate (coursework) course level also grew, by 73.1 per cent. Commencing HDR enrolments, however, experienced relatively modest growth of 20.7 per cent.

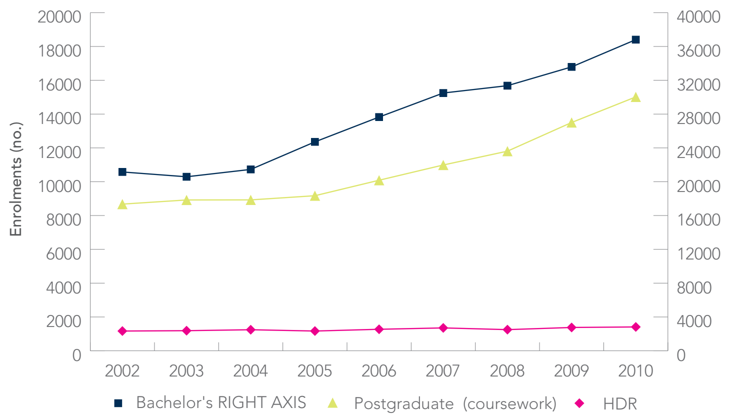


Figure 4.8.1 Commencing enrolments in Health, by course level

Consistent with the growth in enrolments, completions increased for undergraduate and postgraduate (coursework) course levels in Health between 2002 and 2010. Completions at the undergraduate course level increased by 41.5 per cent (see Figure 4.8.2a). At the postgraduate (coursework) course level they increased by 79 per cent during the period.

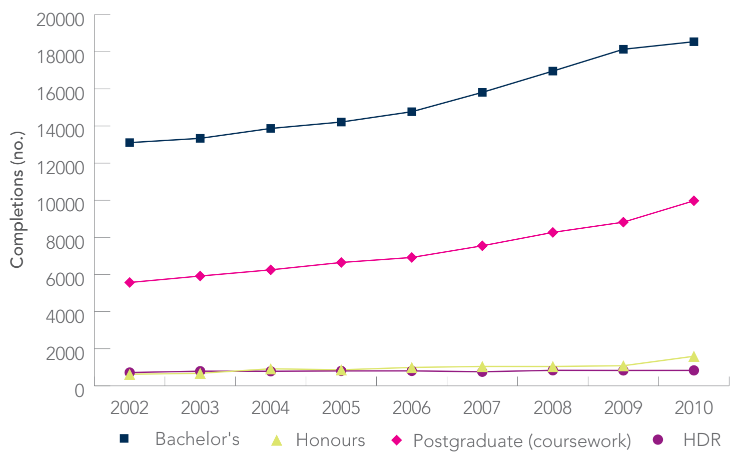


Figure 4.8.2a Course completions in Health, by course level

Completions at the bachelor's honours course level increased by 74 per cent, but from a relatively low base (see Figure 4.8.2b). Honours completions in 2010 are excluded from this analysis because the increase in such completions in 2010 is not representative of the higher education sector but is instead confined to one institution. For an analysis and discussion of the increase in honours completions in 2010, see Section 4.3.2.

In comparison with completions in other course levels, HDR completions showed only modest growth of 16.2 per cent between 2002 and 2010.

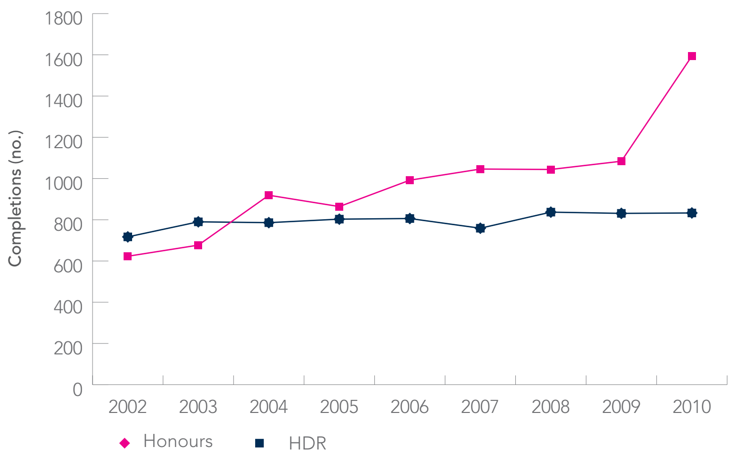


Figure 4.8.2b Course completions in Health: honours and HDR

Completions at each Health course level (other than HDR) as a proportion of completions at that course level in all fields of education, increased between 2002 and 2010.

In 2010 completions across all course levels in Health accounted for 15 to 20 per cent of completions across all fields of education (see Figure 4.8.3). The share of HDR completions in Health remained relatively stable, at about 15 per cent, between 2002 and 2010; the share of honours completions increased from 7.4 per cent to 12.1 per cent.

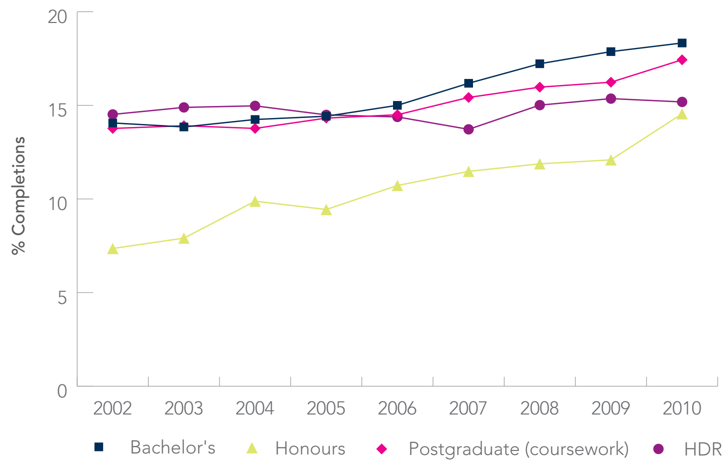


Figure 4.8.3 Course completions in Health as a proportion of all completions

Enrolments by commencing status and gender

Total undergraduate enrolments in Health increased by 64.5 per cent from 2002 to 2010 (see Figure 4.8.4). The growth in enrolment numbers for undergraduates in Health is underpinned by comparable levels of growth in both commencing (74 per cent) and continuing undergraduate (61 per cent) students.

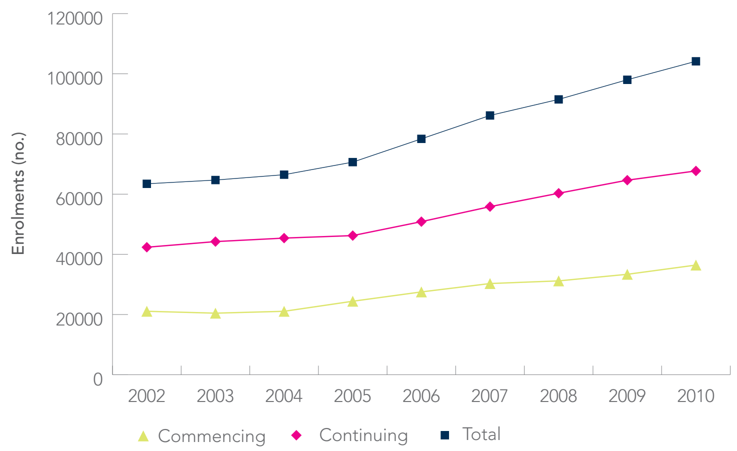


Figure 4.8.4 Undergraduate enrolments in Health, by student status

Female students were overrepresented in Health undergraduate enrolments, accounting for 70 to 80 per cent of commencing students during 2002 to 2010 (see Figure 4.8.5). The overrepresentation of female students in Health can also be seen by examining the gender distribution of teaching in all narrow disciplines of Health (see Table 4.8.1).

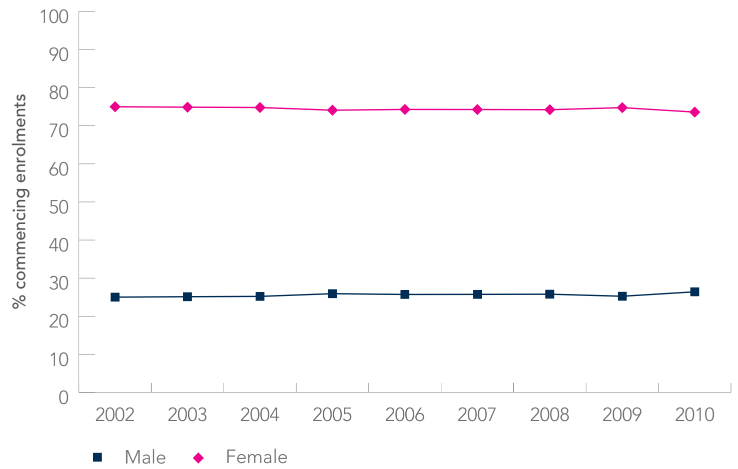


Figure 4.8.5 Undergraduate enrolments in Health, by gender

Total postgraduate (coursework) enrolments in Health increased by 77.7 per cent during 2002 to 2010 (see Figure 4.8.6). This growth is underpinned by 73.1 per cent growth in commencing student enrolments.

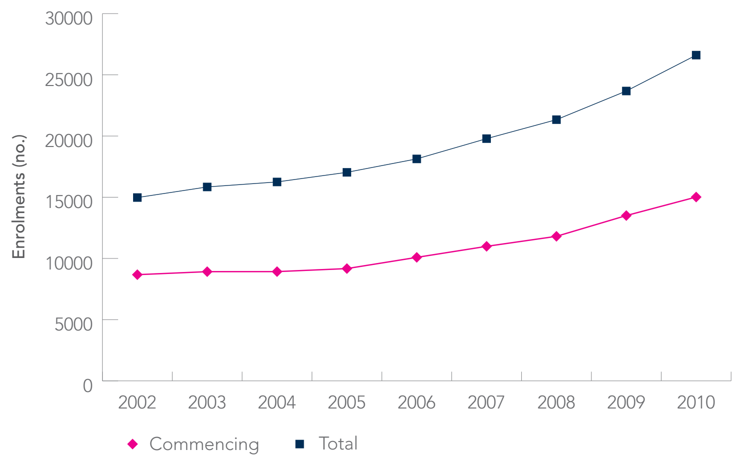


Figure 4.8.6 Postgraduate (coursework) enrolments in Health

Total HDR enrolments in Health increased by 22.5 per cent from 2002 to 2010 (see Figure 4.8.7). This increase is relatively modest compared with the growth seen in enrolments for other course levels. Total enrolments in both undergraduate and postgraduate (coursework) course levels increased by more than 50 per cent.

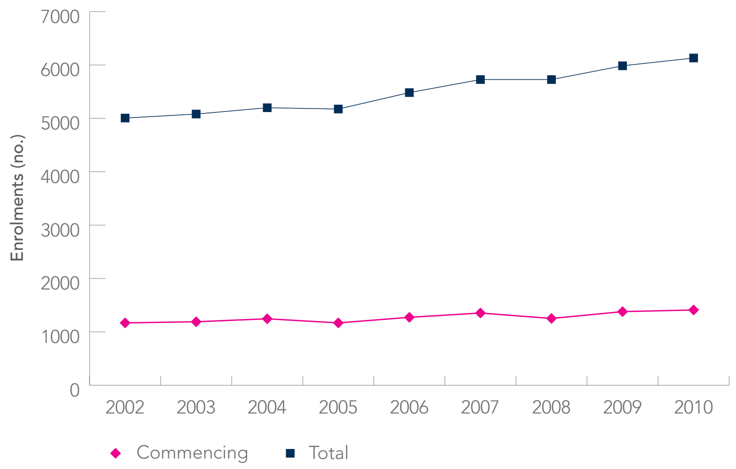


Figure 4.8.7 HDR enrolments in Health

4.8.2 Teaching in broad discipline group 06, Health

The subjects taught in broad discipline group 06, Health, are analysed here in order to cast light on what students study as part of their course. The analysis of student load in Health is performed at the broad (two-digit) and narrow (four-digit) discipline levels for selected course levels.

Teaching of subjects in Health disciplines to all domestic undergraduate students

Total undergraduate teaching in Health to students in all fields of education increased by 72.1 per cent during 2002 to 2010 (see Figure 4.8.8). This growth is underpinned by growth in teaching of commencing students, up by 91.3 per cent, and of continuing students, up by 65.1 per cent.

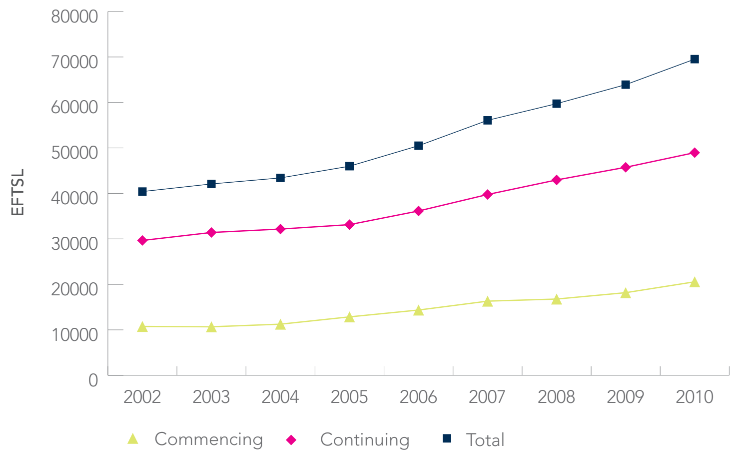


Figure 4.8.8 Teaching of Health to undergraduate students in all fields of education

Teaching of Health disciplines to Health undergraduates

In 2010 almost 96 per cent of total Health teaching provided to all domestic undergraduates was delivered to Health students (see Figure 4.8.9). Between 2002 and 2010 teaching of Health to undergraduates in Health increased by 76 per cent. During this period commencing Health students received about 30 per cent of Health teaching; continuing students received the remainder (see Figure 4.8.9; right axis).

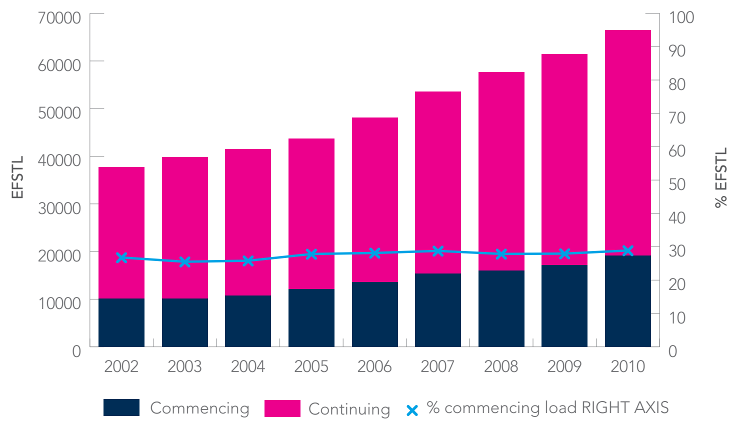


Figure 4.8.9 Teaching of Health to domestic undergraduate Health students

Service teaching in broad discipline group 06, Health

Between 2002 and 2010 an average of 4.7 per cent of all teaching in Health was delivered to undergraduate students enrolled in non-Health fields of education. Health is thus not a major service teaching discipline. In 2010 almost all the service teaching (97.6 per cent) in Health was received by undergraduate students in Natural and Physical Sciences, 55.1 per cent, and Society and Culture, 42.5 per cent.

4.8.3 Health teaching to students enrolled in Health: narrow disciplines

A deeper examination of student load allows the determination of what Health narrow disciplines are being taken by and taught to domestic Health students. This is done by analysing student load at the four-digit level for Health students enrolled at selected course levels.

Undergraduate: bachelor's pass and graduate entry

Teaching in the narrow discipline of Nursing accounted for the largest student load to commencing undergraduate students enrolled in Health between 2002 and 2010 (see Figure 4.8.10). Teaching in Nursing increased by 82.6 per cent during 2002 to 2010. In 2010 the Nursing load constituted 45.5 per cent of all teaching to commencing undergraduate students in the broad discipline group Health.

Medical Studies was the next-largest narrow discipline taught in 2010, accounting for 14.3 per cent of teaching in all Health. Teaching in Medical Studies more than doubled between 2002 and 2010.

Teaching in the next three largest narrow disciplines in Health also experienced growth. Other Health increased by 110.5 per cent; Public Health increased by 93.4 per cent. Teaching in Rehabilitation Therapies grew relatively less, by 43.9 per cent..

Teaching in five of the other six narrow disciplines also grew, accounting for between 300 and 500 EFTSL. Only teaching in Optical Science did not increase, remaining constant at less than 50 EFTSL between 2002 and 2010.

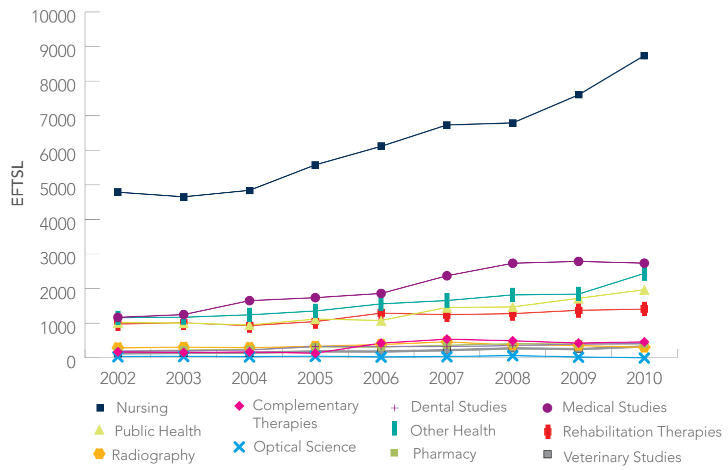


Figure 4.8.10 Teaching of Health narrow disciplines to commencing undergraduate students in Health

Consistent with the growth in teaching to commencing students, growth is also evident in the teaching of Nursing and Medical Studies to continuing undergraduate students. Teaching to the former increased by 59.5 per cent between 2002 and 2010 (see Figure 4.8.11). Teaching of Medical Studies increased much more, by 121.6 per cent, during the period.

Rehabilitation Therapies was the third most commonly taught narrow discipline for continuing students but showed only a relatively modest increase of 13.4 per cent from 2002 to 2010.

Other Health was the fourth most commonly taught narrow discipline. Teaching in this narrow discipline more than doubled. With the exception of Optical Science, teaching in all the other remaining narrow disciplines increased, accounting for between 1000 and 2000 EFTSL during the period. Teaching in Optical Science grew only slightly, by five per cent.

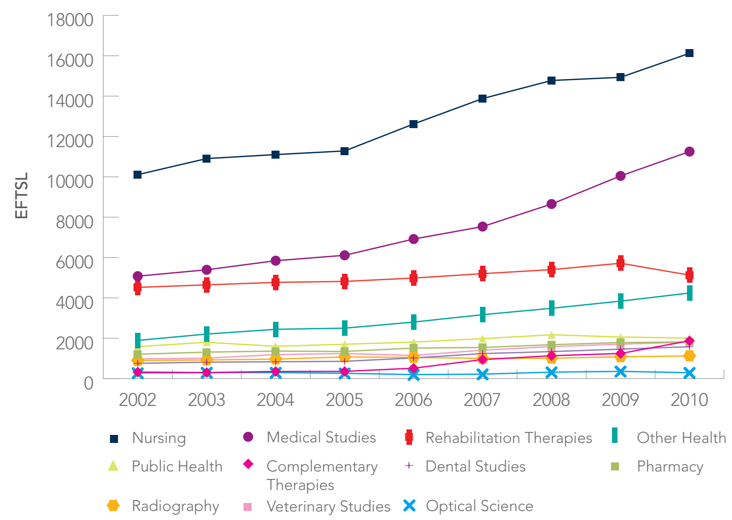


Figure 4.8.11 Teaching of Health narrow disciplines to continuing undergraduate students in Health

Teaching of Health narrow disciplines to female students

The overrepresentation of female students in commencing undergraduate enrolments in Health is detailed in Section 4.8.1. This overrepresentation can also be depicted through an analysis of the teaching in Health narrow disciplines received by female students (see Table 4.8.1). In 2009 more than of half of the teaching in each Health narrow discipline was delivered to female undergraduates. The proportions of teaching in Health narrow disciplines delivered to female students ranged from 56 per cent for Medical Studies to 89 per cent for Nursing.

Table 4.8.1 Teaching of Health narrow disciplines to female undergraduate students enrolled in Health, 2009.

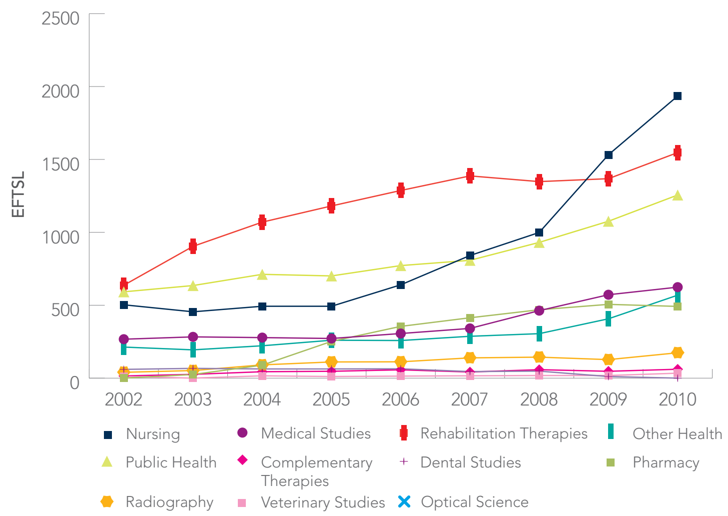
Health narrow discipline	Proportion of teaching load (%)
Medical Studies	56
Nursing	89
Pharmacy	64
Dental Studies	61
Optical Science	66
Veterinary Studies	77
Public Health	76
Radiography	66
Rehabilitation Therapies	77
Complementary Therapies	78
Other Health	64

Postgraduate (coursework) in Health

There was considerable growth in the teaching of Nursing, Rehabilitation Therapies and Public Health at the postgraduate (coursework) level between 2002 and 2010 (see Figure 4.8.12). These were the three most commonly taught narrow disciplines: they accounted for about 70 per cent of all teaching at this course level in 2010.

Teaching in Nursing almost quadrupled over the period 2002 to 2010. Teaching in Rehabilitation Therapies increased by 142.9 per cent; teaching in Public Health increased by 112.2 per cent.

The next three most commonly taught narrow disciplines were Medical Studies, Other Health and Pharmacy, all of which increased from low bases during the period.



Note: The narrow discipline of Optical Science is not shown due to low numbers (EFTSL less than 10) for most of the time series.

Figure 4.8.12 Teaching of Health narrow disciplines to postgraduate (coursework) students in Health

Higher degree by research in Health

In contrast with the considerable growth in student load at the postgraduate (coursework) level in Health, the student load to HDR students at the narrow discipline level either experienced relatively modest growth or remained largely static (see Figure 4.8.13).

Total student load to all HDR students in Health is dominated by the narrow discipline of Medical Studies, which accounted for about 50 per cent of all load to HDR students between 2002 and 2010. The Medical Studies load increased by 13.5 per cent during the period.

Public Health is the next largest narrow discipline, accounting for about 15 per cent of load in all Health narrow disciplines in 2002 to 2010. Teaching of Public Health increased by 27.1 per cent during the period.

Following Public Health were the narrow disciplines of Nursing, Other Health and Rehabilitation Therapies, which collectively accounted for about 26 per cent of HDR student load in 2010.

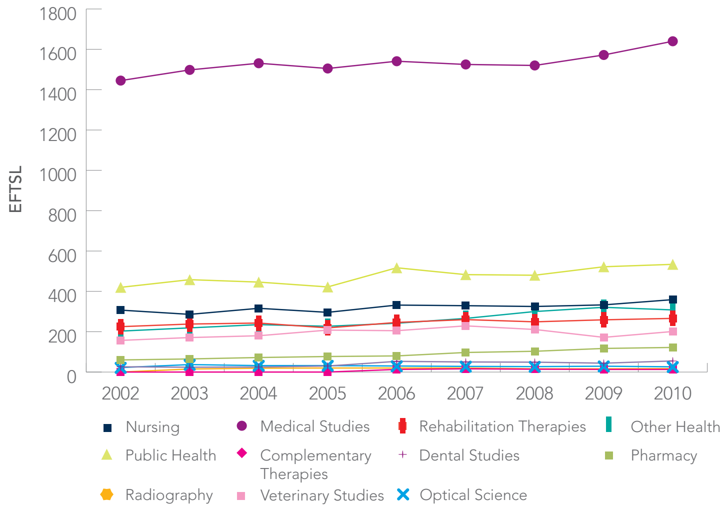


Figure 4.8.13 Teaching of Health narrow disciplines to HDR students in Health

4.9 The main findings from companion reports: a summary

This section summarises the main findings from the companion publications to the Health of Australian Science report—*Unhealthy Science? University Natural and Physical Sciences to 2009–10* (Dobson 2012) *and STEM and Non-STEM First-Year Students* (Universities Australia 2012).

4.9.1 The role of international students

Australia's Chief Scientist commissioned Ian Dobson, from the University of Helsinki and Monash University, to carry out a system-wide analysis of enrolments in the Natural and Physical Sciences. A summary of the primary findings relating to international students is presented here. These complement and extend findings described earlier in this chapter. Detailed information about Dobson's analysis of science enrolments can be found in *Unhealthy Science?*

Dobson's analysis of enrolments at all course levels highlights the importance of international students in the Australian higher education system. One of the main determinants of the trends evident in higher education enrolments from 2002 to 2010 was the increasing number of enrolments by international students: numbers increased by 150 215, or 81.2 per cent. In comparison, domestic enrolments (all course levels) increased by a similar magnitude in absolute terms (145 821) but by a much lower level of growth, at 20.5 per cent. The growth in Management and Commerce as a field of education, in particular, was strong: the number of international student enrolments in this field of education (all course levels) increased from 81 602 in 2002 to 165 807 in 2010—an increase of 103.2 per cent.

International students have also had a considerable impact on other fields of education. International student enrolments in Engineering increased by 81.8 per cent between 2002 and 2010, from 13 588 to 24 709. Although the number of international enrolments in Information Technology declined by 14 per cent during the period, IT's share of international student enrolments was 55.8 per cent in 2009.

There were considerable increases in enrolments by international students in Natural and Physical Sciences, both at the undergraduate and at the PhD levels. The number of international students enrolling at the undergraduate level in science increased from 4538 in 2002 to 8481 in 2009, or by 86.9 per cent. Enrolments at the PhD level increased from a low base of 945 to 2479, or by 162.3 per cent, during the period.

4.9.2 Students' attitudes to studying Science, Technology, Engineering and Mathematics at university

The Chief Scientist commissioned Universities Australia to conduct a survey of first-year undergraduate students in order to determine their attitudes in relation to Science, Technology, Engineering and Mathematics, or STEM. There were two samples—STEM students (enrolled in a STEM course) and non-STEM students (enrolled in another university course). More information about this survey can be obtained from STEM and Non-STEM First-Year Students (Universities Australia 2012). The survey findings are subject to two particular limitations:

- a low response rate of 12 per cent, with a final usable sample size of 1552, made up of 701 STEM students and 851 non-STEM students from 13 participating universities
- gender and age differences between STEM and non-STEM respondents.

In summary, a number of common underlying factors influenced the study choices of both STEM and non-STEM students. First, career aspirations were identified as the strongest influence on both STEM and non-STEM students when choosing a university course. Second, both STEM and non-STEM students commented that the enthusiasm and encouragement of secondary school teachers were of crucial importance to their choice of course. Third, for both samples the choice of Year 12 subjects was overwhelmingly determined by interest in specific subjects.

CHAPTER 5

5. PUBLICLY FUNDED RESEARCH

Australian research is funded through a range of government sources in varying portfolios and programs as well as through industry and private sources.

This chapter mainly looks at trends and patterns in funding from the competitive grant schemes administered by the Australian Research Council, the National Health and Medical Research Council and the Cooperative Research Centres program. Together these schemes support much of the basic research done in Australia. Funding under these mechanisms accounted for 47 per cent of all research income during 2006 through 2008 reported through the Excellence in Research for Australia audit (ARC 2011a).

These are, however, not the only sources of funding for scientific research in Australia (see, for example, DIISR 2011; Harris & Meyer 2011). Such funding also occurs through Commonwealth budget appropriations to portfolio research agencies such as CSIRO and Geoscience Australia, which are also discussed briefly here. Funding schemes such as the Education Investment Fund and the National Collaborative Research Infrastructure Strategy also provide support for research and have been particularly important for fields such as marine science, terrestrial ecology and astronomy.

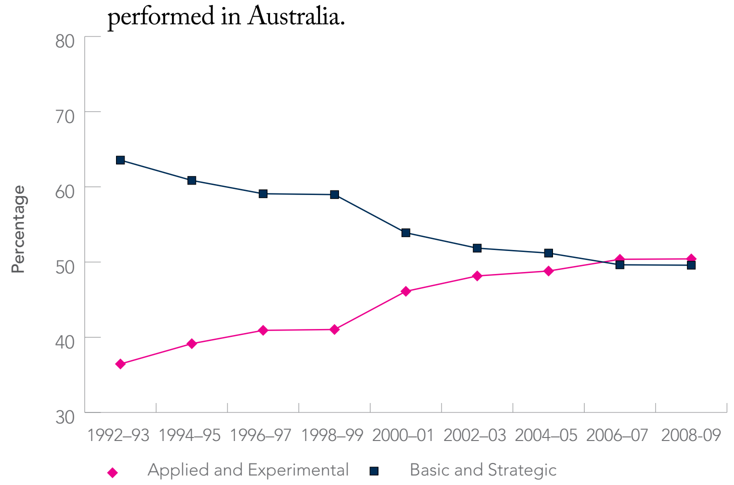
5.1 Main findings

- The past decade has seen growth in science support through competitive grant schemes administered by the Australian Research Council and the National Health and Medical Research Council.
- Fields such as Biology, Chemistry, Agricultural and Veterinary Sciences, Earth Sciences, Engineering, and Mathematics increased support through the ARC over the 2002 through 2010 period.
- Biological Sciences and Medical and Health Sciences saw growth in support from ARC and NHMRC, as measured by number of projects and funding, over 2001 through 2010.
- Funding growth has been accompanied by increasing competition for grants in the past decade.
- Success rates (the proportion of successful grant applications) fell between 2001 and 2008 in ARC schemes.
- Funding rates (funding granted compared with funding requested) for successful proposals fell between 2001 and 2008 in ARC schemes.
- Success rates for early career researchers (ECR) followed the general downward trend among ARC schemes. The number of ECR-only proposals dropped from 2001 to 2008.

5.2 General funding trends

Basic research adds to the bank of intellectual capital on which society draws in order to progress and transform. Applied research develops this intellectual capital into new technologies and innovative processes that directly improve the health, productivity and prosperity of Australia. In a broad sense, basic research includes strategic research, and applied research includes experimental research. The mix of research expenditure throughout the economy is currently about 20 per cent basic research and about 80 per cent applied research (see Section 2.5). The Commonwealth holds the largest stake in expenditure on basic research, controlling 75 per cent of it, largely through the higher education sector.

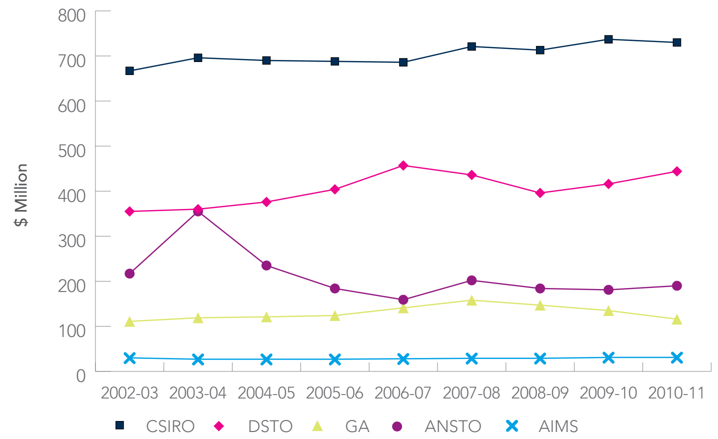
Figure 5.2.1 shows that in the past two decades the proportion of higher education expenditure directed to basic research has steadily decreased. It is not clear what the most suitable mix of basic and applied research should be in our universities, but it is clear that continuation of this trend will have a major impact on the overall amount of basic research performed in Australia.



Source: Research and Experimental Development Table, Australian Bureau of Statistics.

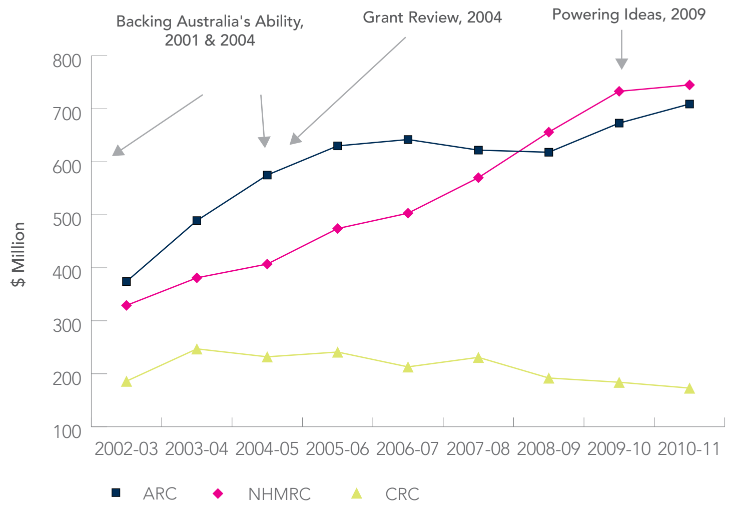
Figure 5.2.1 Proportion of higher education expenditure directed to basic and applied research

Spending on science and innovation through Commonwealth portfolio research agencies and through competitive grant schemes represents a major component of government spending on research and development. Expenditure in the five main Australian Government portfolio agencies (see Figure 5.2.2) and the three main competitive grant schemes (see Figure 5.2.3) was nearly equal to total government expenditure on R&D in 2008–09 (see Section 2.5). Trends in funding in the portfolio agencies were mixed between 2002–03 and 2010–11. In real terms, expenditure through CSIRO (the Commonwealth Scientific and Industrial Research Organisation) rose 9.5 per cent, and through DSTO (the Defence Science and Technology Organisation) it rose 25 per cent. ANSTO (the Australian Nuclear Science and Technology Organisation) saw a reduction of 13 per cent, and funding through AIMS (the Australian Institute of Marine Science) and GA (Geoscience Australia) were essentially unchanged.



Note: Expenditure adjusted for inflation to 2010–11 dollars using annual consumer price index data from the Australian Bureau of Statistics.
Source: Data from the Commonwealth Science Research and Innovation Budget Tables (www.innovation.gov.au/Innovation/Policy/AustralianInnovationSystemReport/AISR2011/appendix-1-science-research-and-innovation-budget-tables/index.html).

Figure 5.2.2 Overall expenditure for Australian Government portfolio research agencies—CSIRO, DSTO, AIMS, ANSTO and GA, 2002–03 to 2010–11



Note: Also shown are dates of key Australian Government policy reviews of the research system—Backing Australia's Ability, Sustaining the Virtuous Cycle (the Grant Review), a review of health and medical research funding, and Powering Ideas, a government policy agenda for innovation as a whole.

Source: NHMRC grant expenditure data from http://www.nhmrc.gov.au/_files_nhmrc/file/grants/dataset/research_fundg_2002-2011_at_1apr11.xls; other data sources and CPI adjustment factors as for Figure 5.2.2. Expenditure adjusted for inflation to 2010–11 dollars as in Figure 5.2.2.

Figure 5.2.3 Overall expenditure for Australian government programs administering the main competitive grant systems: ARC, NHMRC and CRC program, 2002-03 to 2010-11

In the main competitive funding systems, the Australian Research Council saw a nearly twofold increase in real terms between 2002–03 and 2010–11. During the same period funding through the National Health and Medical Research Council more than doubled[1], whereas the Cooperative Research Centres program saw a 7 per cent reduction in overall funding in real terms (see Figure 5.2.3).

5.3 Overall ARC funding

Australian Research Council funding nearly doubled in real terms between 2002 and 2010 (see Figure 5.2.3). Although funding to science fields (see Table 5.3.1 for fields included) grew in keeping with this overall pattern, science's share of ARC funding declined slightly (see Figure 5.3.1). Science fields retained a steady proportion of the number of projects funded (see Figure 5.3.2).

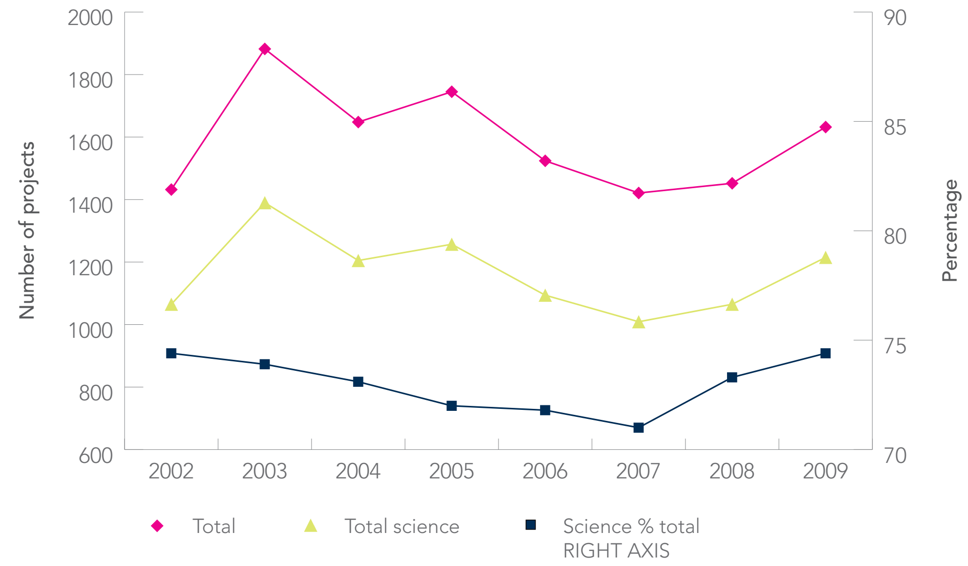
Table 5.3.1 Science fields included for ARC funding analysis, 2002 to 2009

RFCD	Description
29	Engineering and Technology
27	Biological Sciences
32	Medical and Health Sciences
25	Chemical Sciences
24	Physical Sciences
28	Information, Computing and Communication Sciences
38	Behavioural and Cognitive Sciences
23	Mathematical Sciences
26	Earth Sciences
30	Agricultural, Veterinary and Environmental Sciences

[1] In comparison, the US National Science Foundation saw an approximately 30 per cent increase in funding in real terms during the same period (http://dellweb.bfa.nsf.gov/NSFHist_constant.htm) and National Institutes of Health funding grew approximately 35 per cent (http://officeofbudget.od.nih.gov/approp_hist.html).

Notes: Funding expressed in 2010–11 equivalent dollars, adjusted as in Figure 5.2.2.
Schemes included are Centres of Excellence, Discovery Indigenous Researchers Development, Discovery Projects, Federation Fellowships, Australian Laureate Fellowships, Future Fellowships, Linkage Projects (APAI only), Linkage APD CSIRO, Linkage Infrastructure, Equipment and Facilities, Linkage Projects, Special Research Initiatives, Linkage International, ARC Research Networks and Special Research Initiatives (Thinking Systems).
Source: ARC National Competitive Grant Program funding trend data—www.arc.gov.au/general/searchable_data.htm.

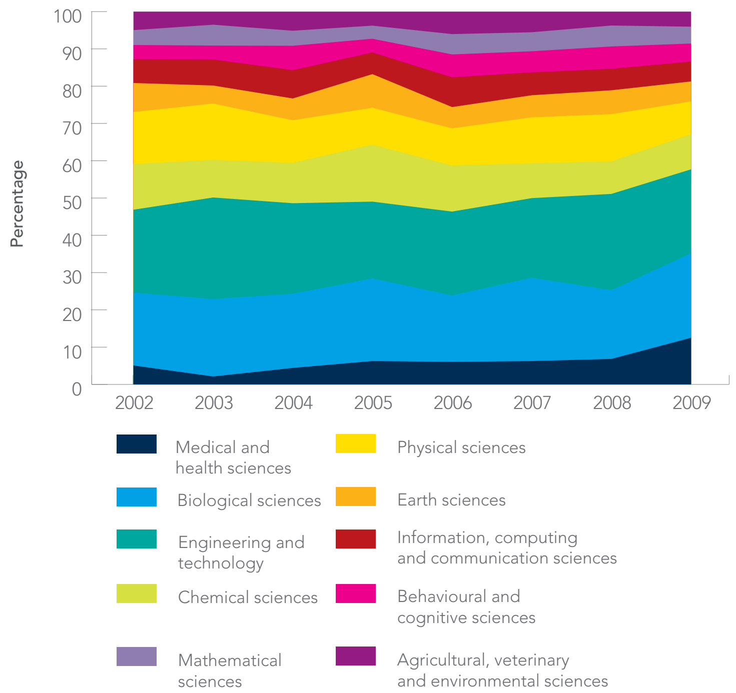
Figure 5.3.1 Overall funding and share of funding for science fields in selected schemes in the ARC competitive grants program, 2002 to 2009



Note: Fields and schemes as for Table 5.3.1 and Figure 5.3.1.
Source: ARC National Competitive Grant Program funding trend data—www.arc.gov.au/general/searchable_data.htm.

Figure 5.3.2 Overall projects and share of projects for science fields in selected schemes in the ARC competitive grants program, 2002 to 2009

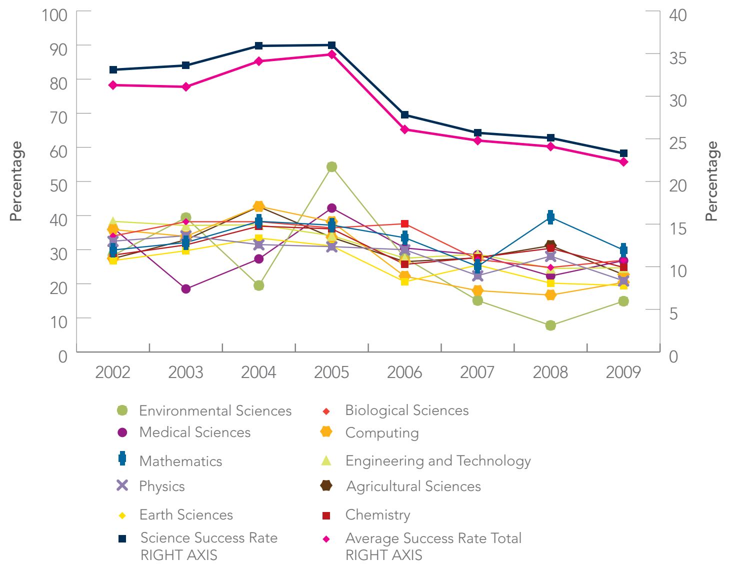
The distribution of this funding for the science disciplines shows a mixed pattern of some slight growth in funding along with unchanging or decreasing number of projects. Engineering and Technology, Biological Sciences, and Medical and Health Sciences all increased their share of funding between 2002 and 2009 (see Figure 5.3.3). Medical and Health Sciences, Biological Sciences, Physical Sciences, Engineering, and Mathematical Sciences also showed increases in the number of ARC projects during the period (ARC 2011b).



Note: Fields and schemes as for Table 5.3.1 and Figure 5.3.1.
Source: ARC National Competitive Grant Program funding trend data—www.arc.gov.au/general/searchable_data.htm.

Figure 5.3.3 Trends in funding share for science fields in selected schemes in the ARC competitive grants program, 2002 to 2009

The average success rate for ARC proposals across all fields declined between 2001 and 2008, suggestive of increasing pressure on the available funds. Success rates in total science slightly exceeded overall success rates and tracked the general downward trend (see Figure 5.3.4).[2] Individual science disciplines displayed varied patterns but broadly declined; only Mathematical Sciences showed no net decrease in success rate during 2001 to 2008.



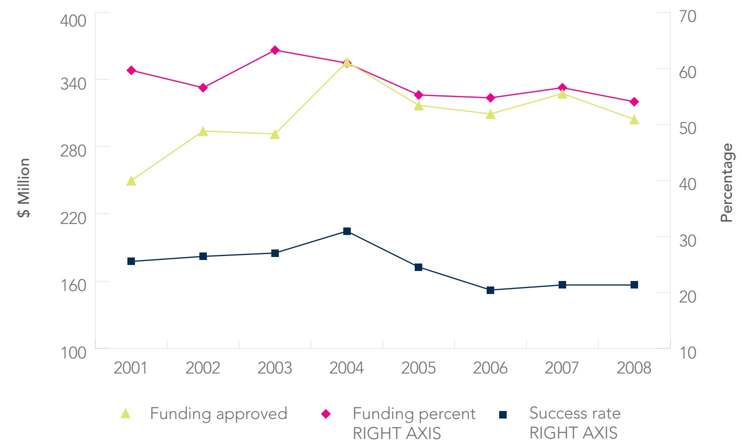
Note: Fields and schemes as for Table 5.3.1 and Figure 5.3.1.
Source: ARC National Competitive Grant Program funding trend data—www.arc.gov.au/general/searchable_data.htm.

Figure 5.3.4 Success rates for science fields and overall in selected schemes in the ARC competitive grants program, 2001 to 2008

Proposal pressure (as measured by the number of applications) increased for most schemes between 2001 and 2008. The number of Discovery Project and Linkage Infrastructure, Equipment and Facilities Project applications increased, by 35 per cent and 33 per cent respectively. Linkage Project applications increased by 6 per cent. Linkage International applications increased more than threefold from 2001 to 2006, then fell by a similar amount between 2007 and 2008 (the scheme was discontinued in 2009). The only scheme showing a decrease in applications during the period was Federation Fellowships, which fell 13 per cent to 2007 (ARC National Competitive Grant Program funding trend data).

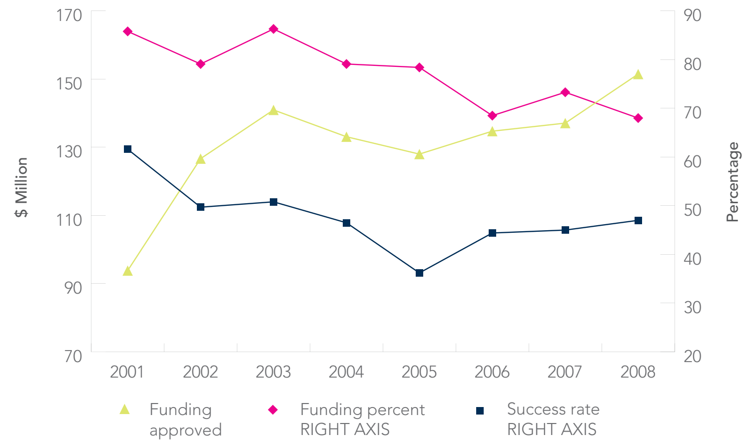
The ARC Discovery, ARC Linkage and ARC Linkage Infrastructure Equipment and Facilities grant schemes are important funding sources for most science disciplines. Figures 5.3.5 and 5.3.6 show changes in the approved funding, funding percentages and success rates between 2001 and 2008 for Discovery and Linkage schemes. In both schemes the level of funding awarded to successful grants increased between 2001 and 2008. However, the level of funding approved as a proportion of the funding requested in successful proposals declined during the period, suggesting either underfunding of projects or grant proponents asking for more funding than necessary. In the ARC Discovery Projects scheme, in particular, approved funding was about 54 per cent for successful grants in 2008. These overall patterns are also evident in the Linkage Infrastructure Equipment and Facilities scheme (ARC National Competitive Grant Program funding trend data).

[2] In comparison, US National Science Foundation success rates declined from an average of 29 per cent in 2002 to 23 per cent in 2010—http://dellweb.bfa.nsf.gov/awdfr3/default.asp.



Note: Funding expressed in 2010–11 equivalent dollars, adjusted as in Figure 5.2.2.
Source: ARC National Competitive Grant Program funding trend data—www.arc.gov.au/general/searchable_data.htm.

Figure 5.3.5 Total approved funding and success rates in the ARC Discovery Projects scheme, 2001 to 2008.



Note: Funding expressed in 2010–11 equivalent dollars, adjusted as in Figure 5.2.2.
Source: ARC National Competitive Grant Program funding trend data—www.arc.gov.au/general/searchable_data.htm.

Figure 5.3.6 Total approved funding and success rates in the ARC Linkage Projects scheme, 2001 to 2008

The ARC Discovery grant scheme includes a mechanism for assisting early-career researchers (ECR) to improve their chance of success in accessing competitive funding. Early-career researchers, as defined by the ARC[3], can be identified as such on an ARC Discovery application involving multiple investigators or they may submit an application involving only ECR investigators. Both the number of proposals approved and the success rate of ARC Discovery Projects involving ECR declined during 2001 to 2008 (see Figure 5.3.7).

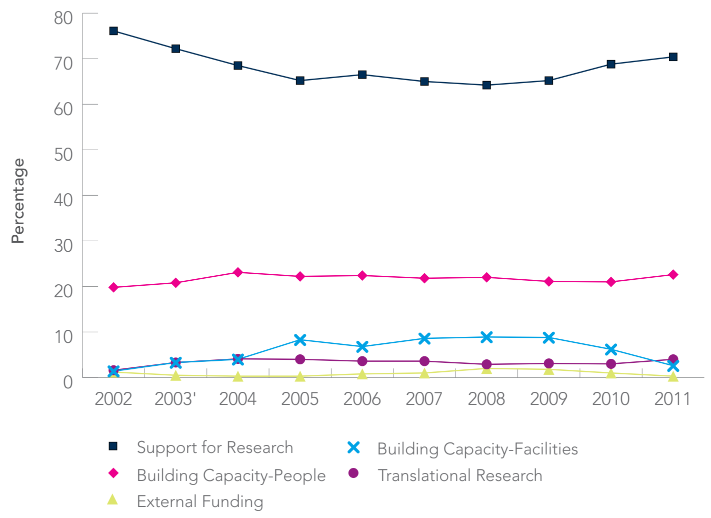
Source: ARC National Competitive Grant Program funding trend data—www.arc.gov.au/general/searchable_data.htm.

Figure 5.3.7 Number of projects funded and success rates for early career researchers in the ARC Discovery Projects scheme, 2001 to 2008

[3] Early Career Researchers are researchers who are within five years of being awarded a doctorate when they submit their grant applications. www.arc.gov.au/applicants/researcher_early.htm.

5.4 Overall NHMRC funding

Funding for the National Health and Medical Research Council more than doubled between 2002 and 2010 (see Figure 5.2.3; NHMRC 2011). The share of support for basic research declined slightly relative to human capacity–building and translational research during the period (see Figure 5.4.1). The share of support for Biomedical Research declined between 2001 and 2011, whereas Health Services, Clinical Medicine and Public Health increased their shares (NHMRC 2011).



Source: NHMRC grant expenditure data from http://www.nhmrc.gov.au/_files_nhmrc/file/grants/dataset/research_fundg_2002-2011_at_1apr11.xls

Figure 5.4.1 Share of NHMRC funding, by funding purpose, 2002 to 2010

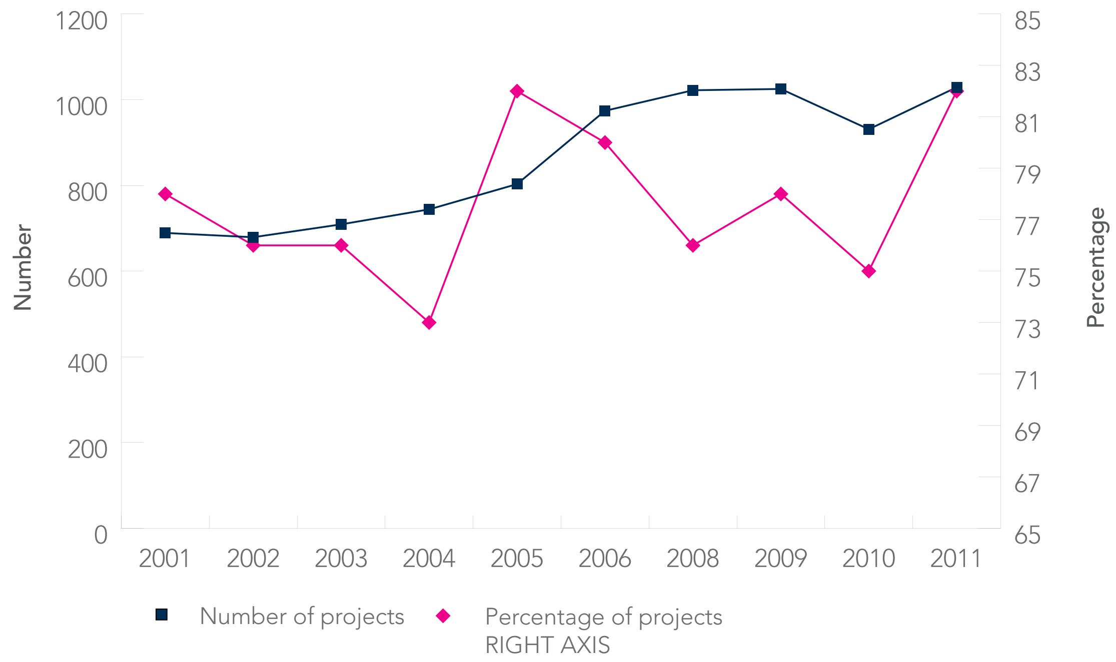
The decadal trend in NHMRC grant applications and success rates shows a doubling of applications between 2000 and 2011 (see Figure 5.4.2) and success rates declining from about 30 to about 23 per cent.[4] In addition to approving funding for successful applications, the NHMRC also classifies unsuccessful applications into those that are 'not fundable' (falling into a scoring level considered not worthy of funding support) and those that are 'fundable but not funded' (scored as worthy of funding but funding is unavailable). The number of applications falling into this latter category nearly tripled between 2002 and 2011, while the number of funded projects increased by about 89 per cent (Figure 5.4.2). This pattern is indicative of increasing proposal pressure on the NHMRC funding scheme.

Source: NHMRC grant expenditure data from http://www.nhmrc.gov.au/_files_nhmrc/file/grants/dataset/research_fundg_2002-2011_at_1apr11.xls

Figure 5.4.2 Applications—funded, not fundable and fundable but not funded—for NHMRC project grants, 2000 to 2011

[4] The US National Institutes of Health grant success rates declined from about 31 per cent in 2002 to about 18 per cent in 2011—http://report.nih.gov/success_rates/Success_ByActivity.cfm.

NHMRC funding is strongly concentrated in two ANZSRC (Australian and New Zealand Standard Research Classification) fields of research (at two-digit level) considered for the Health of Australian Science project—Biological Sciences and Medical and Health Sciences. Grants in these two fields account for the majority of NHMRC funding and number of projects, and support for them grew, along with overall NHMRC funding, between 2002 and 2010. The number of projects in these fields also grew and their share of overall NHMRC projects grew slightly from 2002 to 2011 (see Figure 5.4.3).

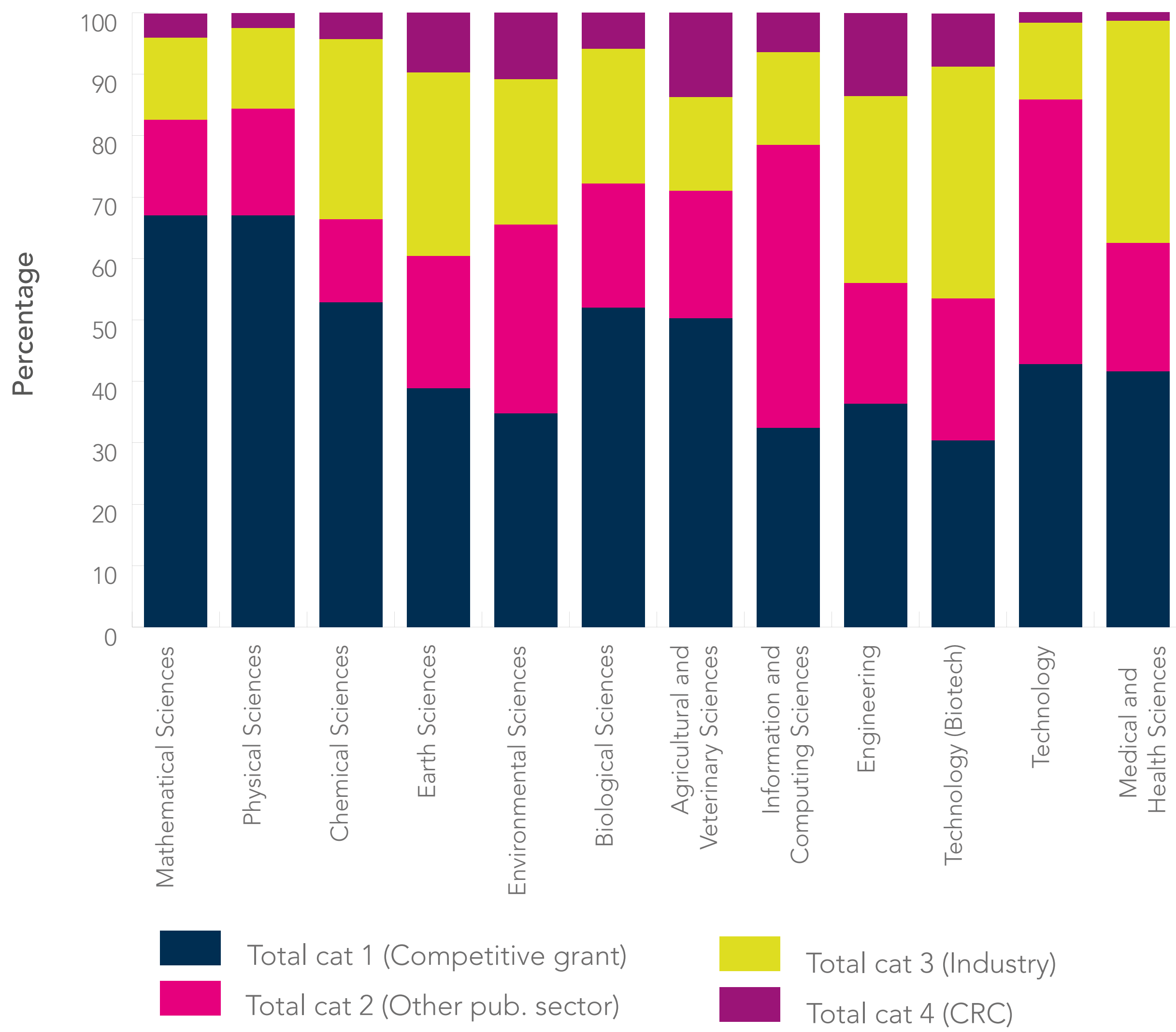


Source: NHMRC grant expenditure data from http://www.nhmrc.gov.au/_files_nhmrc/file/grants/dataset/research_fundg_2002-2011_at_1apr11.xls

Figure 5.4.3 Number of projects in NHMRC schemes for Health of Australian Science fields (see Table 1.2.1), 2002 to 2011

5.5 Mix of funding for science fields

Figure 5.5.1 shows the mix of funding sources for university scientific research from 2006 to 2008 as reported to the ERA audit (ARC 2011a). Mathematical Sciences, Physical Sciences, Chemical Sciences, Biological Sciences, and Agricultural and Veterinary Sciences were dominated by competitive grant funding. In view of the declining success rates for science funding from this source, these fields could face increased funding pressure. Although no discipline received a majority of its university research funding from industry, Biotechnology, Medical and Health Sciences, Engineering, Earth Sciences and Chemical Sciences had the greatest degree of support from industry. Similarly, although no discipline received more than 12 per cent of its funding from the Cooperative Research Centres program, Earth Sciences, Environmental Sciences, Agricultural and Veterinary Sciences, and Engineering received a greater degree of support from this source than other fields during the audit period.



Notes: Figure refers to Higher Education Research Data Collection research income submitted to ERA 2010 for 2006 to 2008.
Category 1 income is income received from programs listed on the Australian Competitive Grants Register. The grants are highly competitive and have a strong element of peer review.
Category 2 income is any other research income received from the Australian Government that is not eligible for inclusion as Category 1 research income. This includes income from both state and local governments.
Category 3 income is income from industry and other non–Australian Government organisations, mainly referring to contract, grant, donation, bequest and foundation income from Australian industry. The category includes income from competitive, peer-reviewed grants for research from non-Australian industry or government agencies, including non-Australian industry collaborative research grants, as well as income from non-Australian industry or governments that cannot be included in International A research income.
Category 4 income is income received by Cooperative Research Centres in which the relevant institution is a core participant (that is, a signatory to the CRC's Commonwealth Agreement).
Source: 2010 Excellence in Research for Australia audit (ARC 2011a).

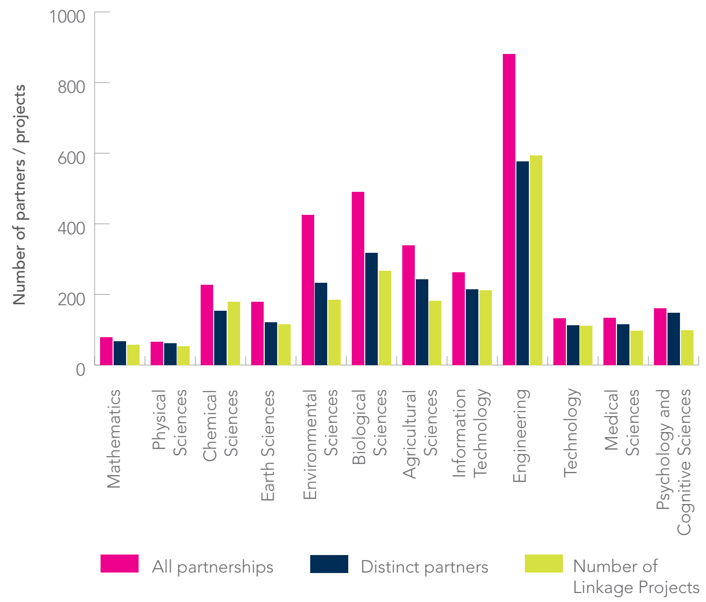
Figure 5.5.1 Funding sources for science disciplines, 2006 to 2008

In order to assess science fields' involvement in ARC funding schemes, this project examined the proportion of funding for each two-digit field of research in ARC funding schemes between 2002 and 2010. Mathematical Sciences, Psychology, Biological Sciences, and Information and Computing Sciences received the highest proportional funding from the Discovery Projects Scheme (see Figure 5.5.2).

Source: ARC National Competitive Grant Program funding trend data—www.arc.gov.au/general/searchable_data.htm.

Figure 5.5.2 Funding sources for science fields, by scheme, 2002 to 2010

In the Linkage Projects scheme, Agricultural and Veterinary Sciences was most reliant on this source of funding, followed by Environmental Sciences, Engineering, Medical and Health Sciences, and Information and Computing Sciences. Engineering and Biological Sciences had the greatest number of projects in the scheme in 2002 to 2008 (Figure 5.5.3). Engineering, Biological Sciences and Environmental Sciences had the greatest number of partnerships. Because this scheme involves industry partner participation, fields dependent on it can be vulnerable to industry's willingness and ability to contribute to projects (required under the terms of the scheme) and changes in funding in the scheme itself.



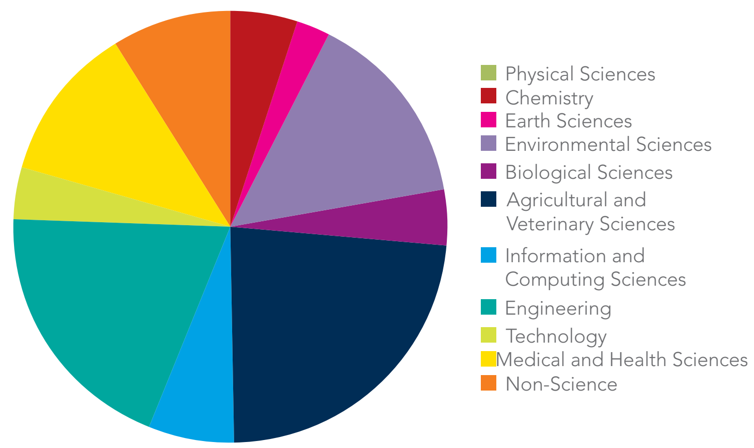
Source: ARC National Competitive Grant Program funding trend data—www.arc.gov.au/general/searchable_data.htm.

Figure 5.5.3 Projects and partnerships: science fields in the Linkage Projects scheme, 2002 to 2008

No field had more than about 11 per cent of its funding in the Linkage Infrastructure, Equipment and Facilities scheme, but Physical Sciences (at about 11 per cent), Chemical Sciences, Earth Sciences and Engineering had the greatest proportion of their National Competitive Grants Program funding in this scheme.

ARC Centres of Excellence receive episodic funding: 10 science-focused ARC centres began in 2005 and another 11 in 2011 (projects beginning in 2002 to 2010 are considered for this analysis). Environmental Sciences, Chemical Sciences and Earth Sciences received the greatest proportion of funding under the scheme. Funding for co-funded Centres of Excellence is highly concentrated: two centres dominate. The Information and Communications Technology Research Centre of Excellence, or NICTA, began funding in 2003 and continues, with about $280 million over the project life; this single centre is a major component of Technology funding. The Australian Stem Cell Centre[5] was funded at the level of $50 million from 2003 to 2011 and appears as a major component of funding for Medical and Health Sciences. Similarly, the $42 million Special Research Initiative Bionic Vision Australia, which began funding in 2010, accounts for a significant component of Technology funding for 2002 to 2010.

The Cooperative Research Centres program began in 1991. Between 2002 and 2010, 90 such centres were active at some time. Funding in the program declined in real terms by about 7 per cent during that period (see Figure 5.2.3). Although CRCs are multidisciplinary in nature, the greatest overall effort in the program is in Agricultural and Veterinary Sciences, followed by a large degree of activity in Engineering, Environmental Sciences, and Medical and Health Sciences (see Figure 5.5.4).



Note: Analysis is based on information from 46 active centres.
Source: DIISR (2011).

Figure 5.5.4 Cooperative Research Centres: self-reported activity in fields of research, as of 2011

[5] This centre was succeeded in 2011 by the $21 million Special Research Initiative Stem Cells Australia.

5.6 Conclusions

The analysis presented here suggests a pattern of growth in the overall ARC and NHMRC budgets. Fields such as Biology, Chemistry, Agricultural and Veterinary Sciences, Earth Sciences, Engineering, and Mathematics benefited from increased support through the ARC over the 2002 through 2010 period. Similarly, Biological Sciences and Medical and Health Sciences saw growth in support from ARC and NHMRC over the decade.

Along with this growth in science support, a challenge is presented by increasing pressure on funding sources for science. In the ARC-administered National Competitive Grants Program there is a broad-based pattern of decreasing success rates in most fields of science. The pattern of declining success rates was particularly striking in the Linkage International scheme before it ended in 2009, indicative of increasing unmet demand for international collaboration—an important component of the growth in Australian publication outputs (see Chapter 6). Overall success rates for NHMRC project grants declined between 2000 and 2010, there being an increase in the number and proportion of applications assessed as worthy of funding but for which funding was not available (NHMRC 2011).

In NHMRC funding schemes the share of support for 'basic' research declined slightly, in favour of slight growth in human capacity–building and facilities support research and in translational research (that is, 'translating' basic research discoveries into health practice and policy)[6]. Similarly, the proportion of research expenditure for biomedical research declined relative to clinical medicine, public health and health services (NHMRC 2011).

The long-term decline in funding support for approved projects in the Linkage Infrastructure, Equipment and Facilities scheme could point to vulnerability in Australian access to large-scale research infrastructure. Overall, CRC funding decreased from its peak in 2007–08.

Other Commonwealth funding schemes might in future play roles similar to those discussed here—for example, the National Collaborative Research Infrastructure Strategy, Super Science Fellowships and the National Environmental Research Program—but continued pressure on funding in these core competitive grants schemes poses a challenge for basic research.

[6] For example, www.nhmrc.gov.au/media/events/2011/towards-national-network-enhance-leadership-research-translation-and-implementation.

CHAPTER 6

6. INTERNATIONAL RESEARCH INVOLVEMENT AND IMPACTS

Collaboration is vital for science in order to complement capabilities, and the Australian research community has a long history of strong and enduring international connections.

Such collaboration underpins a range of research efforts in which Australia's size makes the nation's human 'critical mass' insufficient, or the scale of effort requires infrastructure not easily available to any single country.

In astronomy, for example, Australia, participates in the Gemini Project[1] along with the United States, the United Kingdom, Canada, Chile, Brazil and Argentina; this gives Australian researchers access to optical and infra-red telescopes in Chile and Hawaii. These facilities, built at a cost of about A$200 million, would be difficult for any single country, especially Australia, to establish and maintain alone. In marine geoscience, Australia is a partner in the Integrated Ocean Drilling Program[2], a partnership led by the United States, the European Union and Japan. Participation in the program gives Australian scientists direct access to seafloor drilling technology that is worth about US$1 billion and has annual running costs of about US$200 million.

Involvement in large-scale international projects can bring about a high degree of 'leverage' for Australian funds.[3]

Indirectly, participation also gives Australian researchers opportunities to collaborate with overseas researchers and complementary capabilities apart from the sampling and observation technologies themselves. International collaborative projects also catalyse national partnerships. The Australian consortium for the Integrated Ocean Drilling Program involves 14 universities and two government agencies; similarly, the Australian Gemini partnership is a multi-institution consortium. International engagement also offers opportunities for attracting students and researchers to Australia and keeps Australian science current and globally relevant.

This chapter examines trends in the levels and patterns of Australia's international scientific collaboration and trends in scientific publications and their impact in terms of citations in the literature.

[1]www.gemini.edu/about; ausgo.aao.gov.au.
[2]www.iodp.org.au/index.php?p=about; www.iodp.org.
[3]Australia's contribution to the Integrated Ocean Drilling Program is US$1.4 million per year, implying a leverage factor of over 100.

6.1 Main findings

- Growth in internationally collaborative publications is a major source of overall growth in publication output. Whereas overall publication numbers approximately doubled between 2002 and 2010, the number of internationally co-authored publications more than tripled.
- Australia has an impact that is higher than the global average in most fields of research and maintains a high and increasing share of global publications.
- International collaboration on grants in Australian Research Council funding schemes —that is, the number of grants for which there is international collaboration—grew between 2002 and 2009 but by less than the growth in internationally co-authored publications.
- The global landscape of collaboration through publication co-authorship is changing. Growth in historically strong collaborations with North America and Europe continues, but much faster growth is occurring with emerging areas of scientific strength in Asia. In several fields of research—such as mathematics, engineering and chemistry—China is now Australia's leading partner in collaboration.

6.2 Data sources

This chapter examines the global engagement and impact of Australian science, as viewed mainly from the perspective of publications. The analysis uses data from the Elsevier–Scopus database of publications (SCImago 2007), the Thomson–Reuters database of publications (Thomson–Reuters 2011), the Australian Research Council, and the US National Science Foundation, as well as drawing on other studies based on these data sources.

The detailed categorisation of scientific fields from these data sources might differ somewhat from the Australian and New Zealand Standard Research Classification[4] (see also Chapter 1 of this report). Also used are selected fields of research classified in the earlier Research Fields, Courses and Disciplines classification scheme[4], the All Science Journal Classification scheme as used by Elsevier–Scopus[5], and Thomson–Reuters classifications[6], such that they overlap as closely as possible with the ANZSRC fields of research examined in the bulk of this report.

The analysis here examines outputs at a level of field aggregation as close as possible to the ANZSRC 'two-digit' level. The Scopus and Thomson–Reuters databases differ in their coverage and classification, although a recent comparison of bibliometric indices calculated from both sources (Archambault et al. 2009) showed a very high correlation (r2 = 0.99) for indicators of scientific output and impact by country, suggesting that these metrics are stable and independent of database choice. Some differences arise from the indexing databases' aggregation and grouping of fields. For example, Scopus considers 'Agricultural and Biological Sciences' as one field and considers 'Veterinary Sciences' as another, whereas ANZSRC places Agricultural and Veterinary Sciences together in a single field. Another possible source of bias arises from the type of outputs on which different fields might concentrate. For example, outputs for Computing and Information Sciences and Engineering are much more heavily concentrated in conference papers than is the case for other science fields (ARC 2011a) and thus might be undercounted in journal-heavy indexing services such as Scopus and Thomson–Reuters. Additionally, joint publication is but one measure of collaboration: researchers can interact in many ways and on many levels—conferences, workshops, field expeditions, student supervision, and so on.

For the purpose of analysing and mapping international networks of collaboration, this project synthesises data from 17 fields and sub-fields in the Elsevier–Scopus database (in Sections 6.4 and 6.7). The analysis followed the Scopus classification with the exception of omitting clinical sub-fields in the AJSC two-digit field of Medicine in order to reflect this report's focus on basic biomedical sciences as opposed to clinical sciences. The analysis also combined agricultural sub-fields with veterinary science to create a grouping as closely aligned as possible to the ANZSRC field of Agricultural and Veterinary Sciences.

[4]www.abs.gov.au/Ausstats/abs@.nsf/Latestproducts/1297.0Main per cent20Features52008?opendocument&tabname=Summary&prodno=1297.0&issue=2008&num=&view=; Correspondence Tables: www.abs.gov.au/Ausstats/abs@.nsf/Latestproducts/1297.0Main per cent20Features72008?opendocument&tabname=Summary&prodno=1297.0&issue=2008&num=&view=
[5]www.info.sciverse.com/documents/files/scopus-training/resourcelibrary/xls/title_list.xlsx (see 'ASJC Code List').
[6]http://ip-science.thomsonreuters.com/mjl/scope/scope_sci/.

6.3 The changing global landscape of science

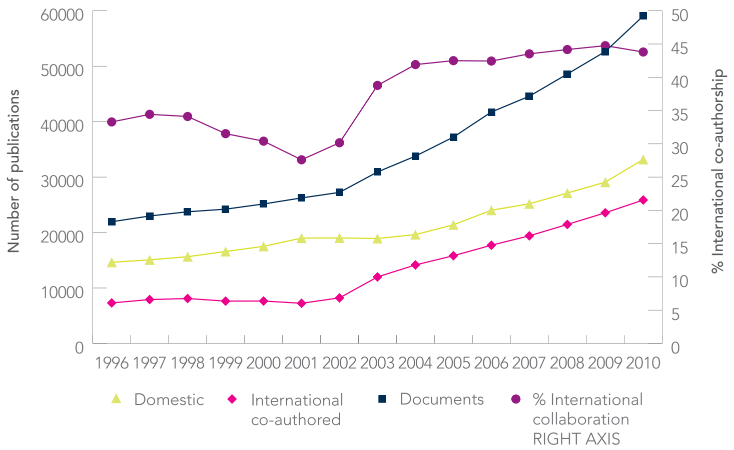
Rankings of research output are changing, and nations such as China, India, South Korea and Brazil are moving up the ladder in terms of national research publication outputs (SCImago 2007; Royal Society 2011). Despite this the United States still leads global rankings of research output in terms of both quantity and quality (SCImago 2007; Wagner 2011). China has, however, overtaken the United Kingdom as the second-ranked country in scientific publication output and on current trends will probably overtake the United States in this regard by the end of the decade (Royal Society 2011). In addition, emerging regional scientific centres—for example, Nanjing, Shanghai, Sao Paulo, Seoul and Taipei—have risen dramatically in the rankings of global cities for scientific publication outputs (Royal Society 2011). The growth in many Asian nations' scientific output could be underestimated since Asian journals might be underrepresented in scientific indexing databases (Wagner 2011); this could also be true of other emerging regions, such as South America.

The United States remains the leading nation for research collaborations with Australia and most other nations (Barlow 2011). For example, about 29 per cent of research publications from the United States are internationally collaborative, and 17 per cent of all internationally co-authored papers involve US authors (Royal Society 2011). Regional collaborations—such as those among the 'BRIC' countries (Brazil, Russia, India and China)—have also grown, although in the BRIC case they remain much lower in volume than these countries' collaborations with G7 nations (Royal Society 2011).

6.4 Trends in collaboration

Globally, scientific collaboration has become more extensive and diverse. The proportion of papers with one or more international co-authors increased from about 25 to over 35 per cent over the past 15 years (Royal Society 2011).

In recent years the highest growth in Australian-authored publications has been through internationally co-authored publications, rather than purely 'domestic' publications (see Figure 6.4.1; see also Matthews 2008). International collaboration is extensive: over 40 per cent of Australian scientific publications are co-authored with overseas collaborators (Australian Academy of Sciences 2011; SCImago 2007).



Source: SCImago data, www.scimagojr.com

Figure 6.4.1 Growth in Australian (domestic) publications and internationally co-authored publications, 1996 to 2010

Australia's primary research links are with the European Union, and Australian-European publication output is growing faster than that with Australia's next largest (and single largest national) partner, the United States (Matthews 2008). The greatest increase in collaboration has occurred with emerging national partners such as China and India (Barlow 2011; Adams et al. 2010), where there has also been high growth in scientific activity as measured by the number of researchers and publications (National Science Board 2010). Collaborations with Japan, in contrast, have levelled off in recent years (Barlow 2011).

The greatest growth in Australia–US co-authorship between 1995 and 2009 was in the Australian university sector, there being apparently less growth in US co-authorship among government research organisations such as CSIRO, ANSTO and Geoscience Australia (Barlow 2011).
The extent to which this pattern is representative of global collaboration more broadly is not clear. Analysis of co-publication through databases such as Thomson–Reuters' Web of Knowledge might underestimate collaboration where publication of peer-reviewed journal articles is not the most important output. This type of data could introduce a bias towards activity in the university sector (Barlow 2011) and/or toward collaboration with nations other than the United States, or with international scientific bodies such as the Intergovernmental Panel on Climate Change.

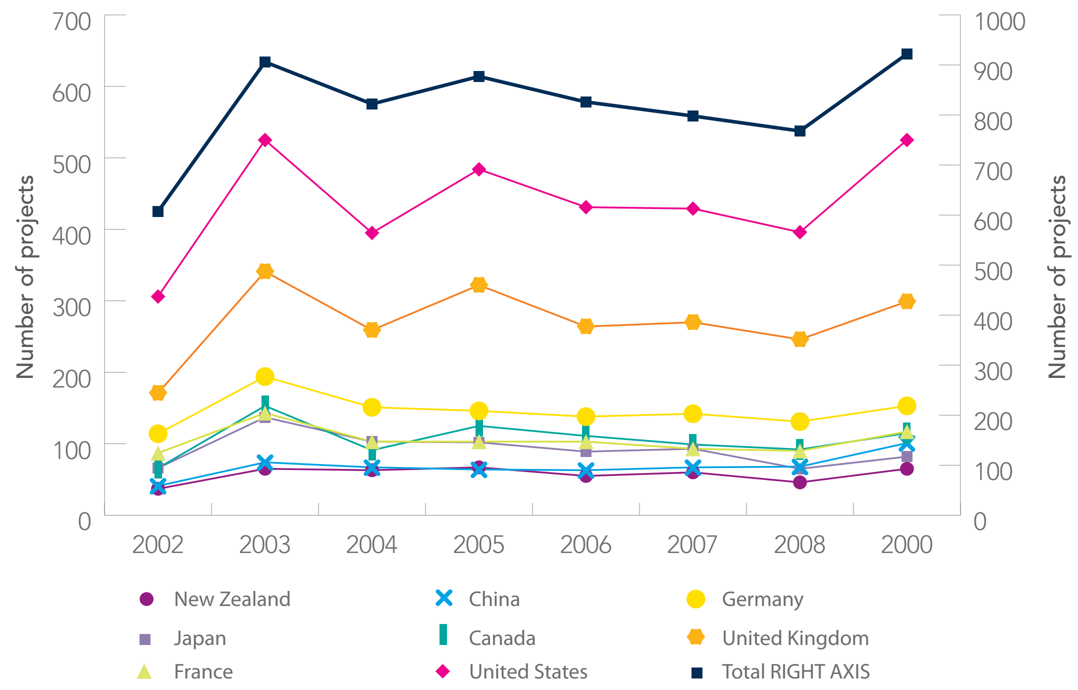
Although the United States is the largest national collaborative partner for Australia and for most other countries around the world—among them New Zealand, Singapore and Thailand in our region—for many countries in our region this is not the case (UNESCO 2010). UNESCO notes that in the Southeast Asia – Oceania region the greatest level of collaboration for some of our neighbours is with Japan (Indonesia and Vietnam), China (Malaysia), France (French Polynesia and New Caledonia) and Australia itself (Fiji and Papua New Guinea).

Although the pattern of co-authorship is largely mirrored by research collaboration on grants, it is worth noting that, whereas China ranked sixth in terms of grant collaboration in 2009 (and seventh or eighth between 2002 and 2008), it now ranks third in co-authorship with Australia (see Tables 6.4.1 and 6.4.2 and Figures 6.4.2 and 6.4.3). International collaboration in science publications nearly tripled between 2002 and 2009; international collaboration on Australian Research Council research projects (in a wide range of schemes) grew by about 52 per cent during the same period, increasing from 42 to 56 per cent of all funded projects (ARC 2011b).

Table 6.4.1 Top seven countries by grant collaboration with Australian researchers in selected ARC schemes and by co-authorship, 2009

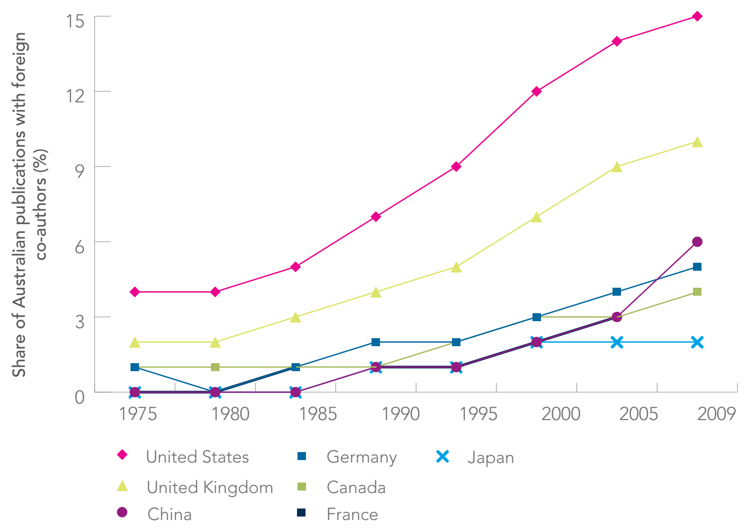
Rank by ARC project collaboration	Rank by co-authorship
United States	United States
United Kingdom	United Kingdom
Germany	China
France	Germany
Canada	Canada
China	France
Japan	Japan

Notes: More than one country could be collaborating on a single ARC project; where this is the case the project number is double-counted for the countries involved.
The schemes included are Centres of Excellence, Discovery Indigenous Researchers Development, Discovery Projects, Federation Fellowships, Australian Laureate Fellowships, Future Fellowships, Linkage Projects (APAI Only), Linkage APD CSIRO, Linkage Infrastructure Equipment and Facilities, Linkage Projects, Special Research Initiatives, Linkage International, ARC Research Networks, and Special Research Initiatives (Thinking Systems).
Sources: (Project collaboration) Australian Research Council: www.arc.gov.au/general/searchable_data.htm; (co-authorship) Barlow (2011); Thomson–Reuters data.



Source: Australian Research Council: www.arc.gov.au/general/searchable_data.htm

Figure 6.4.2 Collaborative grants in selected schemes in the ARC's competitive grants program: top eight collaborating countries, 2002 to 2009



Source: Barlow (2011); Thomson–Reuters data.

Figure 6.4.3 Growth in co-authored publications with most-partnered countries, 1975 to 2009

In terms of the measure of collaborative publication volume, Australia maintains high levels of collaboration in historically strong links such as those with the United States, the United Kingdom, Germany, Canada and France and increasingly in growing partnerships such as those with nations such as China and Singapore (see Table 6.4.2). This report's analysis of international collaboration shows that in 2010 China was Australia's top source of collaboration in chemistry, engineering and mathematics and the second-top source in agricultural and veterinary science and immunology. In contrast, China was ranked eleventh for collaboration in medical science.

The US National Science Foundation uses an alternative index of collaboration, measuring the intensity of collaboration pairs relative to both countries' overall international collaborations (see Table 6.4.2). Australia's patterns of high-intensity collaboration (joint proportion of international collaboration), as represented by the US NSF index, is different from those represented by collaboration volume, with New Zealand, Singapore and South Africa being the leading partners. Growth in the US NSF index suggests expanding collaboration with the index partner relative to the partner's overall international collaboration.

Australia's collaboration volume with Asian countries—although still lower than collaboration with historically large partners such as the United States—has grown at the same rate as or faster than the growth rate of those nations' collaboration with the world or with the United States (see Table 6.4.3).

Table 6.4.2 Total Volume of collaboration, and index of collaboration between Australia and other countries in 1995 and 2010

	Total Collaborations				Collaboration Index			
Rank	Country	1995	Country	2010	Country	1995	Country	2010
1	United States	1448	United States	4,223	New Zealand	4.49	New Zealand	3.92
2	United Kingdom	763	United Kingdom	2,854	Singapore	2.01	Singapore	1.66
3	Germany	381	China	1,815	South Africa	1.86	South Africa	1.5
4	Canada	320	Germany	1,496	China	1.11	United Kingdom	1.16
5	Japan	225	Canada	1,184	Iran	1.11	Iran	1.13
6	France	223	France	1,057	United Kingdom	1.05	China	1.06
7	New Zealand	203	New Zealand	789	United States	0.8	Ireland	0.97
8	China	161	Netherlands	736	Canada	0.76	Canada	0.89
9	Sweden	143	Italy	699	Sweden	0.65	Denmark	0.88
10	Netherlands	131	Japan	694	India	0.61	Chile	0.85
11	Italy	119	Switzerland	561	Japan	0.6	Finland	0.82
12	Switzerland	87	Sweden	511	Denmark	0.56	Netherlands	0.81
13	Russia	85	Spain	497	Israel	0.56	Sweden	0.8
14	Israel	73	Singapore	404	Argentina	0.55	India	0.77
15	Denmark	69	Belgium	347	Germany	0.52	United States	0.75
16	South Africa	63	Denmark	332	Netherlands	0.51	Austria	0.71
17	Belgium	61	India	330	Austria	0.5	Switzerland	0.7
18	Spain	53	South Africa	277	Chile	0.5	Taiwan	0.68
19	India	48	Austria	276	Ireland	0.42	Norway	0.67
20	Austria	47	South Korea	270	Belgium	0.38	Japan	0.64
21	Singapore	36	Finland	239	France	0.37	Poland	0.63

	Total Collaborations				Collaboration Index			
Rank	Country	1995	Country	2010	Country	1995	Country	2010
22	Poland	30	Brazil	226	Norway	0.37	Belgium	0.61
23	Norway	26	Poland	220	Switzerland	0.36	Czech Republic	0.61
24	Brazil	25	Russia	203	South Korea	0.33	Israel	0.61
25	Finland	21	Taiwan	194	Czech Republic	0.32	Germany	0.6
26	South Korea	21	Norway	187	Italy	0.32	France	0.58
27	Czech Republic	20	Ireland	184	Russia	0.31	Italy	0.56
28	Argentina	20	Israel	182	Mexico	0.31	Brazil	0.56
29	Mexico	16	Iran	151	Taiwan	0.3	Argentina	0.55
30	Taiwan	15	Czech Republic	144	Brazil	0.27	Hungary	0.5

Notes: Using data for the world, Australia and the United States, the 2010 US–Australia index is computed as follows:
Australia–US co-authorships as a proportion of US international co-authorship = 4223/79 581 = 0.0531.
Australia's proportion of total international co-authorship = 13 188/185 303 = 0.0712.
US–Australia co-authorships as a proportion of Australia's international co-authorship = 4223/13 188 = 0.3202.
US proportion of total international co-authorship = 79 581/185 303 = 0.4295.
The indexes for any country pair are always symmetrical. The Australia–US and US–Australia indexes are the same, as follows:
Australia–US index: 0.0531/0.0712 = 0.75 and
US–Australia index: 0.3202/0.4295 = 0.75.
The index value would be 1 if the two countries co-author with each other at the rate that they co-author with all countries.
Source: National Science Board (2012); www.nsf.gov/statistics/seind12/c5/c5s.htm#sb6.

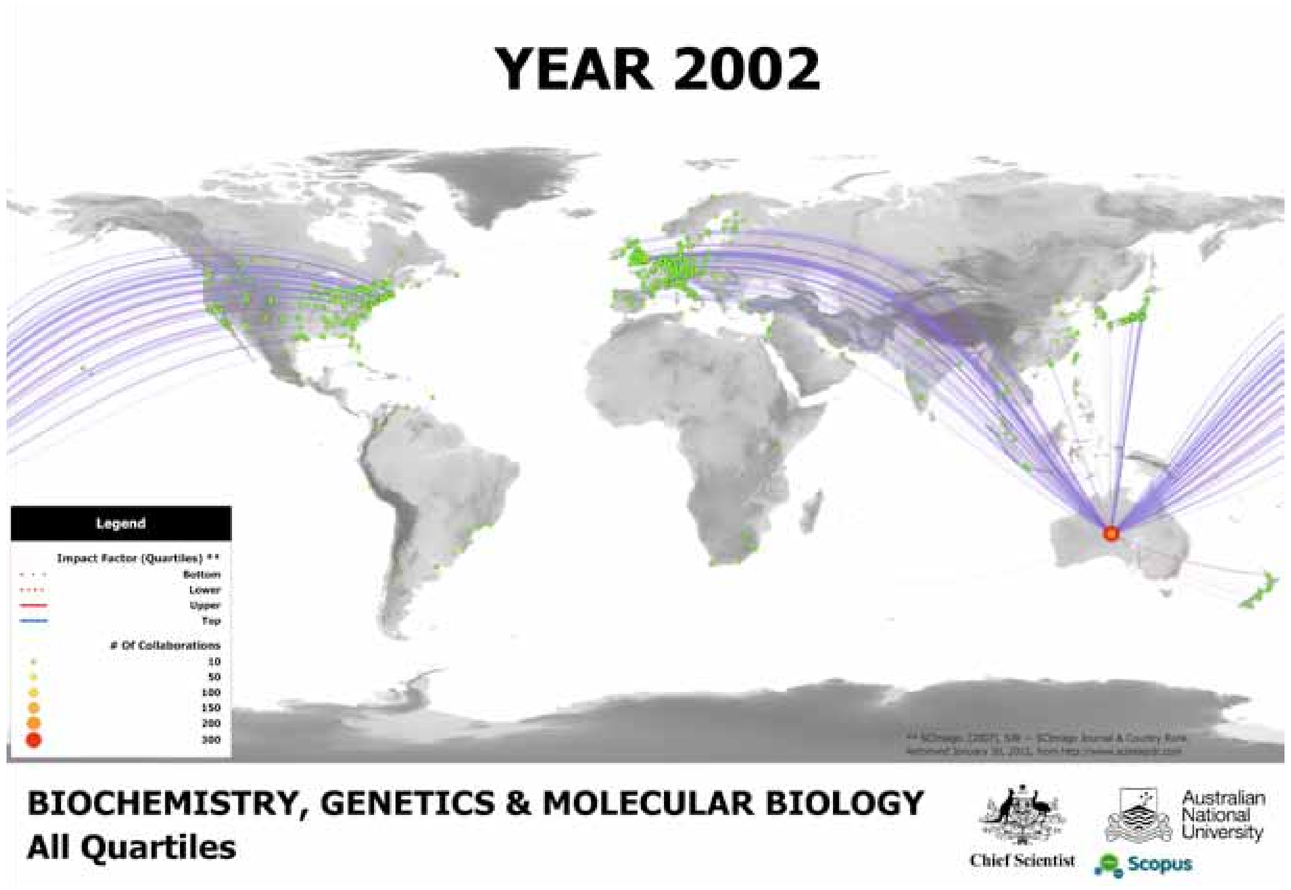
Table 6.4.3 Change in collaboration (as measured in multiple from 1995 to 2010) globally, and among Australia, the United States, and a sample of Asian nations.

World	World	Multiple	United States	Multiple	Australia	Multiple
1995	79 128		36 361		3 940	
2010	185 303	2	79 581	2	13 188	3
United States						
1995	36 361		n/a		1448	
2010	79 581	2	n/a	n/a	4223	3
China						
1995	2 914		1 112		161	
2010	24 164	8	10 917	10	1 815	11
India						
1995	1 583		606		48	
2010	6 033	4	2 021	3	330	7
Japan						
1995	7 554		3 603		225	
2010	15 144	2	5 587	2	694	3
Singapore						
1995	359		106		36	
2010	3 424	10	1 062	10	404	11
South Korea						
1995	1 283		821		21	
2010	8 064	6	4 342	5	270	13
Taiwan						
1995	1 013		742		15	
2010	4 032	4	2 063	3	194	13

n/a Not available.
Source: National Science Board (2012); www.nsf.gov/statistics/seind12/c5/c5s.htm#sb6

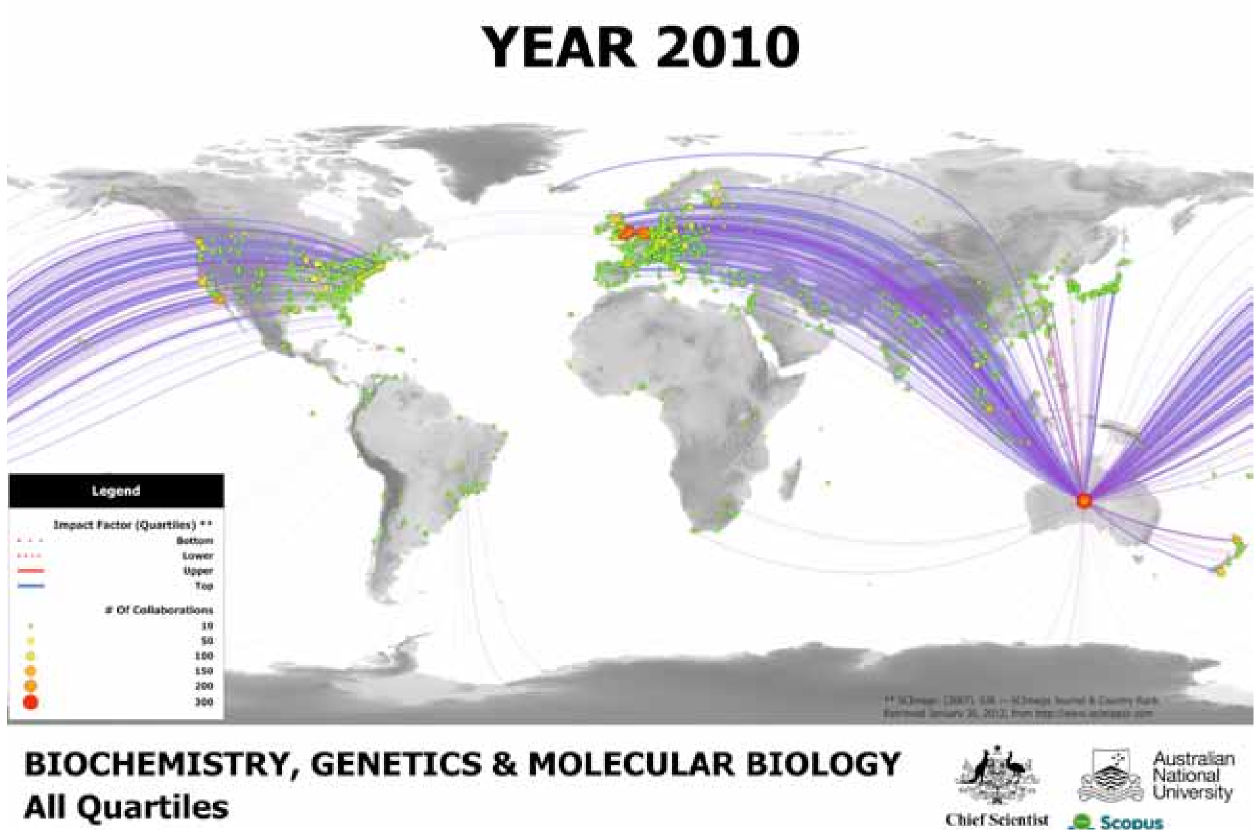
The changing geography of collaboration towards increased involvement with Asia and (at a lower overall level) with southern Africa and South America pervades most fields of research. It can be illustrated by two examples in which the volume, pattern and impact of Australian internationally collaborative publications changed between 2002 and 2010.

In Biochemistry, Genetics and Molecular Biology the volume of international co-authorship by Australian researchers grew between 2002 and 2010 (see Figures 6.4.4 and 6.4.5) as the average impact (as measured by journal impact factor) of Australian and global publications in this field grew (see also Table 6.7.4). The proportion of global outputs represented by Australian publications, as well as their relative impact (measured against global averages), also increased during the period. In this field international collaboration in 2010 remained relatively focused on the dominant regions of high impact, volume and collaboration in 2002—that is, North America and Europe—with some growth in collaboration with China and other emerging nations and regions (see Figure 6.4.5).



Note for Figures 6.4.4 through 6.4.7: The 'geodesics' (originally defined as a segment of a great circle on the Earth), or paths, between Australia and locations of overseas collaborations represent instances of co-authorship. In cases of multiple-country collaboration, one publication can be represented by more than one path. The paths are colour-coded by journal impact factor and by quartile of journal impact factor for journals ranked in the field, with 2010 as the reference year. The size and colour of symbols represent the number of collaborations with a mapped location. Source: Analysis and mapping by Australian National University Research Office, using Scopus data.

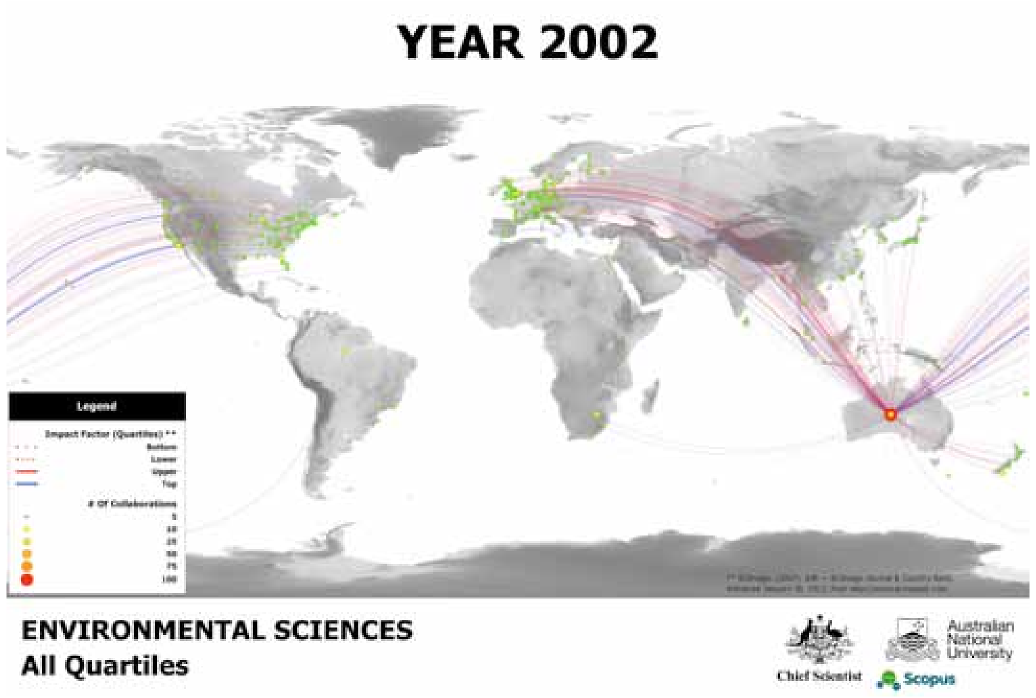
Figure 6.4.4 Australian international collaboration in Biochemistry, Genetics and Molecular Biology, 2002



Source: Analysis and mapping by Australian National University Research Office, using Scopus data.

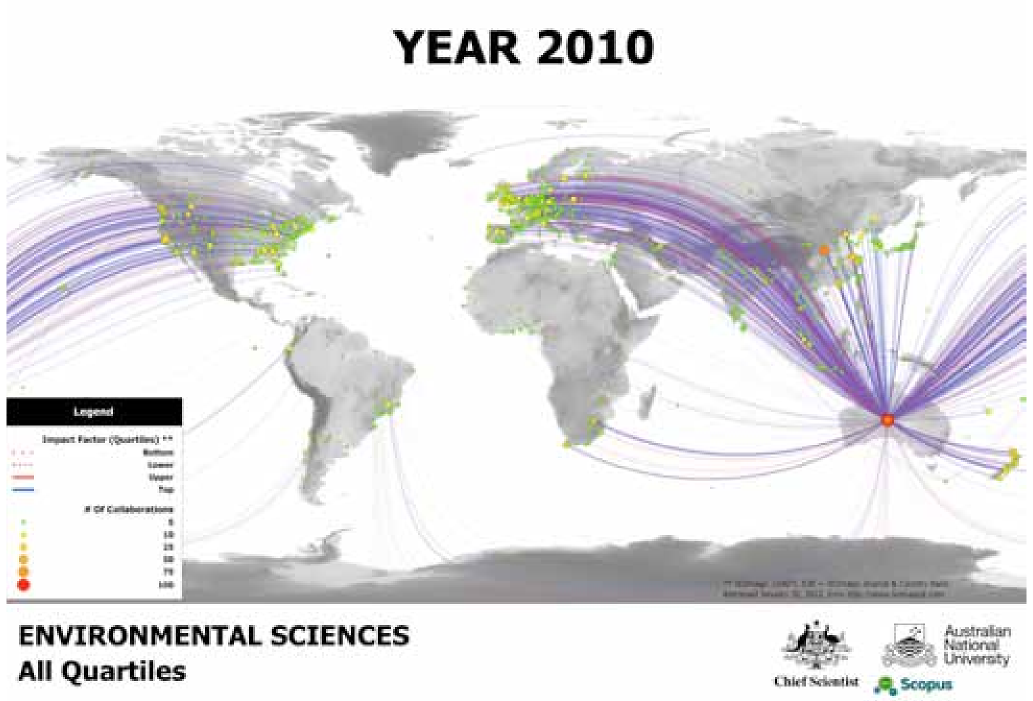
Figure 6.4.5 Australian international collaboration in Biochemistry, Genetics and Molecular Biology, 2010

In Environmental Science the volume of international co-authorship by Australian researchers also grew between 2002 and 2010 (see Figures 6.4.6 and 6.4.7) as the average impact (measured by journal impact factor) of Australian and global publications in this field grew (see also Table 6.7.4). The relative impact of Australian publications (measured against global averages) also increased during the period. In this field the map of international collaboration changed considerably, with greater relative increase in collaboration with China to become Australia's third-ranked collaboration country in this field. In addition, the period saw the emergence of collaboration in Environmental Science with Africa, the Middle East and South America where little had previously existed (see Figure 6.4.7).



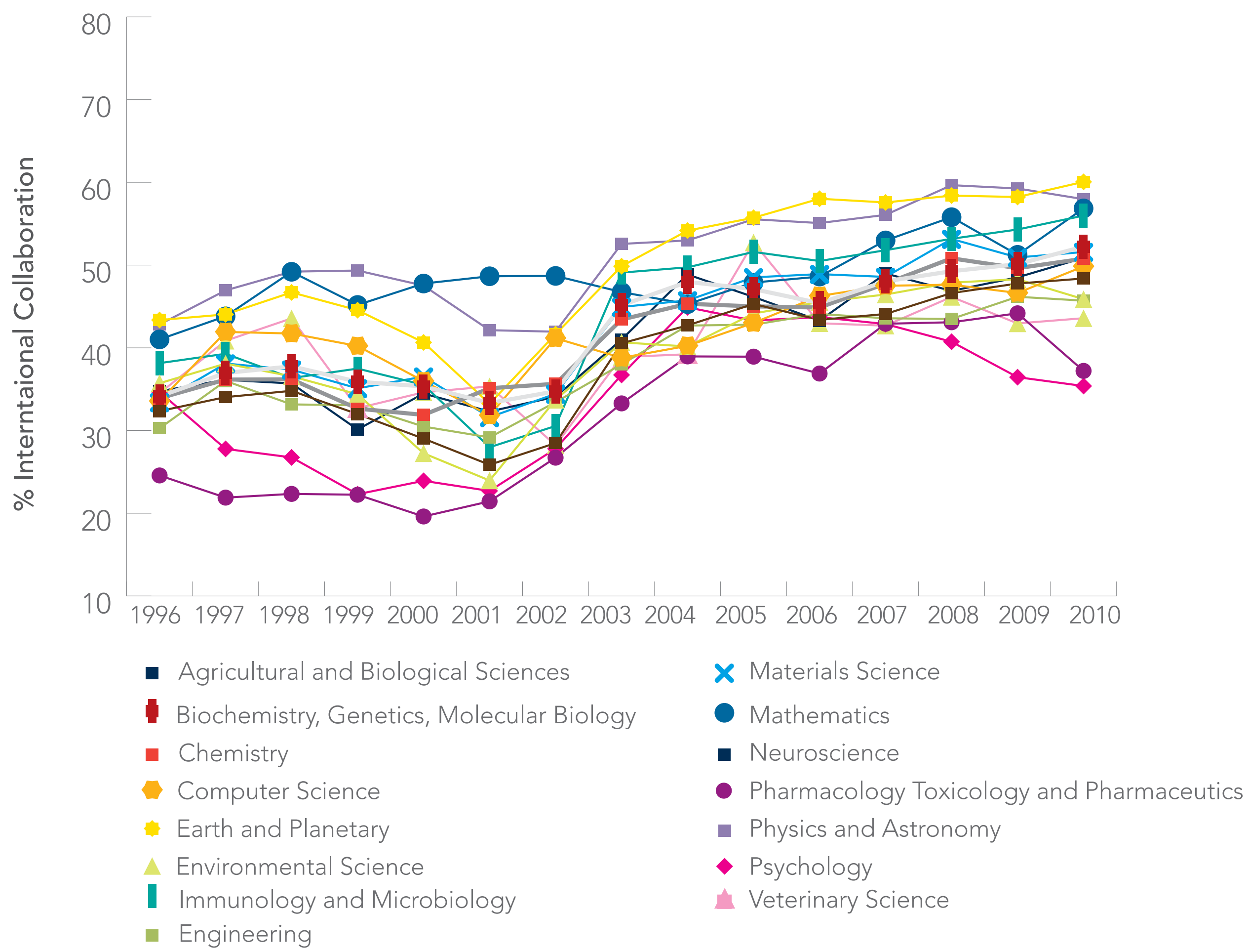
Source: Analysis and mapping by Australian National University Research Office, using Scopus data.

Figure 6.4.6 Australian international collaboration in Environmental Science, 2002



Source: Analysis and mapping by Australian National University Research Office, using Scopus data.

Figure 6.4.7 Australian international collaboration in Environmental Science, 2010



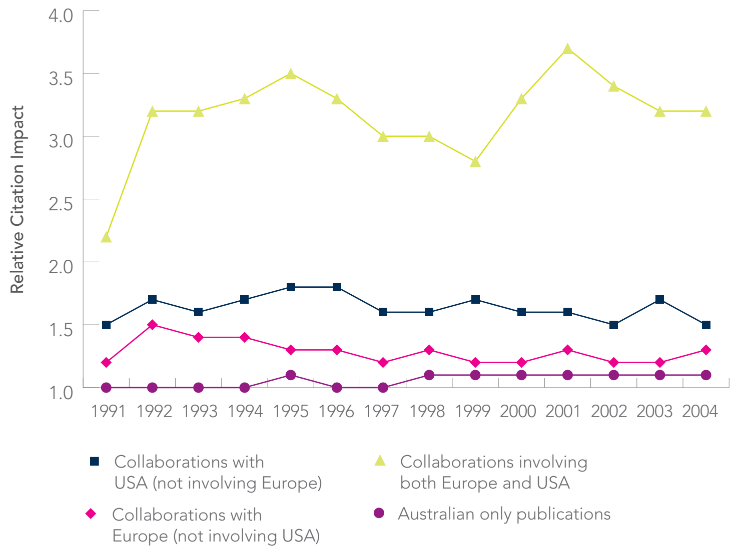
Source: SCImago data, www.scimagojr.com

Figure 6.4.8 Australian international collaboration, by field, 1996 to 2010

All fields of science showed growth in international collaboration during the 1996 to 2010 period (see Figure 6.4.8), with a dip in most fields in about 2001 to 2002. The degree of collaboration varies among disciplines, with Earth and Planetary Science, Physics and Astronomy, Mathematics, Biochemistry, and Genetics and Molecular Biology all having higher levels of international collaboration than most other disciplines.

6.5 Effect of collaboration

Co-authorship has shown a clear association with the citation impacts of publications. For example, from 1991 to 2004 collaborative publications involving US or European co-authors had higher relative citation rates than Australian-only publications, and publications with both US and European collaborators had about three times the citation rates of Australian-only publications (Matthews et al. 2009a; see Figure 6.5.1). The impacts of publications in Medical and Health Sciences, Physical Sciences, Agricultural and Veterinary Sciences, Mathematical Sciences, and Earth Sciences were particularly increased by this multilateral collaboration (Matthews et al. 2009a).



Source: Matthews et al. (2009a).

Figure 6.5.1 Relative citation rates for Australian-only publications, Australia–US, Australia–Europe and Australia–Europe–US collaborations

6.6 Relative strengths

Comparisons of research strengths, as shown by relative citation intensities, show that Australia performs well vis-à-vis its international partners in a wide range of scientific fields, among them earth science, immunology, biochemistry, space science, and ecology and environment (Matthews et al. 2010). In the Southeast Asia – Oceania region Australia leads in the number of scientific papers and citations and in other innovation indices such as the number of registered patents (UNESCO 2010).

Regional emerging nations, notably Singapore, show very strong growth in scientific output (UNESCO 2010), and Australian collaboration with Singapore is already strong (see Table 6.4.2). A comparison of Australian and EU research strengths showed Australia leading the European Union in some fields, with greater relative publication impact in geosciences, physics, plant science and animal science (Matthews et al. 2009b). Although Australia had lower relative citation impacts than the United States in the natural and physical science fields, it was closest to 'parity' with the United States in the fields of ecology and environment, space science, plant and animal science, and mathematics (Matthews et al. 2010). In terms of 'h-index'[7] (a measure of research output and impact), Australia ranked 10th from 1996 to 2009 and 9th in 2010 in research overall (SCImago 2007). Australia shows relative strengths in science compared with many European nations. For example, the EU-27 and Australia have joint strengths in earth science, physics, plant sciences and animal science, whereas Australia shows somewhat greater strength than the EU-27 in clinical medicine, ecology, mathematics, and space science (Matthews et al. 2010).

6.7 The output and impacts of Australian science

Australia has a relatively high scholarly output in science: it produces about 3 per cent of world scientific publications with only about 0.3 per cent of the world's population (DIISR 2011; Adams et al. 2010). Australian published scholarly outputs (including fields other than science) increased at a rate of about 5 per cent a year between 1999 and 2008 compared with about 4 per cent a year growth in global output over the same period (Adams et al. 2010). Australia consistently ranked 10th or 11th globally in terms of research outputs between 1996 and 2010 in Scopus-indexed publications (SCImago 2007), and 10th globally in terms of papers and total citations in Thomson–Reuters indexed publications from 2001 to 2011 (Thomson–Reuters 2011). Australian research also has a high impact relative to population: Australian publications accounted for about 4 per cent of global citations in 2004 through 2008 (Royal Society 2011).

[7]The h-index expresses the number of papers (h) that have received at least h citations. It measures both publication output and scientific impact and is scalable at multiple levels, being applicable at the individual researcher level, whole country, whole fields of research, and so on.

The Australian Research Council assessed research publication impacts by field for 2001 to 2005 in all ARC-supported research (Biglia & Butler 2009) and found citation impacts higher than global benchmarks in most fields of Natural and Physical Sciences. The pattern was similar for Australian publications in Natural and Physical Sciences between 2005 and 2010 (Thomson–Reuters Incites data; see Table 6.7.1).

Table 6.7.1 Outputs and relative impacts of Australian natural and physical science publications, 2005 to 2010

Field	Number of Publications	Number of Citations	Relative citation impact
Physical Sciences	14 158	94 987	1.42
Environmental Sciences	6 195	37 106	1.25
Earth Sciences	9 639	52 743	1.23
Mathematical Sciences	9 955	42 662	1.2
Agricultural and Veterinary Sciences	13 397	61 245	1.17
Technology	3 197	15 656	1.14
Chemical Sciences	12 938	83 765	1.11
Medical and Health Sciences	65 339	463 124	1.11
Engineering	29 907	144 414	1.05
Biological Sciences	28 881	212 411	1.0
Information and Computing Sciences	4 739	10 030	0.99

Note: Relative citation impact represents the ratio of average citations per paper divided by the global average of citations per paper in that field.
Source: InCites/Thomson–Reuters (2011).

This study assessed overall trends in Australian publications (Table 6.7.2) as well as strengths and weaknesses of science fields considered under Scopus indexing for 2002 to 2010 on the basis of both outputs and impacts (see Tables 6.7.3 to 6.7.4 and Figures 6.7.1 to 6.7.3). The assessment yields a complex pattern for the entire period and some emerging patterns when changes are examined. All fields showed growth in output, and most increased their share of global publications in their disciplines (see Table 6.7.4). With already high rates of international collaboration, all the fields considered increased their rates of international co-authorship (see Table 6.7.4).

On the basis of outputs and impacts and share of international outputs over 1996 to 2010 and 2002 to 2010, Agricultural and Biological Sciences, Earth and Planetary Sciences, Biochemistry Genetics and Molecular Biology, Immunology, and Environmental Sciences particularly show consistent strength (see Figures 6.7.1 to 6.7.3 and Table 6.7.4). Some leading fields by output and by international share do show trends over time that suggest weakening relative positions with some declines in document output and citation impact relative to international averages (see Table 6.7.4). Historically strong fields, such as agricultural sciences, engineering, nuclear physics, and some fields of medical science, show changes over the decade in terms of relative impacts and proportion of global output that suggest some weakening in their relative global positions (Table 6.7.4). It is important to note that, in assessing these fields relative to each other, apparent weaknesses can occur in an overall context of international strength (see Table 6.7.1)

Table 6.7.2 Overall Australian publication output, as indexed by Scopus, 1996 through 2010

Year	Documents	Citable Documents	Citations	Self Citations	Citations per Document	Self Citations per Document	Cited Documents	Uncited Documents	Per cent International Collaboration	Per cent Region	Per cent World
1996	21 945	21 081	494 833	102 021	22.6	4.7	19 635	2 310	33.3	83.2	1.9
1997	22 982	22 138	507 482	104 062	22.1	4.5	20 571	2 411	34.4	83.1	2.0
1998	23 745	22 713	567 986	113 100	23.9	4.8	21 172	2 573	34.1	82.8	2.0
1999	24 215	22 843	554 310	112 153	22.9	4.6	21 585	2 630	31.5	82.6	2.1
2000	25 155	23 557	563 133	113 395	22.4	4.5	22 069	3 086	30.4	83.7	2.1
2001	26 241	24 502	560 254	115 990	21.4	4.4	22 785	3 456	27.6	84.1	2.0
2002	27 239	25 352	546 229	114 467	20.1	4.2	23 568	3 671	30.2	84.3	2.0
2003	30 920	28 815	579 237	123 511	18.7	4.0	26 809	4 111	38.8	84.3	2.2
2004	33 783	31 552	577 844	122 254	17.1	3.6	28 636	5 147	41.9	84.6	2.1
2005	37 214	34 788	531 045	118 527	14.3	3.2	30 986	6 228	42.5	84.2	2.1
2006	41 734	38 908	498 201	115 941	11.9	2.8	33 744	7 990	42.4	84.8	2.3
2007	44 586	41 581	430 007	102 341	9.6	2.3	35 197	9 389	43.5	85.0	2.3
2008	48 583	44 985	348 469	86 077	7.2	1.8	36 613	11 970	44.2	85.1	2.4
2009	52 645	48 596	230 409	61 134	4.4	1.2	35 647	16 998	44.8	85.9	2.5
2010	59 058	53 838	94 556	27 676	1.6	0.5	27 306	31 752	43.8	86.4	2.7

Note: 'Region' in this analysis is defined by Scopus as including Australia, New Zealand, Indonesia, Papua New Guinea, Fiji, New Caledonia, and Pacific islands other than the Northern Marianas (www.scimagojr.com/countrysearch.php?region=Pacific Region).
Source: SCImago, Australian Country Report, www.scimagojr.com/countrysearch.php?country=AU.

Table 6.7.3 Australian output in selected science fields, over the period 1996 through 2010

Field	Number of Documents	Citations per document (average)	Per cent world	Per cent region (average)
Agricultural and Biological Sciences	46321	11.0	4.2	77.8
Biochemistry, Genetics and Molecular Biology	41152	18.9	2.4	86.6
Chemistry	16629	14.1	1.6	85.8
Computer Science	18295	6.8	2.2	86.4
Earth and Planetary Sciences	24346	12.2	4.0	82.4
Engineering	29274	6.4	1.5	88.5
Environmental Science	22148	12.4	3.8	79.1
Immunology and Microbiology	14099	19.0	3.0	87.0
Materials Science	14805	9.7	1.5	88.7
Mathematics	15531	5.3	2.3	84.7
Neuroscience	8015	17.9	2.9	85.7
Pharmacology Toxicology and Pharmaceutics	7424	12.6	1.7	84.5
Physics and Astronomy	19956	10.3	1.7	89.2
Psychology	8181	10.2	3.7	83.1
Veterinary Science	3198	6.8	2.4	73.5

Note: Outputs in these fields accounted for approximately 79 per cent of all Australian publications indexed by Scopus for 1996 to 2010 and approximately 71 per cent in 2010.
Source: SCImago data, www.scimagojr.com

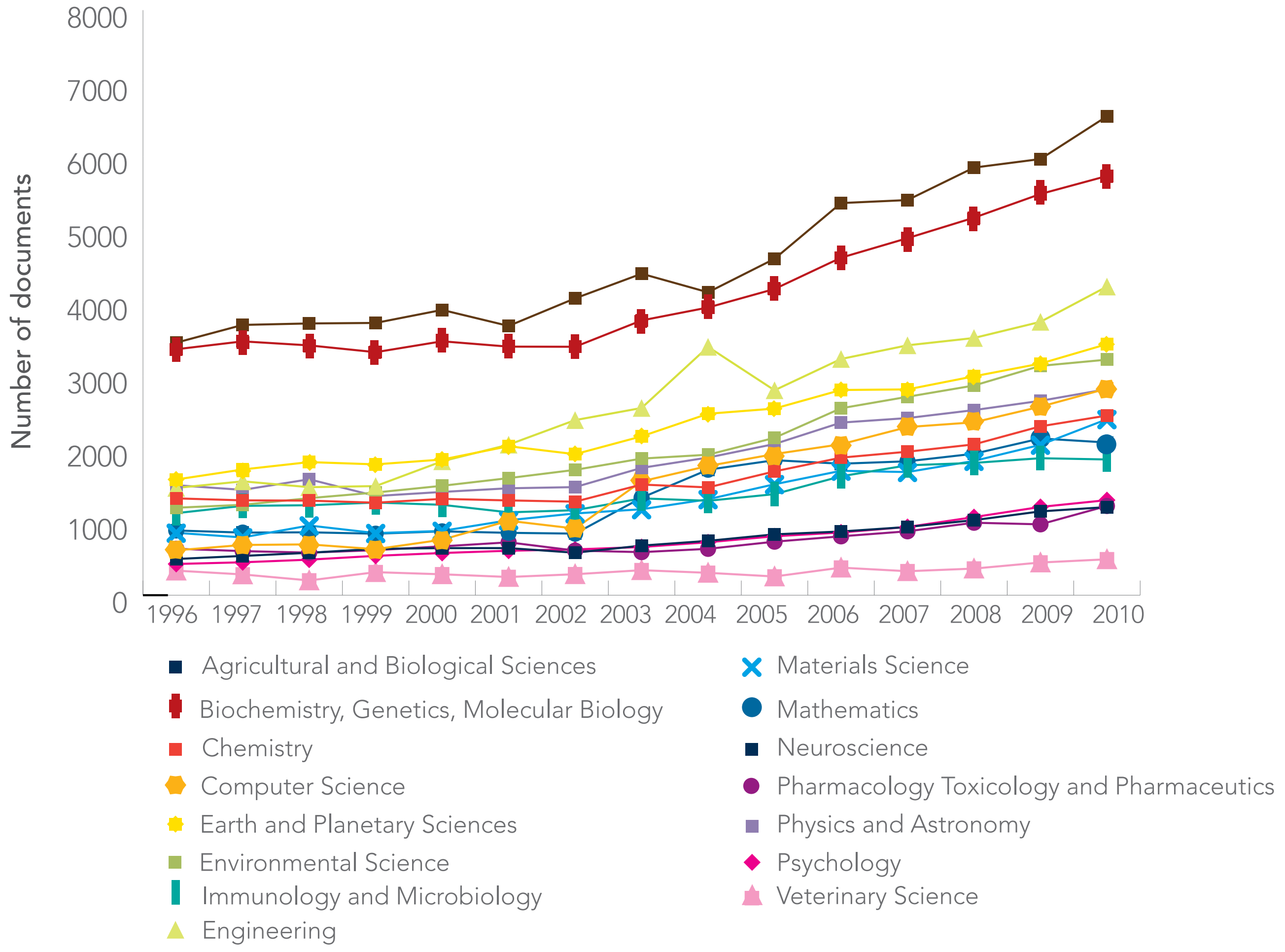
Table 6.7.4 Trends in scientific output and impact: selected fields of research, 2002 to 2010

Field/Year	Total publications	Australian-only publications	International co-authored publications	Per cent international co-authored	Per cent of world	Average Australian Impact Factor (IF)	Australian IF/ Global IF	Average global Impact Factor (IF)
Agricultural and Veterinary Sciences								
2002	1258	882	376	29.9	4.8	1.20	1.09	1.10
2010	2376	1298	1078	45.4	4.4	1.78	1.36	1.31
Biochemistry, Genetics and Molecular Biology								
2002	3621	2401	1220	33.7	2.3	3.41	0.94	3.61
2010	6930	3328	3602	52.0	2.8	4.32	1.13	3.81
Molecular Biology								
2002	387	273	114	29.5	1.9	4.01	0.93	4.33
2010	1559	673	886	56.8	2.7	4.53	1.09	4.15
Chemistry								
2002	1271	876	395	31.1	1.3	2.04	1.03	1.99
2010	3344	1703	1641	49.1	1.8	3.28	1.18	2.77
Computer Science								
2002	958	629	329	34.3	1.7	0.92	1.21	0.76
2010	5664	3108	2556	45.1	2.1	1.70	1.29	1.32
Earth and Planetary Sciences								
2002	2040	1123	917	45.0	3.3	1.87	1.22	1.53
2010	3675	1376	2299	62.6	4.3	2.22	1.31	1.69

Field/Year	Total publications	Australian-only publications	International co-authored publications	Per cent international co-authored	Per cent of world	Average Australian Impact Factor (IF)	Australian IF/ Global IF	Average global Impact Factor (IF)
Engineering								
2002	2726	1867	859	31.5	1.3	0.77	1.35	0.57
2010	7083	3860	3223	45.5	1.8	1.76	1.33	1.32
Environmental Science								
2002	1856	1334	522	28.1	3.5	1.44	1.08	1.33
2010	3663	2084	1579	43.1	4.0	2.26	1.11	2.04
Immunology & Microbiology								
2002	1359	965	394	29.0	2.8	3.34	1.02	3.26
2010	1829	791	1038	56.8	3.0	4.53	1.21	3.73
Materials Science								
2002	1447	1011	436	30.1	1.4	1.13	1.13	1.00
2010	3776	1802	1974	52.3	1.8	2.49	1.33	1.87
Mathematics								
2002	893	482	411	46.0	2.0	0.76	0.95	0.80
2010	3003	1393	1610	53.6	2.1	1.11	1.17	0.95
Medicine (non-clinical)								
2002	3950	3285	665	16.8	1.2	2.36	1.09	2.16
2010	5548	3538	2010	36.2	0.9	3.52	1.33	2.65
Neuroscience								
2002	989	685	304	30.7	2.4	2.95	0.96	3.08
2010	2087	1112	975	46.7	3.9	3.48	0.99	3.50
Pharmacology								
2002	855	673	182	21.3	1.6	2.20	1.26	1.74
2010	1475	814	661	44.8	1.9	3.19	1.34	2.38

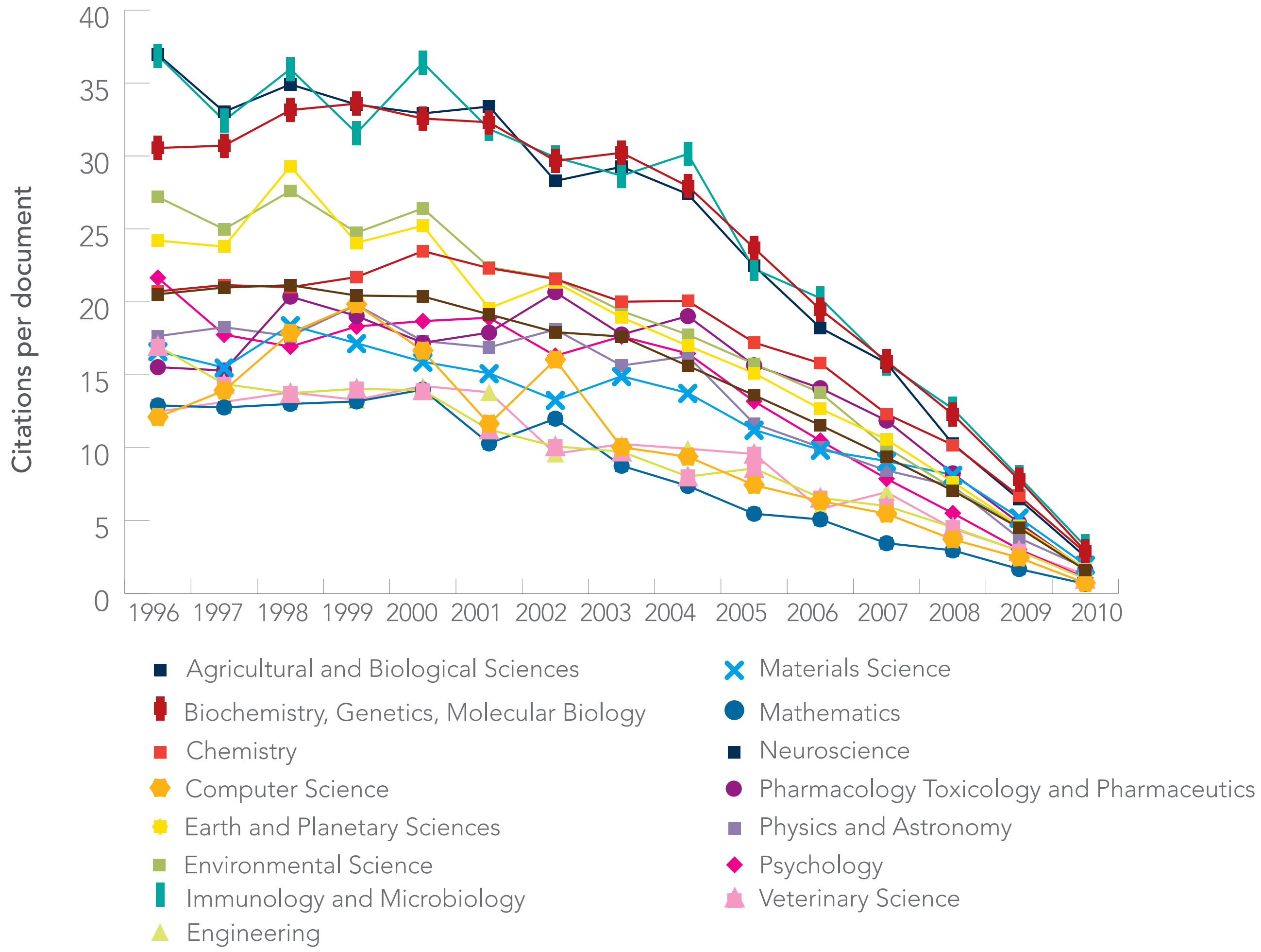
Field/Year	Total publications	Australian-only publications	International co-authored publications	Per cent international co-authored	Per cent of world	Average Australian Impact Factor (IF)	Australian IF/ Global IF	Average global Impact Factor (IF)
Physics & Astronomy								
2002	2080	1207	873	42.0	1.4	1.70	1.18	1.44
2010	4948	1980	2968	60.0	1.9	2.16	1.29	1.67
Psychology								
2002	973	735	238	24.5	3.4	1.35	0.97	1.39
2010	1960	1235	725	37.0	4.3	2.09	1.09	1.91
Nuclear and High-Energy Physics								
2002	153	73	80	52.3	1.3	2.25	1.10	2.05
2010	225	85	140	62.2	1.3	1.87	1.13	1.65

Note: Analysis carried out by Australian National University Research Office. For this analysis Agricultural and Veterinary Science is an aggregation of AJSC codes 1102, 1104, 1107, 1108, 1111, 3402, 3403; to best overlap with ANZSRC Code 07, 'Agricultural and Veterinary Sciences.' Impact Factor as used in this table reflects the impact factors of the journals in which the publications analysed appeared, in the years in which they were published. The impact factor of a journal is the average number of citations received per paper published in that journal during the two preceding years.
Source: Data from Elsevier–Scopus.



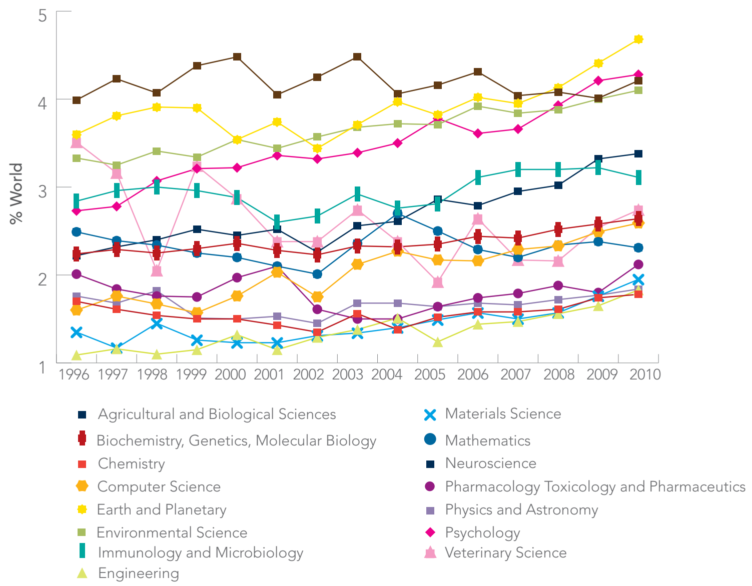
Source: SCImago data, www.scimagojr.com

Figure 6.7.1 Australia's document outputs, by field, 1996 to 2010



Note: The apparent drop in citation rates in recent years is a consequence of the time lag between papers being published initially and citations of them appearing in the literature. Note the stabilisation of citation rates for papers older than about 8 to 10 years.
Source: SCImago data, www.scimagojr.com

Figure 6.7.2 Australia's citations per document by field, 1996 to 2010



Source: SCImago data, www.scimagojr.com.

Figure 6.7.3 Australia's document outputs as proportion of world publications, by field, 1996 to 2010

6.8 Conclusions

Growth in internationally collaborative publications is a major source of overall growth in Australian research outputs. Whereas overall publication output by Australian researchers approximately doubled between 2002 and 2010, internationally co-authored publications more than tripled. Growth in internationally co-authored publications appears, however, to have levelled off between 2008 and 2010.

International collaboration (the number of grants on which there is international collaboration) in most Australian Research Council funding schemes increased along with co-authorship. A mechanism now exists across all ARC funding schemes to engage in international collaboration. This may in part address the challenges of sustaining international scientific engagement, which is increasingly necessary to achieve high-impact research.

The global landscape of collaboration is changing. Although growth with historically strong regions of collaboration in North America and Europe continues, collaboration is growing most rapidly in emerging areas of scientific strength, especially in Asia. Overall, China is now Australia's third-largest national partner in publication collaboration.

In several fields of research—such as chemistry, engineering and mathematics—China is now Australia's leading partner in collaboration by co-authorship. Australia's collaboration with Asian nations is still lower in volume in most fields compared with historically important partners such as the United States and Europe. Growth in Australian–Asian collaboration has, however, equalled or exceeded Asian nations' growth in collaboration with the world and with the United States. Moreover, the 'intensity' of collaboration (bilateral engagement's proportion of total global engagement), reveals deep engagement with partners in our region and elsewhere—such as Singapore, New Zealand and South Africa.

Overall, international collaboration is greatest in earth sciences, physics and biological sciences such as biochemistry, genetics, molecular biology and immunology: in these fields more than half the publications have international co-authors.

The pattern of increasing engagement with Asian nations is not uniform. Fields such as environmental sciences, chemistry, engineering, and mathematics exemplify the trend towards deepening engagement with China.

All the fields of science considered for this report showed growth in publication outputs during the past decade. Australia retains a high and growing share of global publications, and it has higher than global, and generally growing, impact in most fields of research analysed. It also retains a steady, high ranking globally in research outputs in a context of emerging national science centres, particularly in Asia, moving up the global ladder. This historical stability is robust despite the choice of metric: Australia has held a ranking of 11th by publication volume and 10th by 'h-index' for most of the period from 1996 to 2010.

Most fields of science show this pattern, and most fields' share of global publications have increased in the past decade. Some fields, such as computer science, show particularly high rates of publication growth from 2002 to 2010. Conversely, historically strong fields in terms of both output and international share—such as agricultural sciences, engineering, nuclear physics, and some fields of medical sciences—show decadal trends that suggest some weakening in their relative global positions.

7. STRENGTHS, VULNERABILITIES AND OPPORTUNITIES

The discussion here integrates many of the findings from earlier chapters in order to identify the strengths, vulnerabilities and opportunities associated with Australia's science system.

Four fields of science—mathematics, physics, chemistry and agricultural sciences—are presented as case studies later in the chapter. Each case study presents trends in secondary school participation (except agriculture), university education from undergraduate through to higher degree research programs, the demand for graduates, the Excellence in Research for Australia ratings for the fields and sub-fields under consideration, research funding, research outputs and impacts through publication, and patterns in international collaboration.

7.1 Main findings

Australian science's primary areas of strength lie in its research outputs and international connections:

- Most fields of the Natural and Physical Sciences show research performance at or above international standards.
- Australia has produced a high and growing proportion of global publications relative to population, with higher than global average impacts. This historical pattern continues.
- The Australian research community is increasingly connected to the global science community through collaboration in relation to grants and large-scale international projects, co-authorship on papers, and other forms of interaction such as international visits, student enrolment and symposia.

The vulnerabilities lie mainly in the educational foundations, staffing levels and funding structures that are needed to sustain and build on the historical successes of Australian science:

- Participation rates for the enabling subjects of mathematics, chemistry and physics have been declining in secondary schools.
- The academic staffing profile could pose challenges for maintaining capability in research areas as senior researchers at level E begin to retire; particularly if there is an insufficient proportion at level C to take up research leadership roles.
- A gender imbalance in the enabling sciences shows women accounting for smaller percentage shares in scientific careers and at senior academic levels. In physics, for example, women account for only 21 per cent of academic staff. The imbalance could represent difficulties in sustaining the scientific workforce if a large proportion of talented potential scientists do not take up science careers.
- Student participation in the enabling sciences at tertiary level has been in long-term decline. Continuing science undergraduates' participation in mathematics, physics and chemistry declined during the 1990s and did not recover during the 2000s.
- The funding necessary for supporting basic research is increasing, but at the same time there is greater competition for grants and fellowships, especially for younger researchers.

Some potential opportunities arise from the challenges:

- If the gender imbalance that exists in many of the science disciplines were redressed employers would have access to a potentially larger high-quality pool of science graduates who may take up research in vulnerable disciplines or other STEM and non-STEM careers.
- Declining success rates in competitive grant schemes suggest there is considerable capacity for rapidly increasing the amount of high-quality research that is delivered.
- International students account for an increasing number and proportion of the total tertiary science cohort. This offers an opportunity to expand the research workforce and to build on growth in international collaborations. Vulnerability could emerge, though, if the higher education sector were to become overly dependent on international enrolments for sustaining tertiary science education.

7.2 Sectoral strengths, vulnerabilities and opportunities

The analysis of Australian science reveals a mosaic of strengths, vulnerabilities and opportunities between and within fields and between and within sectors. Many of the key findings from previous chapters are presented in Table 7.2.1 and have been colour-coded to represent a generalised continuum—ranging from strength through to vulnerability. The assigned classification is of course debatable and will depend on different viewpoints and the scale of consideration. Nevertheless, there is a robust overarching pattern in the table. Australian science—in terms of research funding, output and collaboration (the right-hand side of the table)—is broadly healthy with many examples of strength. On the other hand, the supply pipeline to the research workforce and the workforce generally (the left-hand side of the table) display many examples of vulnerability or potential vulnerability. The details are presented in the remainder of this section.

7.2.1 Schools

Analysis of longitudinal data shows that the majority of students who specialise in science subjects in the final year of secondary school go on to pursue science-related study at university (Ainley et al. 2008). National participation rates for enabling subjects in Year 12 have been in gradual but persistent decline. Several trends in participation rates for biology, and the enabling sciences of mathematics, physics, and chemistry are apparent from Figure 3.2.1. An overall decline is observed in the participation rates for physics, chemistry and biology since 1992. Biology, however, remains the most common science subject among Year 12 students. Although the estimation of national participation rates for mathematics is confounded by the various levels of mathematics taught at schools and by inter-jurisdiction differences, participation rates for all levels of mathematics were also in decline between 2002 and 2010.

7.2.2 Higher education

The declining participation rates for enabling science subjects in schools have repercussions for the size and quality of the student cohort available for science education at the tertiary level.

Science in the higher education sector is characterised by a blend of strengths and potential vulnerabilities. This is readily apparent if one examines the teaching of science disciplines to domestic (that is, non-international) students between 2002 and 2010 (International student trends are discussed at the end of Chapter 4).

A clear strength in science is the dominance of Biological Sciences as a discipline taught to science students (for example, those enrolled in a BSc or similar degree course). Subjects taught in the Biological Sciences were the most common among science students at all course levels (see Section 4.4.3). Further, the commonality of Biological Sciences for undergraduates persisted beyond commencing science students to continuing science undergraduates (see Figure 4.4.19). The one course level for which Biological Sciences declined in absolute terms is commencing HDR students (see Figure 4.4.26).

A further strength of the Natural and Physical Sciences in higher education is the amount of service teaching. At the undergraduate level science is a major service teaching discipline—service teaching being where students enrolled in a particular degree (say, Engineering) take subjects in disciplines outside of that degree (say, mathematics).

Table 7.2.1 Australian science: strengths, vulnerabilities and opportunities

Field of education	School	University (undergraduate)	University (higher degree by research)	Research funding	Research output and international collaboration
NATURAL AND PHYSICAL SCIENCES		Overall, N&PS commencing enrolments were flat from 2002 to 2008 N&PS commencing enrolments grew 30 per cent in 2009 and 2010	HDR commencements steady from 2002 to 2010		
Biology	Declining participation rate from 1992 to 2010 but remains the most popular	Most popular discipline for N&PS undergraduates: contributes half of continuing student load and half of honours load Continuing biology load for N&PS undergraduates grew from 1989 to 2000 and from 2002 to 2010	Most popular discipline for N&PS HDR students, accountin for nearly half of student load Commencing biology HDR load declined fromr 2002 to 2010 but from a high base	Increasing share of ARC funding 2002 to 2009 Declining success rates in ARC 2002 to 2008 Stable number of grants in ARC 2002 to 2010	Increase in number of papers, impact and international collaboration 2002 to 2010
Chemistry	Declining participation rate from 1992 to 2010	Continuing chemistry load for N&PS undergraduates declined from early 1990s to 2000 then steady from 2002 to 2010 Chemistry honours steady from 2002 to 2010 Both genders well represented at the continuing undergraduate level	Commencing HDR load changed little from 2002 to 2010	Increase in ARC funding 2002 to 2010 Small decrease in number of projects in ARC since 2003 Declining success rates in ARC 2002 to 2008 Declining proportion of overall R&D spend since 1997"	Increase in number of papers, percentage of global publications and international collaboration 2002 to 2010 Peak in relative impact in 2008 to 2009 Low critical mass of researchers
Earth Sciences	Low and static participation rate from 1992 to 2007	Continuing load for N&PS undergraduates is low but growing Earth Sciences honours declined from 2002 to 2007 then recovered those losses from 2008 to 2010	HDR load in Earth Sciences declined 45 per cent from 2002 to 2010 Commencing HDR load recovered somewhat in 2009 and 2010	Increase in ARC funding 2002 to 2010 Declining success rates in ARC 2002 to 2008 Decreasing number of projects in ARC since 2003	Increase in number of papers, impact and international collaboration 2002 to 2010 Highest level of international collaboration 2010 High relative impact 2005 to 2010 Low critical mass of researchers
Mathematics	Declining participation rate from 2002 to 2010 but from a high base Shift from advanced to elementary level mathematics	Contributes 20 per cent of commencing N&PS student load; drops to 10 per cent for continuing students Continuing load for N&PS undergraduates declined from early 1990s to 2000, then steady from 2002 to 2010 Female students take only a third of load at continuing undergradute level Honours load grew 50 per cent from 2002 to 2010, albeit from a low base	Least popular science discipline for commencing HDR students Commencing HDR load declined 30 per cent from 2003 to 2010 Increase in honours load (2002 to 2010) has not led to increase in HDR load	Increased ARC funding 2002 to 2010 Decreasing number of projects in ARC since 2003 Declining share of overall R&D spend since 1997 Stable success rates in ARC 2002 to 2008	Increase in number of papers, impact and international collaboration 2002 to 2010 Decrease in percentage of global publications since 2004 Low critical mass of researchers
Physics	Declining participation rate from 1992 to 2010	Least popular N&PS discipline for continuing science undergraduates Continuing load for N&PS undergraduates declined from early 1990s to 2000, then steady from 2002 to 2010 Female students take only a quarter of load at continuing undergradute level Honours load grew 60 per cent from 2002 to 2010, albeit from a low base	Commencing HDR load changed little from 2002 to 2010 Increase in honours load has not led to an increase in HDR load	Small increase in number of projects in ARC 2002 to 2010 Increase in ARC funding 2002 to 2010 Declining success rates in ARC 2002 to 2008 Declining share of overall R&D spend since 1997	Increase in number of papers, impact and international collaboration 2002 to 2010 High relative impact over 2005 through 2010 Nuclear Physics: no growth in percentage of global publications 2002 to 2010 Low critical mass of researchers Nuclear Physics trend toward decreased impact 2002 to 2010
AGRICULTURAL SCIENCES	Not applicable	Bachelor's enrolments (in Agriculture and Environment) declined 11.1 per cent from 2001 to 2010; completions declined by 20.4 per cent Completion rate below system-wide average Teaching to undergraduate students in the narrow discipline of Agriculture declined by 18.3 per cent for commencing students and 31 per cent for continuing students (2002 to 2010).	Commencing HDR enrolments remained steady over 2002 to 2010 Agriculture remains the most commonly taught narrow discipline at HDR level, at a low base	Overall increase in ARC funding 2002 to 2010 Declining success rates in ARC 2002 to 2008 Declining share of overall R&D spend since 2001 Large decrease in principal R&D funding source through state and territory governments since 1992 Decreased number of projects in ARC since 2004	Highest overall percentage of global publications 2002 to 2010 Increase in number of papers and international collaboration 2002 to 2010 Trend of decrease in percentage of global publications 2002 to 2010 Low critical mass of researchers
ENGINEERING	Not applicable	Annual bachelor's completions increased 23 per cent from 2002 to 2010 but completion rate is below system-wide average Males students are over-represented in commencing undergraduate enrolments International enrolments grew much faster than domestic	Annual HDR completions grew 8 per cent from 2002 to 2010 International enrolments grew much faster than domestic	Increase in ARC funding and projects 2007 to 2010 Declining success rates in ARC 2002 to 2008 Level of funding as a proportion of total ARC spend maintained from 2002 to 2010	Increase in number of papers and international collaboration 2002 to 2010 High relative impact 2002 to 2010 Trend of decrease in relative impact 2002 to 2010 Chemical and Geomatic Engineeering research ranked below world standard 2006 to 2008
INFORMATION AND COMMUNICATION TECHNOLOGY	Not applicable	Enrolments and completions fell by about 50 per cent from 2002 to 2010 Completion rate is below system-wide average Males students are over-represented in commencing undergraduate enrolments International undergraduate enrolments also fell, but less than the drop in domestic enrolments	HDR completions increased from a low base of 105 to 159 from 2002 to 2010 Enrolments by international students growing much faster than those by domestic students	Declining success rates in ARC 2002 to 2008 Decreased number of projects in ARC 2002 to 2009	Increase in number of papers, impact and international collaboration 2002 to 2010 High growth in papers 2002 to 2010
HEALTH AND MEDICAL SCIENCE	Not applicable	Commencing enrolments grew by more than 70 per cent from 2002 to 2010 Completion rate is above system-wide average Females students are over-represented in commencing undergraduate enrolments.	Commencing HDR enrolments grew by 20.7 per cent from 2002 to 2010	Increase in proportion of ARC funding 2002 to 2009 Increase in number of projects in ARC and NHMRC 2002 to 2010 Declining success rates in ARC and NHMRC 2002 to 2011	Increase in number of papers, impact and international collaboration 2002 to 2010 Immunology has high percentage of global publications 2002 to 2010 Trend of decrease in percentage of global publications 2002 to 2010 (Non-Clinical Medical Science) Neuroscience below global average impact 2002 to 2010

Not applicable or neutral
Possible vunerability
Vunerability
Overall strength

About half of all science teaching between 2002 and 2010 was service teaching (see Figure 4.4.11), and the most common disciplines for service teaching were mathematics and biology (see Figure 4.4.16). A large part of this service teaching was provided to students enrolled in Engineering and Health courses (see Figure 4.4.15). Most service teaching was received by students in their commencing year (see Figure 4.4.13).

The potential vulnerabilities of science centre on the teaching of enabling sciences and the gender imbalance among students of those sciences. Teaching in mathematics, chemistry and physics to continuing undergraduates remained relatively flat from 2002 to 2010 and did not recover from the big declines of the 1990s (see Figure 4.4.30). The higher education sector has undergone considerable expansion in the past two decades, but teaching in the enabling sciences has declined in absolute terms (see Figure 4.4.29).

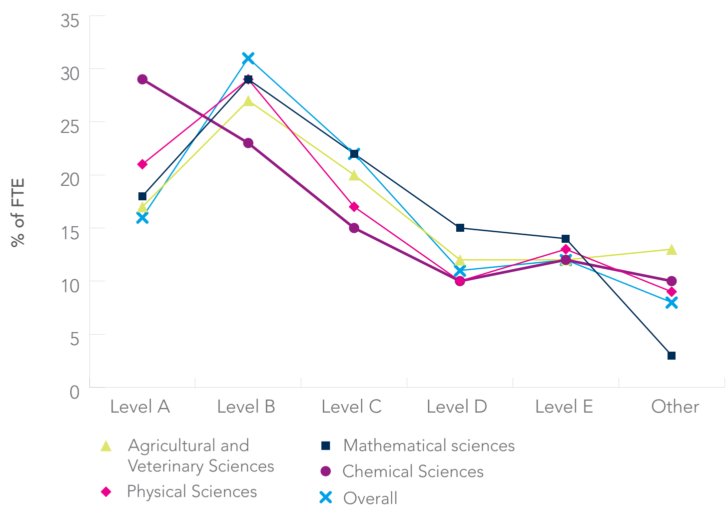
The gender-based distribution of teaching in the enabling sciences suggests an uneven tapping of the potential talent pool (Dobson 2012). Female students are less inclined than males to study enabling sciences at the continuing undergraduate level. They are particularly under-represented in the study of mathematics (35 per cent in 2010) and physics and astronomy (24 per cent in 2010) at the continuing undergraduate level (see Figures 7.3.2 and 7.3.11).

Another important determinant of the trends in higher education enrolments from 2002 to 2010 was the increasing number of enrolments by international students: these enrolments increased by 150 215, or 81.2 per cent (Dobson 2012). In comparison, domestic enrolments increased by a similar magnitude in absolute terms (145 821) but with a much lower level of growth—only 20.5 per cent (Dobson 2012).

International student enrolments in science courses grew faster in the 2000s than domestic enrolments did; the proportion of international student enrolments (all course levels) in Natural and Physical Sciences increased from 10.2 per cent in 2002 to 17.4 per cent in 2009 (Dobson 2012). International PhD enrolments in Natural and Physical Sciences increased from 945 in 2002 to 2479 in 2010, representing growth of 162.3 per cent (Dobson 2012).

7.2.3 Staffing profiles

As of 2006 to 2008 the full-time equivalent staffing profiles in universities for most fields of science show the majority of staff working at level B (see Figure 7.2.1). Most science fields show a sharp drop in relative staff proportions from level B to level C, with minima in staffing at level D for some disciplines. This pattern could represent vulnerabilities in terms of maintaining capacity in research; especially if shortages of senior researchers occur as a consequence of level D and level E staff retiring at a greater rate than the supply of level C researchers coming through.



Source: ARC (2011a).

Figure 7.2.1 Staffing profiles for broad discipline fields and the overall staffing profile across all academic disciplines, 2006 to 2008

Environmental Sciences, Earth Sciences, Mathematical Sciences, Physical Sciences, Chemical Sciences, and Agricultural and Veterinary Sciences had the lowest higher education staffing levels measured by the ERA audit (ARC 2011a), with approximately 1000 or fewer full-time equivalent (FTE) staff within each discipline. These levels were far lower than staffing in the next highest field, approximately 1800 FTE. Medical and Health Sciences had the largest FTE at 4581. Low academic staffing levels may present a challenge to maintaining critical mass in research capacity.

7.2.4 Funding

Overall strength is shown by growth in funding in competitive grant schemes administered by the Australian Research Council and the National Health and Medical Research Council in the past decade.

Vulnerabilities emerge from this increase in funding being accompanied by greater competition for grants. Specifically, success rates (the proportion of successful grant applications) in ARC grant schemes fell in the past decade (see Section 5.3). Funding rates (funding granted as opposed to funding sought) for successful proposals also fell. Similarly, NHMRC success rates declined as applications grew between 2000 and 2011, suggesting that a growing body of high-quality science project proposals has gone unfunded (see Section 5.4).

Another indicator of vulnerability can be found in levels of access to research funding for early career researchers and postdoctoral fellows. Success rates for ECRs followed the general downward trend for success rates in ARC schemes, and the number of ECR-only proposals dropped (see Section 5.3).

Trends in appropriations to the main government portfolio research agencies varied in the past decade (see Figure 5.2.2). In real terms, expenditure through CSIRO rose 9.5 per cent, and through DSTO it rose 25 per cent. Appropriations to ANSTO fell 20 per cent, and those to the Australian Institute of Marine Science and Geoscience Australia were essentially unchanged.

7.2.5 Research impacts and international collaboration

Australia maintains higher than global average impact as well as a high and growing share of global publications in most fields of research. Growth in internationally collaborative publications is a major source of growth in Australian research publication output. Whereas overall publications approximately doubled between 2002 and 2010, internationally co-authored publications more than tripled (see Section 6.4).

The pattern of international collaboration is changing and this may present opportunities. Although growth in historically strong collaborations with North America and Europe continues, much faster growth is occurring with emerging areas of scientific strength in Asia. In several fields of research—including two of the fields profiled in this chapter (mathematics, engineering and chemistry)—China is now Australia's leading partner in collaboration (see Section 6.4).

Funding support for international collaboration is now integrated across National Competitive Grants Program funding schemes, and this provides an opportunity to increase international engagement and deliver high-impact research outputs for Australia. Growth in international collaboration in relation to research grants in most ARC funding schemes increased, but it was less than the growth in internationally co-authored papers (see Section 6.4). This possibly suggests that international collaboration is presently being supported more by overseas sources or sources independent of ARC grants.

7.3 Case studies

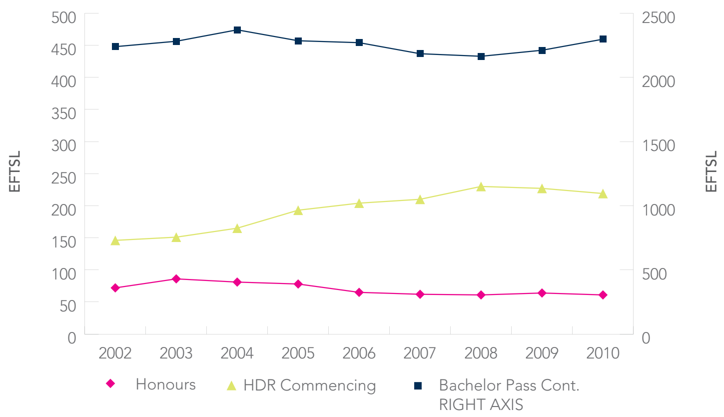
As noted, four fields of science—mathematics, physics, chemistry and agricultural science—are presented here in order to illustrate the strengths, vulnerabilities and opportunities associated with Australia's science system.

7.3.1 Mathematics

Mathematics is arguably the most fundamental enabling science, underpinning scientific research and innovation in all other areas of natural and physical science as well as being central to social sciences such as economics and demography. Mathematical sciences play a crucial role in a broad and diverse range of settings, among them data analysis, forecasting, modelling, risk assessment and design. For example, the use of number theory in internet security and the use of Fourier transforms in the development of wi-fi technology have their basis in fundamental mathematics. Biostatistics, a branch of mathematical sciences, is central to analysing the rapidly expanding body of data in genomics, which in turn is central to research efforts in medicine and agriculture, for example.

University student load in Mathematical Sciences

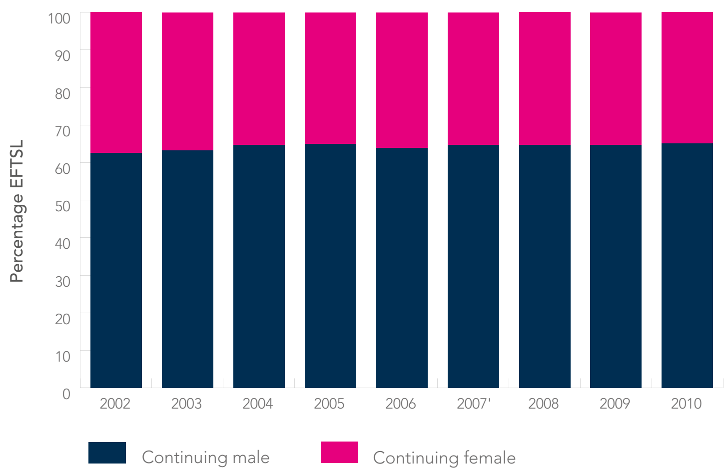
Trends in the study of Mathematical Sciences at Australian higher education institutions show potential vulnerability. Teaching of Mathematical Sciences to continuing (second- or third-year) undergraduates enrolled in Natural and Physical Sciences broadly remained stable within 400 to 500 EFTSL (equivalent full-time student load) between 2002 and 2010 (see Figure 7.3.1). In contrast, teaching at honours level increased by 57.6 per cent, from a low base of 139 EFTSL in 2002 to 219 EFTSL in 2010. This growth in teaching at the honours level has not, however, translated to an increase in HDR (higher degree by research) enrolments in the Mathematical Sciences; the commencing HDR EFTSL declined from 86 EFTSL in 2003 to 61 EFTSL in 2010.



Source: DEEWR Higher Education Statistics.

Figure 7.3.1 Teaching of Mathematical Sciences, by course level

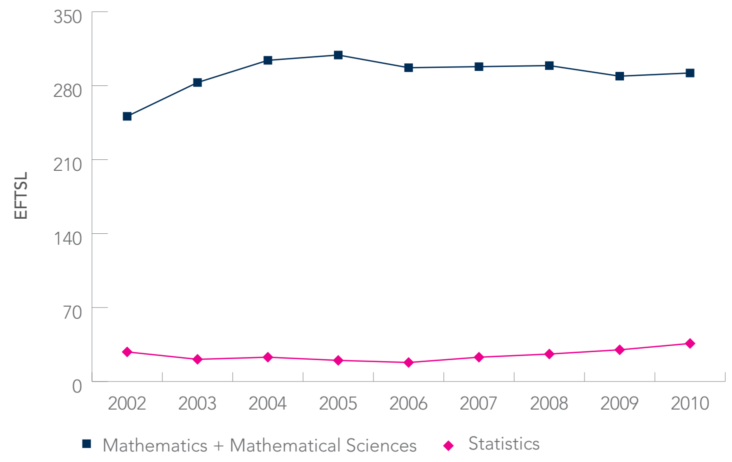
An analysis of mathematics teaching to continuing science undergraduates reveals a gender imbalance: only a third of Mathematical Sciences teaching in Natural and Physical Sciences bachelor's courses was to female students between 2002 and 2010 (see Figure 7.3.2).



Source: DEEWR Higher Education Statistics.

Figure 7.3.2 Gender proportions in Mathematical Sciences load: bachelor's students in Natural and Physical Sciences

Mathematical Sciences includes detailed disciplines and subjects related to mathematics and statistics. Figure 7.3.3 shows the distribution of EFTSL between mathematics- and statistics-related disciplines at the HDR level (for both commencing and continuing HDR students). Mathematics disciplines other than statistics initially increased from 251 EFTSL in 2002 to 309 EFTSL in 2005, or by 23.1 per cent. After 2005 it remained steady. The growth in 2002 to 2005 might have been a result of earlier growth in commencing HDR students, before 2002. Statistics disciplines at the HDR level was limited, accounting for less than 50 EFTSL a year between 2002 and 2010.



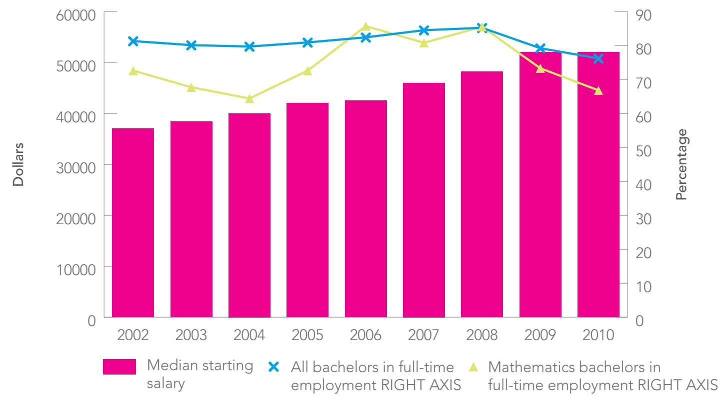
Source: DEEWR Higher Education Statistics.

Figure 7.3.3 Student load in Mathematical Sciences for higher degree by research students

Demand for graduates in Mathematical Sciences

One measure of the demand for graduates is the proportion of bachelor's degree graduates who obtain full-time employment within four months of completing their degree. Between 2002 and 2006 the percentage uptake for graduates in Mathematical Sciences was lower than that for graduates overall (see Figure 7.3.4). The uptake of graduates in Mathematical Sciences increased, however, from just below 75 per cent in 2002 to about 85 per cent in 2006. From 2008 the uptake of all graduates declined, and the uptake of graduates in Mathematical Sciences experienced a sharper decline than that for graduates in other fields. The median starting salary for Mathematical Sciences graduates increased slightly in real terms between 2002 and 2010.

The Australian National Committee for Mathematical Sciences notes that demand for mathematics PhD graduates is projected to grow by 50 per cent by 2020.[1]



Note: The median starting salary for Mathematical Sciences bachelor graduates is also shown (converted to 2010 dollars). Source: Data from Graduates Careers Australia, accessed at http://start.graduatecareers.com.au/Resourcelibrary/GradStatsandGradFiles/index.htm.

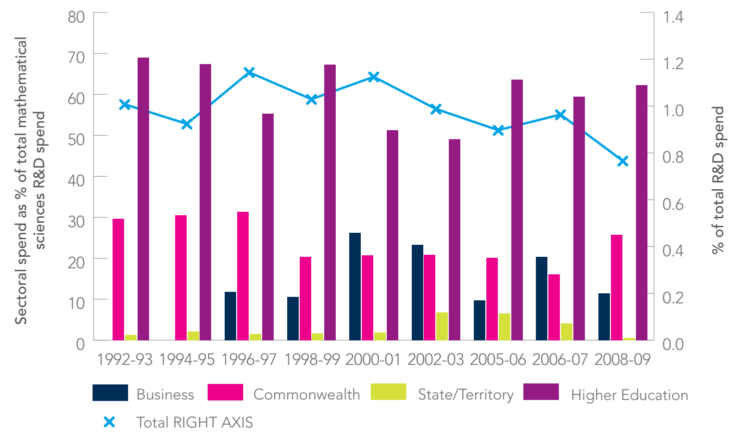
Figure 7.3.4 Proportion of Mathematical Sciences bachelor's degree graduates in full-time employment four months after completion compared with all bachelor's degree graduates in full-time employment

University teaching and research in Mathematical Sciences

The academic staffing profile for Mathematical Sciences overall is similar to the profile for most fields, with a peak at level B (see Figure 7.2.1). This pattern applied to most Mathematical Science sub-disciplines (ARC 2011a). The sub-disciplines show a drop in relative staff proportions from level B to level C, with minima in staffing at levels D and E, although Mathematical Sciences had higher proportions of staff at levels C and D than other disciplines. This staffing profile might lead to vulnerabilities in maintaining research capacity; especially if shortages of senior researchers occur as a consequence of level D and level E staff retiring at a greater rate than the supply of level C researchers coming through.

Research and development spending on Mathematical Sciences

In the late 1990s total gross expenditure on mathematics R&D as a proportion of total R&D for all research disciplines was just over 1.0 per cent. By 2009 it had declined to about 0.8 per cent. The largest contributor to gross expenditure on R&D in mathematics was the higher education sector, followed by the Commonwealth (see Figure 7.3.5); the business and state and territory sectors contributed smaller proportions.

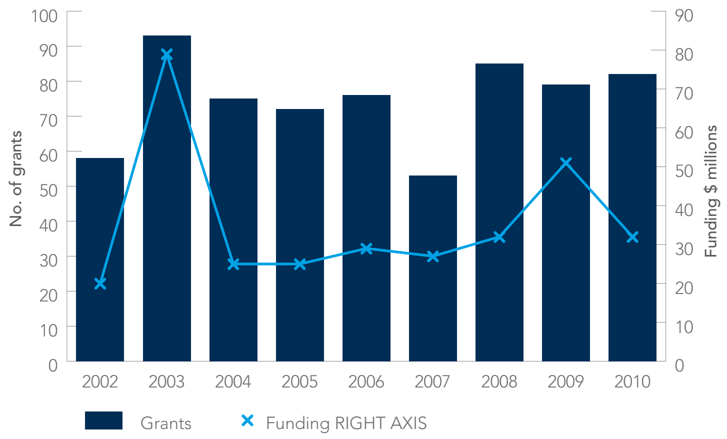


Note: Gross expenditure on R&D by sector, 1992–93 to 2008–09. Source: Data from Australian Bureau of Statistics.

Figure 7.3.5 Sectoral spending as a proportion of total spending on Mathematical Sciences R&D and total spending on Mathematical Sciences R&D as a proportion of total spending on all R&D

Mathematics saw overall growth in the number of mathematics projects and funding in ARC funding schemes between 2002 and 2010 (see Figure 7.3.6). The share of mathematics funding relative to other fields remained about steady for ARC schemes (see Section 5.3). In contrast to most fields of research, success rates for mathematics proposals were nearly steady between 2001 and 2008.

[1] www.science.org.au/natcoms/nc-maths/documents/nc-maths-Exposure-draft-comments.pdf.



Note: Excludes ARC Centres of Excellence, Co-funded Centres of Excellence and Linkage—Special Research Initiatives. Funding amounts converted to 2010 dollars.
Source: Data from Australian Research Council national competitive grants database.

Figure 7.3.6 Trends in funding and grants for Mathematical Sciences: ARC competitive funding schemes, 2002 to 2010

The profile of mathematics funding shows a pattern of heavy dependence on ARC Discovery projects: a higher proportion of mathematics research support came from this scheme than was the case for any other science field. There was only limited involvement in other ARC schemes such as the Large Infrastructure, Equipment and Facilities scheme or through the ARC Centres programs (see Section 5.5). Mathematics had the smallest involvement of any field in industry-linked ARC Linkage projects in 2002-2008, suggesting a low degree of industry involvement at least through ARC-sponsored programs. Consistent with this observation is the fact there is no currently active Cooperative Research Centre reporting activity in mathematics. The Excellence in Research for Australia assessment found that mathematics research in universities received only 14 per cent of its funding from Category 3 (Industry) sources. One sub-field, applied mathematics, reported 77 per cent of its income from commercial sources; it was the only Mathematical Sciences sub-discipline to report this source (ARC 2011a).

International collaboration and research impact

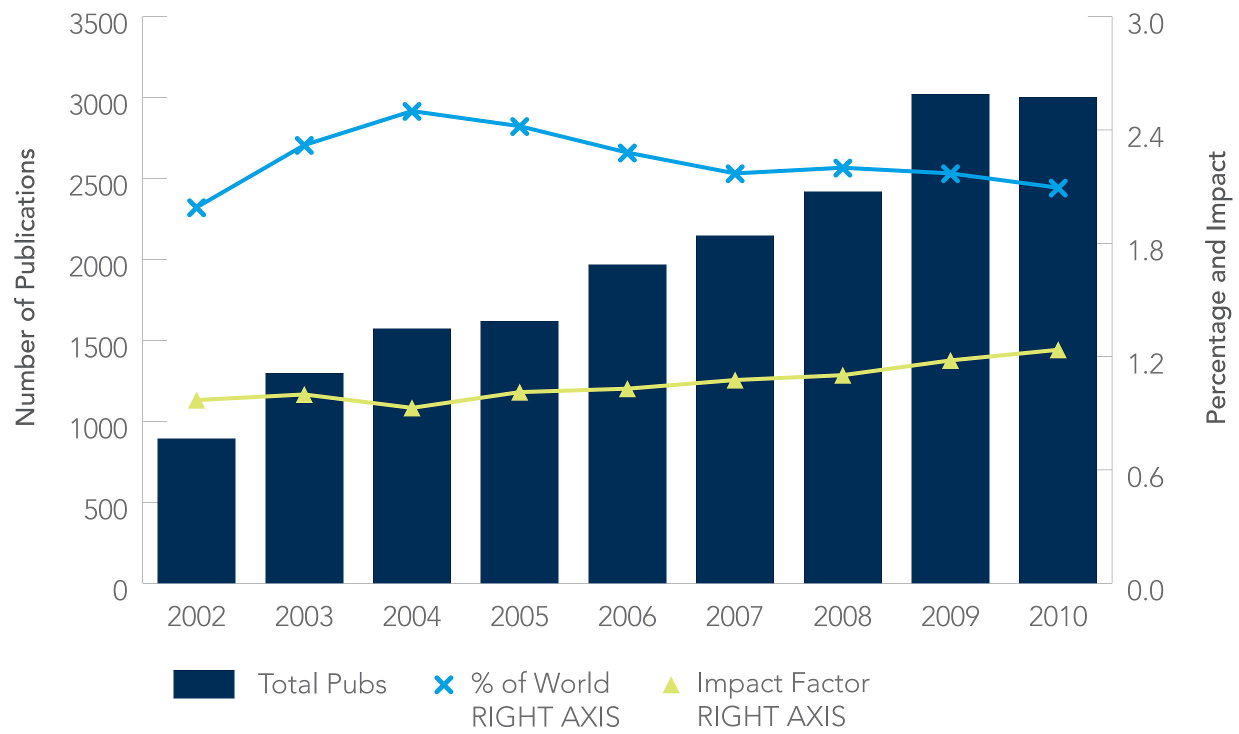
Mathematics research in Australia is at or above global standard in quantity and quality, as measured by the ratings applied by the Excellence in Research for Australia assessment (see Table 7.3.1) and by publications and their impact analysed from bibliometric databases (see Figure 7.3.7). However, the research profile of Mathematical Sciences is supported by a relatively low number of academic staff nationwide, 880 FTE (ARC 2011a), suggesting a human-capacity challenge to maintaining this research output and quality long-term, particularly within some sub-disciplines.

Table 7.3.1 ERA ratings for Mathematical Sciences and sub-fields

Field of research	Rating
Matematical Sciences	3.4
Pure Mathematics	3.2
Applied Mathematics	3.6
Numerical and Computational Mathematics	3.8
Statistics	2.9
Mathematical Physics	4.5
Other Mathematical Sciences	n/a

n/a Not available.
Source: ARC (2011a).

Australian-authored mathematics papers account for just over 2 per cent of all global mathematics papers, and Australian publication output more than tripled between 2002 and 2010, an increase that was somewhat higher than the overall growth rate for publications (see Section 6.7). Growth in publication outputs levelled off between 2009 and 2010. Mathematics' share of global publications grew slightly between 2002 and 2010, peaking in 2004 and declining thereafter.

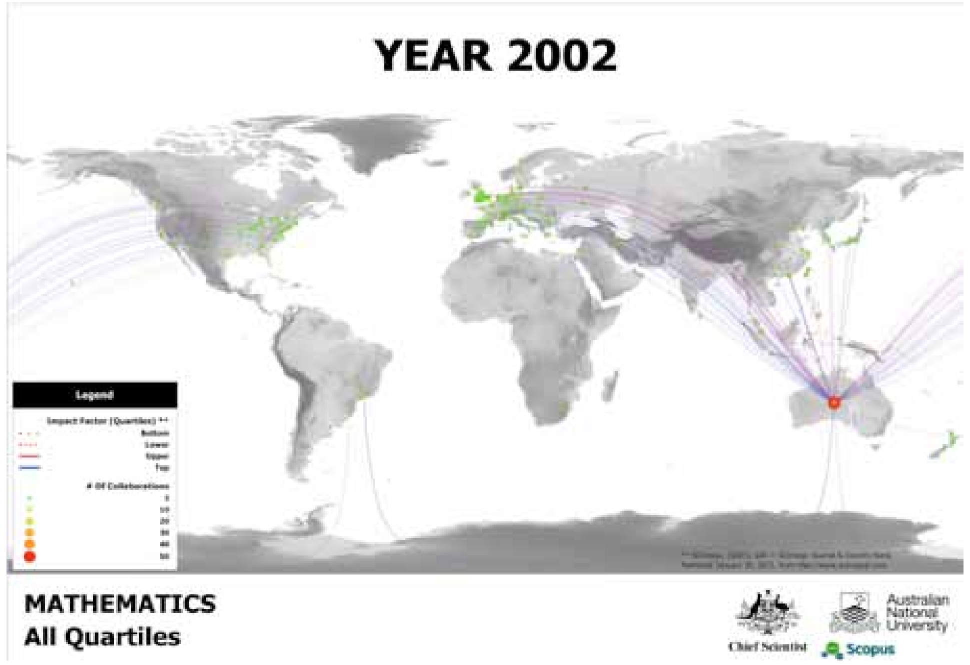


Note: Relative impact = Australian papers' average impact factor over global impact factor.
Source: Data derived from Elsevier–Scopus and analysed by Australian National University Research Office.

Figure 7.3.7 Publication outputs and relative impact in Australian Mathematical Sciences

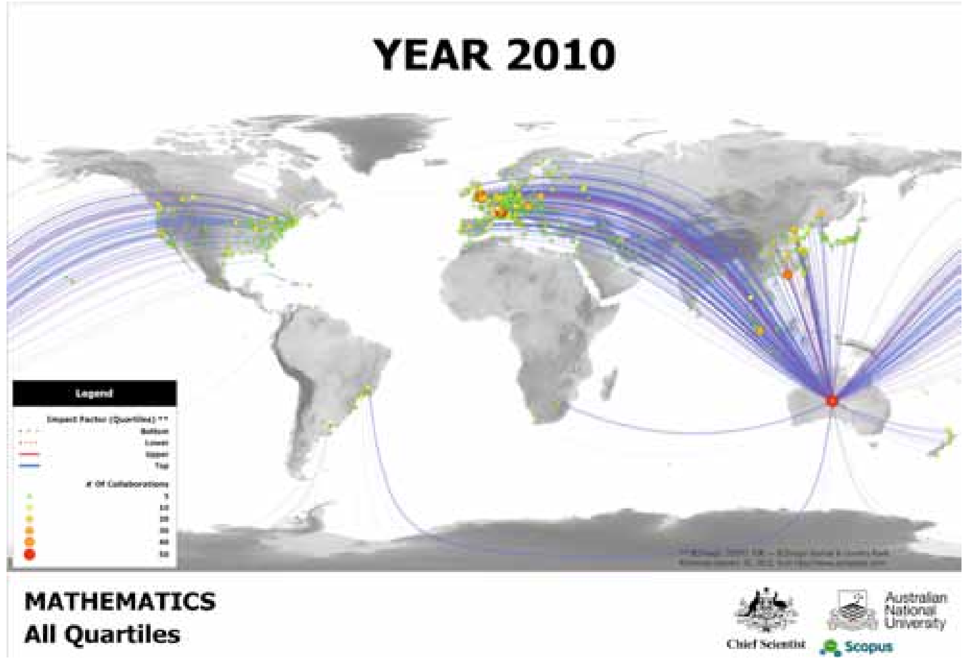
Australia's research impact in mathematics (as measured by the citation impact factors of journals in which papers are published) is above global norms. From 2005 to 2010 Australian mathematics papers ranked fourth among science fields according to Thomson–Reuters data (see Table 6.7.1). The trend in relative impact for mathematics publications shows a slight increase from 2002 to 2010 in Elsevier–Scopus-indexed publications. Thomson–Reuters data suggest, however, that in applied mathematics and statistics the global share and relative impacts of publications declined between 2002 and 2010 (Incites/Thomson-Reuters 2011).

Like many other areas of Australian science, mathematics research is increasingly carried out through international collaboration. Mathematics has a relatively high rate of international co-authorship, over half of all Australian-authored papers having international co-authors. Compared with other Natural and Physical Sciences, however, mathematics has a relatively low number of research grants with international partners. Again as with many other science fields, collaboration has historically been concentrated in North America, Japan and Europe, but it is increasingly moving towards emerging Asian centres of scientific activity, especially China (see Figures 7.3.8 and 7.3.9). China is now Australia's primary national source of mathematics collaboration: Australia–China co-authorship grew about tenfold between 2002 and 2010, and about 12 per cent of all mathematics papers with Australian authors also had Chinese co-authors. The increase in international collaboration is accompanied by a steady increase in impacts for collaborative publications and for Australian mathematics publications overall.



Note: The 'geodesics' (originally defined as a segment of a great circle on the Earth) or paths between Australia and locations of overseas collaborations represent instances of co-authorship. In cases of multiple-country collaboration, one publication can be represented by more than one path. The paths are colour-coded by journal impact factor; indicated by bottom, lower, upper and top quartiles of ranked journal impact factors for journals in the field, with 2010 as the reference year. The size and colour of symbols represent the number of collaborations with a mapped location.Source: Analysis and mapping carried out by Australian National University Research Office, using Elsevier–Scopus data.

Figure 7.3.8 Australian international collaboration in mathematics, 2002



Note: Symbols and data sources as for Figure 7.3.8.

Figure 7.3.9 Australian international collaboration in mathematics, 2010

7.3.2 Physics

Physics is a fundamental enabling science, central to advances in areas ranging from biology and medical science to earth science and energy technology. Australia enjoys a respected place in international physics, having, among other things, a recent winner of the Nobel Prize in this discipline.

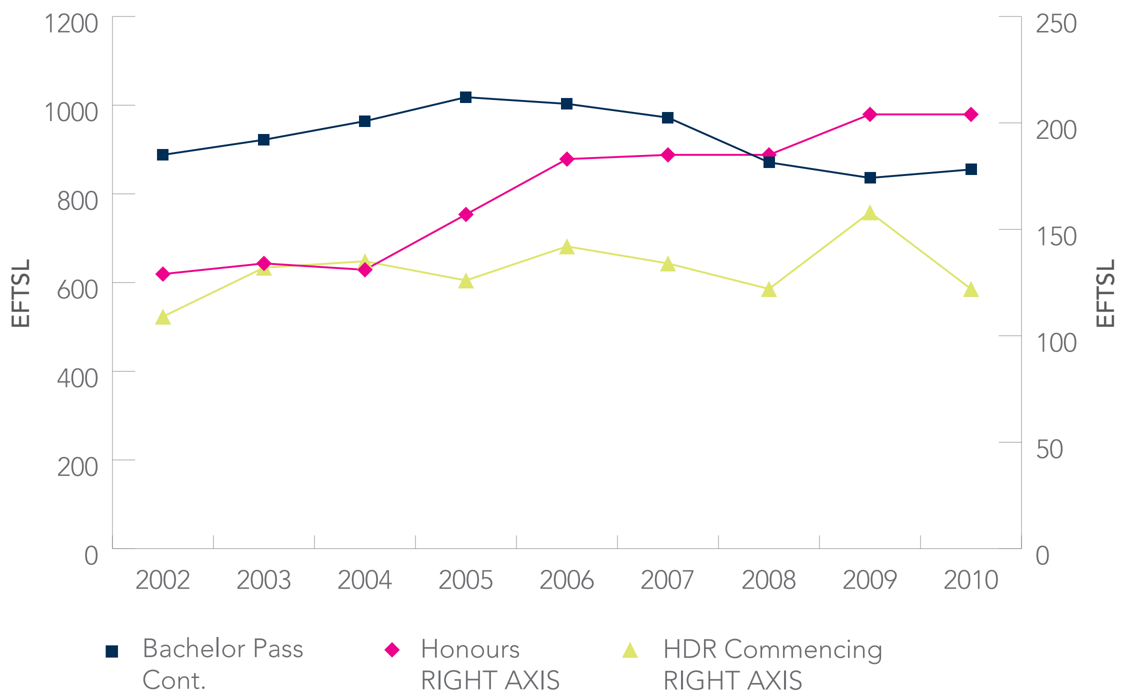
Physics is at present the subject of a field-wide review of capabilities and status in Australia, through a Decadal Plan for Physics being developed by the National Committee for Physics (in exposure draft form as at April 2012[2]). The plan takes in analysis of the field and its recent evolution and identification of emerging opportunities. This case study reinforces and complements that plan.

Higher education

Trends in the study of Physics and Astronomy at Australian higher education institutions show potential vulnerabilities for the discipline. Teaching of Physics and Astronomy to continuing undergraduate students enrolled in the Natural and Physical Sciences remained broadly stable, within 800 to 1000 EFTSL, between 2002 and 2010 (see Figure 7.3.10).

In contrast, as Figure 7.3.10 shows, teaching at honours level increased by 58.1 per cent, from a low base of 129 EFTSL in 2002 to 204 EFTSL in 2010. This growth did not, however, translate into an increase in commencing higher degree by research students in Physics and Astronomy, which experienced relatively modest growth of 11.9 per cent, increasing from a low base of 109 EFTSL in 2002 to 122 EFTSL in 2010.

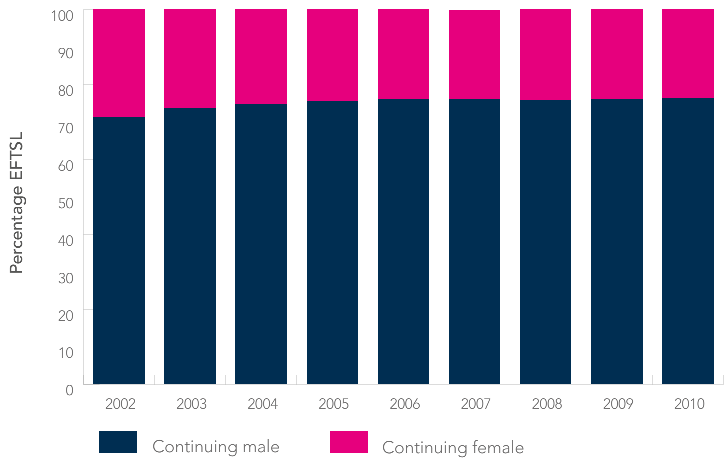
An analysis of Physics and Astronomy teaching to continuing science undergraduates reveals a gender imbalance: female students accounted for only a quarter of student load in Physics and Astronomy between 2002 and 2010 (see Figure 7.3.11).



Source: DEEWR Higher Education Statistics.

Figure 7.3.10 Teaching at undergraduate level in the narrow discipline of Physics and Astronomy, by course level: bachelor's students in Natural and Physical Sciences

[2] www.physicsdecadalplan.org.au/home.



Source: DEEWR Higher Education Statistics.

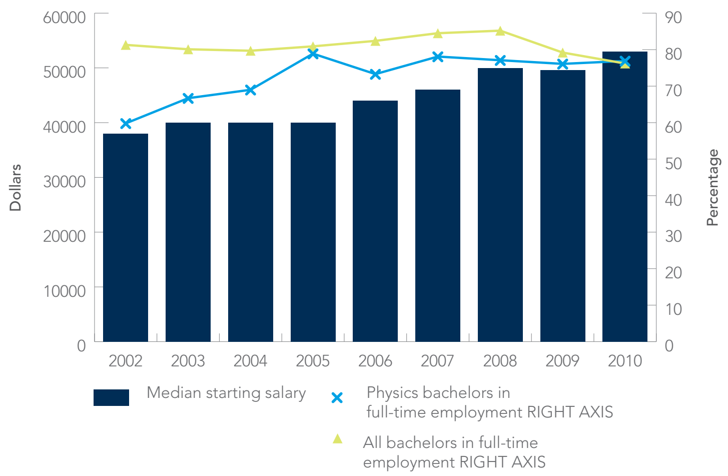
Figure 7.3.11 Gender trends in Physics and Astronomy

Overall, the growth in teaching of Physics and Astronomy at honours level was a positive development, even though it occurred without comparable growth in teaching at the undergraduate levels or enrolments at the HDR levels. Gender imbalances in undergraduate physics suggest that the discipline is not benefiting from the full pool of physics talent.

Demand for graduates in Physical Sciences

Industry is the primary employer of physicists in Australia; government is the next largest, employing physicists mainly in research and advisory roles. A relatively low number of trained physicists graduating from university enter a research career.[3] Industry is strongly dependent on the higher education sector for the supply of graduates, in addition to international graduates and employees from national and international companies.[3]

The demand for graduates can also be measured by the percentage of bachelor's degree graduates in full-time employment within four months of completing their degrees. Between 2002 and 2010 the proportion of physics graduates employed within four months steadily increased, then fluctuated around an average of about 76 per cent during the latter half of the period. The proportion of physics graduates employed remained below the overall percentage of graduates employed from 2002 to 2009 but equalled the overall graduate employment rate in 2010 (see Figure 7.3.12).



Note: The median starting salary for physics bachelor's graduates is also shown (converted to 2010 dollars).
Source: Data from Graduate Careers Australia, http://start.graduatecareers.com.au/Resourcelibrary/GradStatsandGradFiles/index.htm.

Figure 7.3.12 Proportion of bachelor's degree graduates in full-time employment in physics four months after completion compared with all bachelor's degree graduates in full-time employment

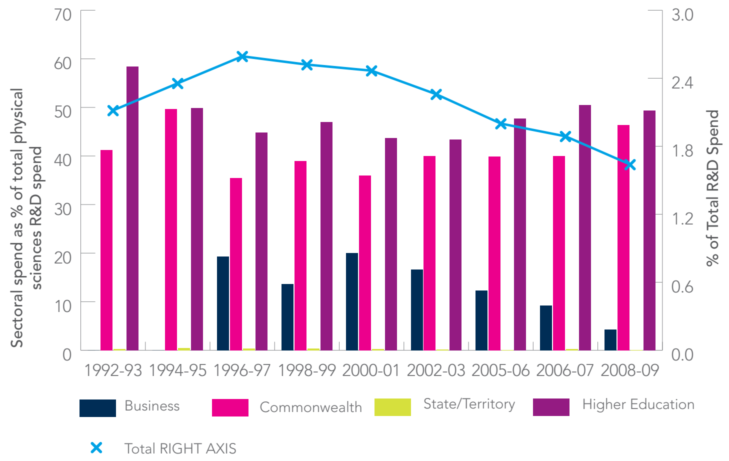
University teaching and research in Physical Sciences

The academic staffing profile for the Physical Sciences discipline overall is similar to the profile for most fields, with a distinct peak at level B (see Figure 7.2.1). This pattern also applied to most Physical Sciences sub-fields, which show sharp drops in relative staff proportions from level B to level C, minima in staffing at level D, and a minor secondary peak in proportions at level E. In the sub-field of Atomic, Molecular, Nuclear, Plasma and Particle Physics there is a lower proportion of staff at level B than in other sub-fields (ARC 2011a). These patterns suggest potential vulnerability in maintaining capacity in some areas of Physics, since shortages of senior researchers might occur as level D and E staff retire, and there are relatively few younger academic researchers following through.

[3] www.physicsdecadalplan.org.au/home

Research and development spending on Physical Sciences

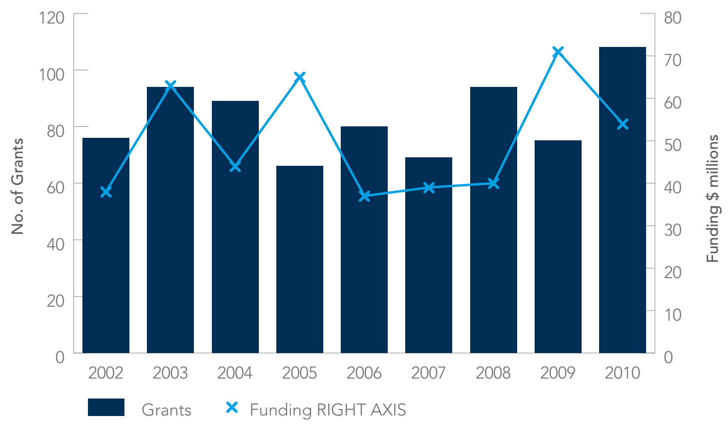
In the late 1990s the total gross expenditure on physics R&D as a proportion of total R&D for all research disciplines was about 2.7 per cent. By 2009 it had declined to about 1.7 per cent. The largest contributor to gross expenditure on R&D in physics is the higher education sector, followed closely by the Commonwealth (see Figure 7.3.13). These two sectors accounted for most of the Physical Sciences R&D spending.



Note: Gross expenditure on R&D by sector, 1992–93 to 2008–09.
Source: Data from Australian Bureau of Statistics.

Figure 7.3.13 Sectoral spending as a proportion of total spending on Physical Sciences R&D and total spending on Physical Sciences R&D as a proportion of total spending on all R&D

For Physical Sciences, there was some growth in overall funding in ARC funding schemes between 2002 and 2010 (see Figure 7.3.14). The number of physics projects was relatively stable over the period, with some growth at the end of the interval. The share of physics funding relative to other fields declined in ARC schemes (see Section 5.3). As with most fields of research, success rates in physics declined between 2001 and 2008.



Note: Excludes ARC Centres of Excellence, Co-funded Centres of Excellence and Linkage—Special Research Initiatives. Funding amounts converted to 2010 dollars.
Source: Data from Australian Research Council national competitive grants database.

Figure 7.3.14 Trends in funding and grants for Physical Sciences: ARC competitive funding schemes, 2002 to 2010

The profile of physics funding from competitive grants shows a pattern of heavy dependence on ARC Discovery projects. Further, this discipline had a higher involvement than most in the Large Infrastructure, Equipment and Facilities scheme, in keeping with the need for many physics projects to have access to large-scale infrastructure such as optical and radio telescopes. The LIEF scheme, however, accounted for only about 11 per cent of physics funding (see Section 5.5). Physics also received a relatively high proportion of support through the ARC Centres programs. It had a relatively small involvement in ARC Linkage projects, suggesting a relatively low degree of industry involvement through ARC-sponsored programs. Similarly, few Cooperative Research Centres list any activity in Physical Sciences. The Excellence in Research for Australia assessment also showed Physical Sciences funding in universities as including only a small contribution from Category 3 (Industry) sources (ARC 2011a).

International collaboration and research impacts

Physics research, as measured through the Excellence in Research for Australia rating (see Table 7.3.2) and by publications and their impact (see Figure 7.3.15), rates highly by global standards in both quantity and quality. Australian-authored physics papers account for about 2 per cent of all global physics papers, and Australian physics publication output more than doubled between 2002 and 2010 (see Section 6.6).

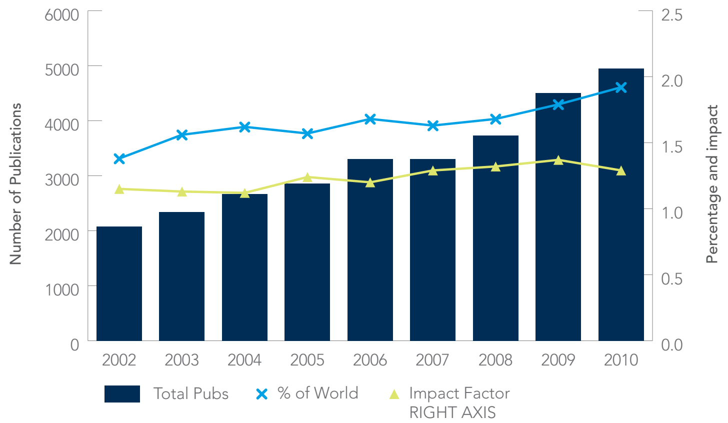
Table 7.3.2 ERA ratings for Physical Sciences and sub-fields

Field of research	Rating
Physical Sciences	3.8
Astronomical and Space Sciences	4.2
Atomic, Molecular, Nuclear, Particle and Plasma Physics	2.9
Classical Physics	5.0
Condensed Matter Physics	3.5
Optical Physics	4.0
Quantum Physics	4.5
Other Physical Sciences	3.6

Source: ARC (2011a).

The impact of physics publications (as measured by the citation impact factors of journals in which the papers are published) is higher than that for most other science fields by global norms. From 2005 to 2010 Australian physics papers had the highest relative impact factors of any science field according to Thomson–Reuters data (Section 6.7). The increase in relative impact appears, however, to have levelled off since 2009 (see Figure 7.3.15). This high research profile is underpinned by a relatively low number of academic research staff nationwide, 965 FTE (ARC 2011a), suggesting a challenge to maintaining this research output and quality long-term, particularly within some sub-disciplines.

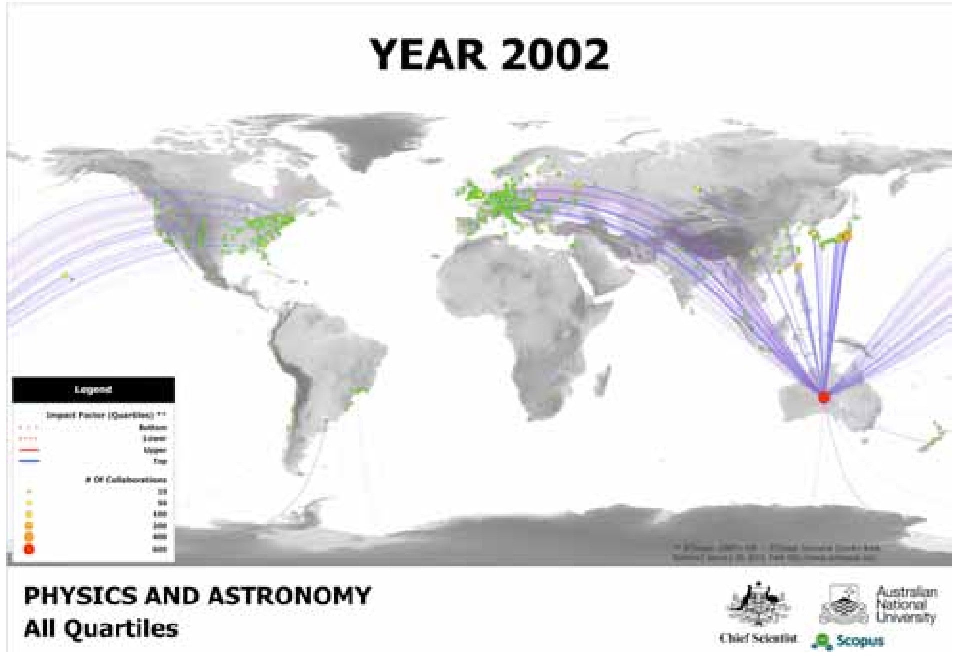
Vulnerabilities appear in the sub-discipline of nuclear physics, for which Australia maintains a steady relative impact of publications and share of global papers, with lower growth of publication outputs than other fields and lower than in physics overall (see Table 6.7.4).



Note: Relative impact = Australian papers' average impact factor over global impact factor.
Source: Data derived from Elsevier–Scopus and analysed by Australian National University Research Office. Data are for the AJSC category "Physics and Astronomy" which most closely matches the ANZSRC field of "Physical Sciences."

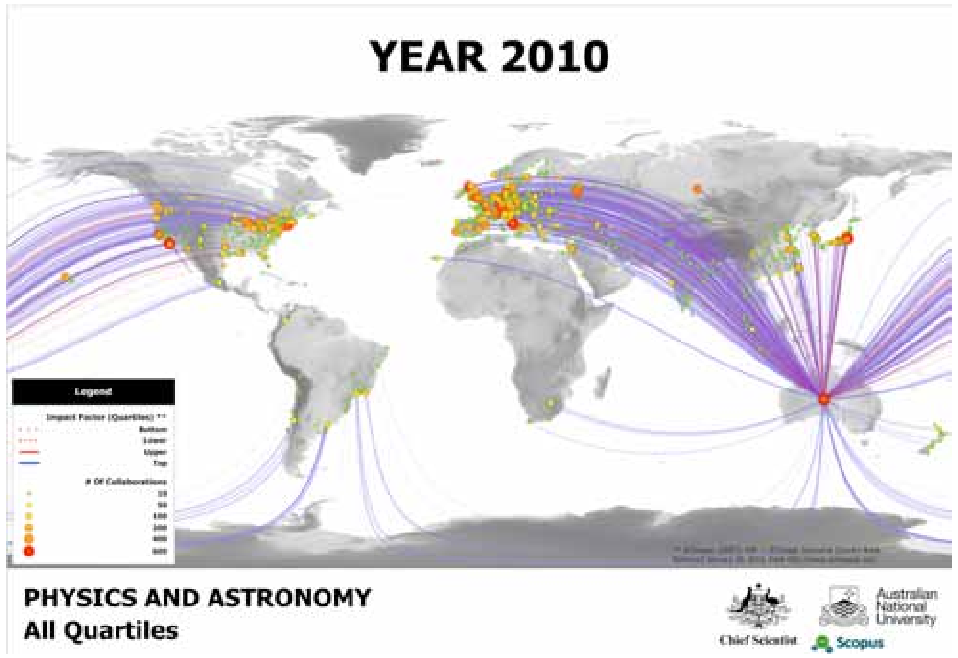
Figure 7.3.15 Publication outputs and relative impact in Australian Physical Sciences

Like many other areas of Australian science, physics research is increasingly carried out through international collaboration. Physics and Astronomy has one of the highest rates of international co-authorship of any field of science. Similarly, Physical Sciences has a relatively high number of grants with international partners (third behind Engineering and Technology and Biological Sciences). Again as with many other science fields, collaboration has historically been concentrated in North America, Europe and Japan, but it is increasingly moving towards emerging Asian centres of scientific activity, especially China (see Figures 7.3.16 and 7.3.17). China is now Australia's fourth-highest national source of collaboration in physics: Australia–China co-authorship grew about ninefold between 2002 and 2010. The increase in international collaboration is accompanied by increased impacts for collaborative publications and for Australian physics publications overall.



Note: The 'geodesics' or paths between Australia and locations of overseas collaboration represent instances of co-authorship. In cases of multiple-country collaboration, one publication can be represented by more than one path. The paths are colour-coded by journal impact factor; indicated by bottom, lower, upper and top quartiles of ranked journal impact factors for journals in the field, with 2010 as the reference year. The size and colour of symbols represent the number of collaborations with a mapped location. Source: Analysis and mapping carried out by Australian National University Research Office, using Elsevier–Scopus data. Data are for the AJSC category "Physics and Astronomy" which most closely matches the ANZSRC field of "Physical Sciences."

Figure 7.3.16 Australian international collaboration in physics, 2002



Note: Symbols and data sources as for Figure 7.3.16.

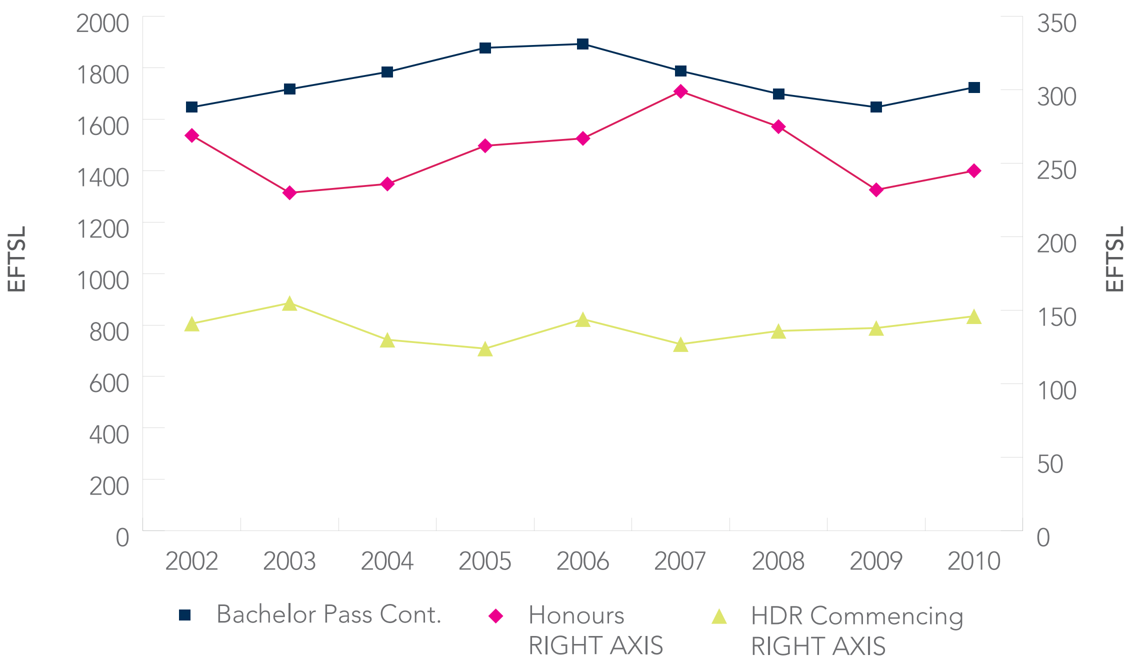
Figure 7.3.17 Australian international collaboration in physics, 2010

7.3.3 Chemistry

Chemistry is a fundamental enabling science, central to scientific research and insight in areas such as earth sciences, environmental sciences, energy technology, biology and medicine (see, for example, Crow 2011). Discoveries and developments in chemistry have led to a number of ground-breaking innovations in a range of fields, among them the discovery of radiocarbon dating, silicon semi-conductor chips and cholesterol-lowering drugs. Chemistry was recently a focus of international attention because 2011 was proclaimed the International Year of Chemistry.[4]

Higher education

Trends in the study of Chemical Sciences at Australian higher education institutions show potential vulnerabilities for the discipline. Teaching of Chemical Sciences to continuing undergraduate students enrolled in the Natural and Physical Sciences initially increased from 1647 EFTSL in 2002 to a peak of 1893 EFTSL in 2006, or by 14.9 per cent (see Figure 7.3.18). This peak was followed by a 13 per cent contraction in teaching between 2006 and 2009. Modest growth, 4.7 per cent, in teaching is evident from 2009 to 2010, with EFTSL increasing from 1647 to 1724.



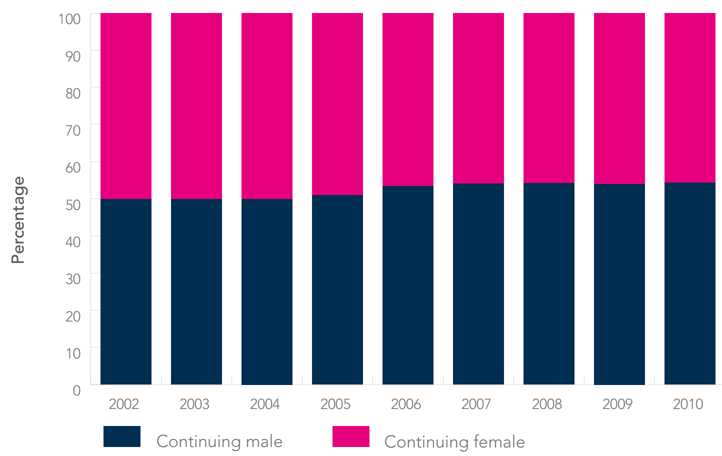
Source: DEEWR Higher Education Statistics.

Figure 7.3.18 Teaching at undergraduate level in the narrow discipline of Chemical Sciences, by course level

[4] www.chemistry2011.org.

Teaching of Chemical Sciences to honours students fell from 269 EFTSL in 2002 to 245 EFTSL in 2010—a decline of 8.9 per cent. With teaching of Chemical Sciences in preceding course levels in decline, commencing higher degree by research load in Chemical Sciences changed little during the period, varying between 120 and 160 EFTSL.

In contrast with the other enabling disciplines of mathematics and physics, the gender balance for chemistry undergraduates is relatively even: female students accounted for half the continuing chemistry load in 2002; the proportion then fell slightly, to 46 per cent in 2010 (see Figure 7.3.19).



Source: DEEWR Higher Education Statistics.

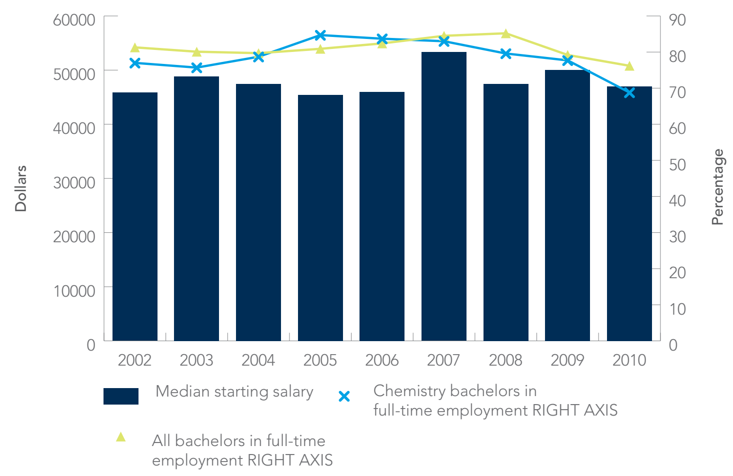
Figure 7.3.19 Gender trends in Chemical Sciences

Overall, the teaching of Chemical Sciences to continuing undergraduate students remained virtually static between 2002 and 2010, while teaching to honours students declined. Commencing HDR load in Chemical Sciences was static during the period.

Demand for graduates in Chemical Sciences

A recent Royal Australian Chemical Institute survey of employers of chemists[5] showed that the vast majority of employers thought their need for chemists in the next 10 years would at least remain constant, if not increase. Skills in chemistry are in high demand—in Chemical Sciences as well as in other fields requiring chemistry experience.

The percentage of chemistry bachelor's degree graduates in full-time employment within four months of degree completion declined between 2002 and 2010 and remained generally lower than for bachelor's degree graduates overall from 2007 to 2010 (see Figure 7.3.20). Median salaries in real terms increased from 2002 to a peak in 2007, then declined from 2007 to 2010.



Note: The median starting salary for chemistry bachelor's graduates is also shown (converted to 2010 dollars).
Source: Data from Graduate Careers Australia, http://start.graduatecareers.com.au/Resourcelibrary/GradStatsandGradFiles/index.htm.

Figure 7.3.20 Proportion of bachelor's degree graduates in full-time employment in Chemistry four months after completion compared with all bachelor's degree graduates in full-time employment

University teaching and research in Chemical Sciences

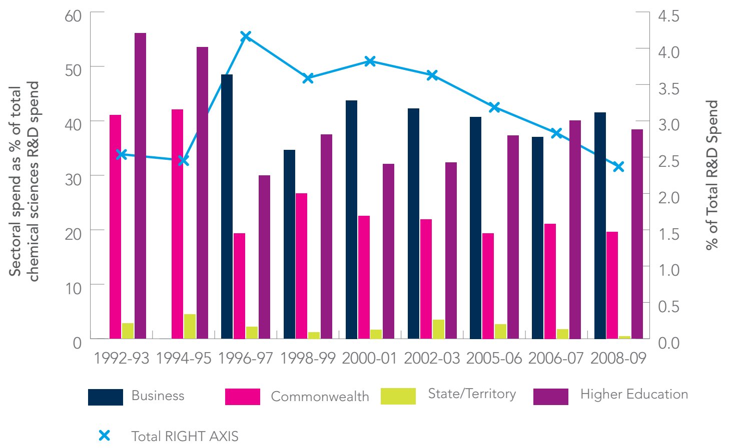
The academic staffing profile for Chemical Sciences differs from that for science overall, a number of sub-fields having their greatest proportion of staff at level A (see Figure 7.2.1). This pattern was characteristic of Inorganic Chemistry, Macromolecular and Materials Chemistry, and Medicinal and Biomolecular Chemistry, suggesting a 'younger' overall profile in these fields and for chemistry overall. Most sub-disciplines in chemistry show a drop in relative staff proportions from level B to level C, with minima in staffing

[5] www.raci.org.au/jobs-careers..

at level D, and a minor secondary peak in proportions at level E (ARC 2011a). As with other fields of science, these patterns might pose challenges for maintaining capacity in some areas: especially if shortages of senior researchers occur as a consequence of level D and level E staff retiring at a greater rate than the (the relatively small) supply of level C researchers coming through.

Research and development spending on Chemical Sciences

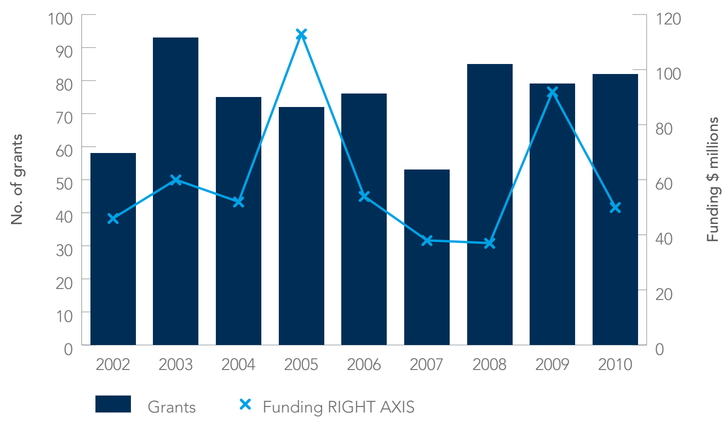
In 1997 the total gross expenditure on R&D in chemistry as a proportion of total R&D for all research disciplines peaked at about 4.3 per cent. By 2009 the proportion had declined to about 2.3 per cent. The largest contributor to gross expenditure on R&D in chemistry is the business sector, followed closely by the higher education sector (see Figure 7.3.21). Chemistry differs from mathematics and physics in this larger contribution from business to its R&D funding profile. The state and territory sector contributes only a very small proportion of chemistry R&D funding.



Notes: There are no data on business sector chemistry R&D spending for 1992–93 and 1993–94.
Gross expenditure on R&D by sector, 1992–93 to 2008–09.
Source: Data from Australian Bureau of Statistics.

Figure 7.3.21 Sectoral spending as a proportion of total spending on Chemical Sciences R&D and total spending on Chemical Sciences R&D as a proportion of total spending on all R&D

Like many other fields of science, chemistry had relatively flat overall funding in ARC funding schemes between 2002 and 2010 (see Figure 7.3.22). The number of chemistry projects declined slightly from a peak in 2003 (see Section 5.3), and the share of chemistry funding relative to other fields declined in a range of ARC schemes. As in most fields of research, success rates in chemistry declined from 2001 to 2008.



Note: Excludes ARC Centres of Excellence, Co-funded Centres of Excellence and Linkage—Special Research Initiatives. Funding amounts converted to 2010 dollars.
Source: Data from the Australian Research Council national competitive grants data base.

Figure 7.3.22 Trends in funding and grants for Chemical Sciences: ARC competitive funding schemes, 2002 to 2010

The profile of chemistry funding from competitive grant schemes shows a pattern of heavy dependence on ARC Discovery projects. Further, this field had a higher involvement than most in the Large Infrastructure, Equipment Facilities scheme, which accounted for about 10 per cent of chemistry funding (see Section 5.5). Chemistry also received about 10 per cent of its support through ARC Centres programs. It had a relatively small involvement in ARC Linkage projects, suggesting a relatively low degree of industry engagement through ARC-sponsored programs. Similarly, Cooperative Research Centre activity in chemistry is limited compared with other fields. The ERA assessment showed chemistry receiving research in universities about 30 per cent of its funding from Category 3 (Industry) sources (ARC 2011a).

International collaboration and research impacts

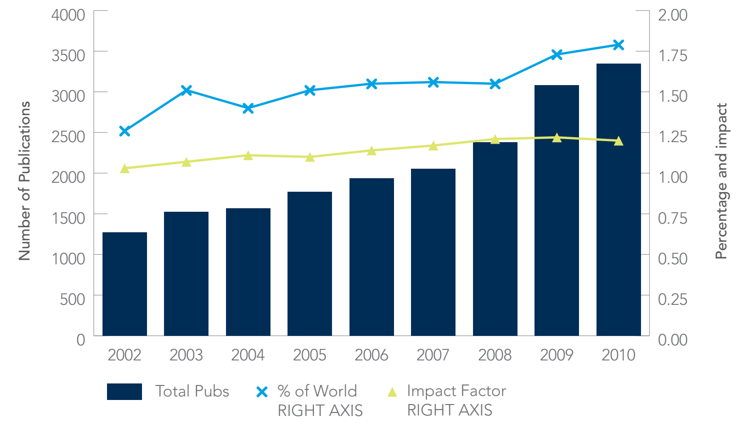
Australian research in chemistry is productive by global standards, in both quantity and quality, as measured by publications and their impact (see Figure 7.3.23) and the ERA rating (see Table 7.3.3). Much of the research profile is generated by a relatively low number of academic staff nationwide, 1154 FTE (ARC 2011a), suggesting a possible challenge to maintaining this research output and quality long-term within some sub-disciplines. Australian-authored chemistry papers account for about 1.8 per cent of all global chemistry papers, and Australian chemistry publication output almost tripled between 2002 and 2010—higher than the overall growth rate for publications (see Section 6.7). Chemistry's share of global publications grew slightly between 2002 and 2010.

Table 7.3.3 ERA ratings for Chemical Sciences and sub-fields

Field of research	Rating
Chemical Sciences	3.5
Analytical Chemistry	3.5
Inorganic Chemistry	2.8
Macromolecular and Materials Chemistry	4.1
Medicinal and Biomolecular Chemistry	3.6
Organic Chemistry	2.9
Physical Chemistry (incl. structural)	3.7
Theoretical and Computational Chemistry	4.5
Other Chemical Sciences	2.5

Source: ARC (2011a).

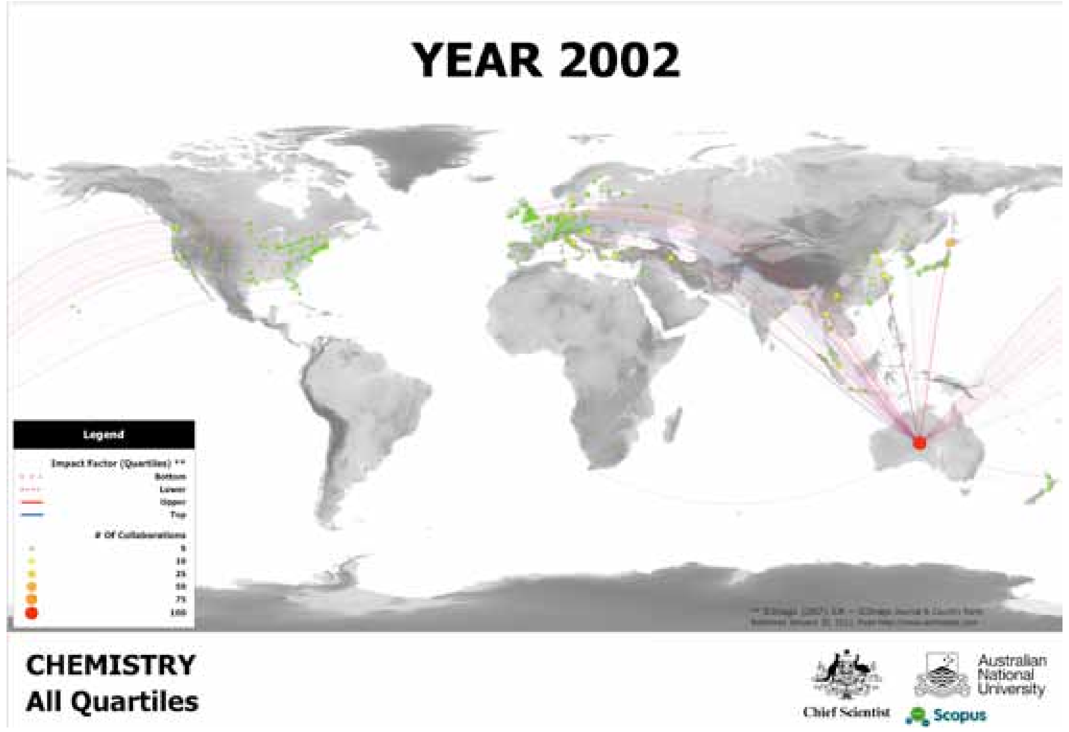
The impact of chemistry publications (as measured by the citation impact factors of journals in which the papers are published) is above global norms, although lower than that of other Australian science fields. From 2005 to 2010 Australian chemistry papers ranked in the middle to lower ranks among science fields according to Thomson–Reuters data (see Table 6.7.1). The trend in relative impact for chemistry publications shows an increase from 2002 to 2008 and a slight decrease from 2009 to 2010.



Note: Relative impact = Australian papers' average impact factor over global impact factor.
Source: Data derived from Elsevier–Scopus and analysed by Australian National University Research Office.

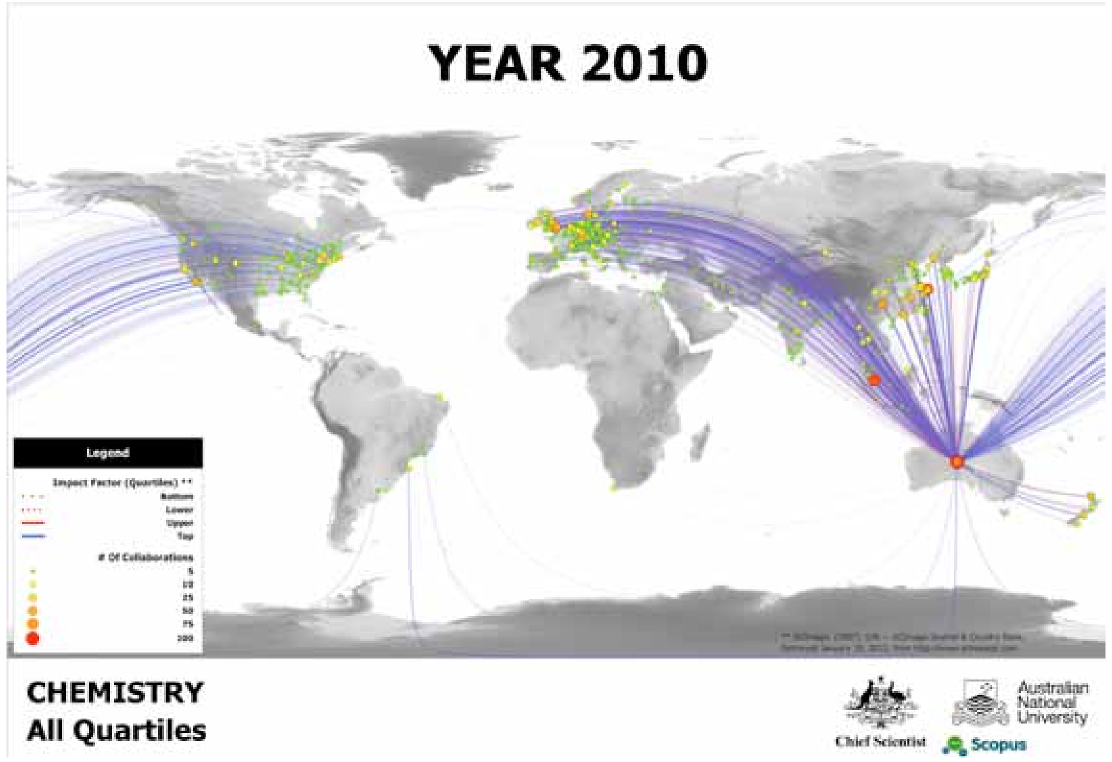
Figure 7.3.23 Publication outputs and relative impact in Australian Chemical Sciences

As in many other areas of science, research in chemistry is increasingly carried out through international collaboration. Chemistry has a relatively high rate of international co-authorship: nearly half of all Australian-authored papers are the product of international collaboration. Chemistry also has a relatively high number of grants with international partners (fourth behind Engineering and Technology, Biological Sciences, and Physical Sciences; ARC 2011b). Again as with many other science fields, this collaboration has historically been concentrated in North America, Japan and Europe, but it is increasingly moving towards collaboration with emerging Asian centres of scientific activity, especially China (see Figures 7.3.24 and Figure 7.3.25). China is now Australia's highest national source of collaboration in chemistry: Australia–China co-authorship grew about tenfold between 2002 and 2010 (see Section 6.7). The increase in international collaboration is accompanied by increased impacts for collaborative publications and for Australian chemistry publications overall.



Note: The 'geodesics' or paths between Australia and locations of overseas collaboration represent instances of co-authorship. In cases of multiple-country collaboration, one publication can be represented by more than one path. The paths are colour-coded by journal impact factor; indicated by bottom, lower, upper and top quartiles of ranked journal impact factors for journals in the field, with 2010 as the reference year. The size and colour of the symbols represent number of collaborations with a mapped location. Source: Analysis and mapping carried out by Australian National University Research Office, using Elsevier–Scopus data.

Figure 7.3.24 Australian international collaboration in chemistry, in 2002



Note: Symbols and data sources as for Figure 7.3.24.

Figure 7.3.25 Australian international collaboration in Chemistry, 2010

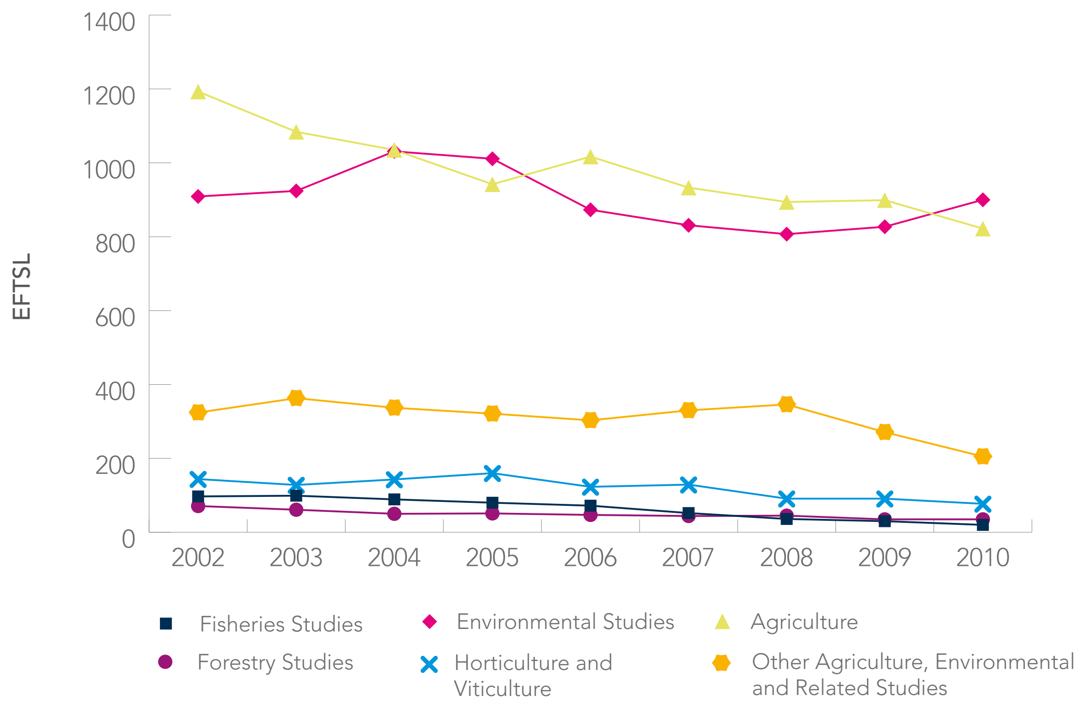
7.3.4 Agricultural Science

The agricultural sciences provide the basis for Australia's food security and for our capacity to contribute to global food security. Discoveries and developments in agricultural science will be vital to meeting the challenges to food production posed by climate change, water resource limitations, burgeoning populations and other future pressures (PMSEIC 2010).

Higher education

Higher education statistics related to agricultural science are collected as part of the field of education or broad discipline group entitled 'Agriculture, Environmental and Related Studies'. The broad discipline group contains disciplines related to both agriculture and the environment. Meaningful analysis of agriculture-related statistics within this group can be performed only by considering student load in agriculture-specific disciplines. The focus here is therefore on the teaching of agriculture disciplines, and does not include the distribution of this teaching by gender.

Teaching in the narrow discipline of Agriculture to continuing domestic undergraduate students enrolled in Agriculture, Environmental and Related Sciences courses declined between 2002 and 2010 (see Figure 7.3.26). Other narrow disciplines related to agriculture also declined over this period.



Source: DEEWR Higher Education Statistics.

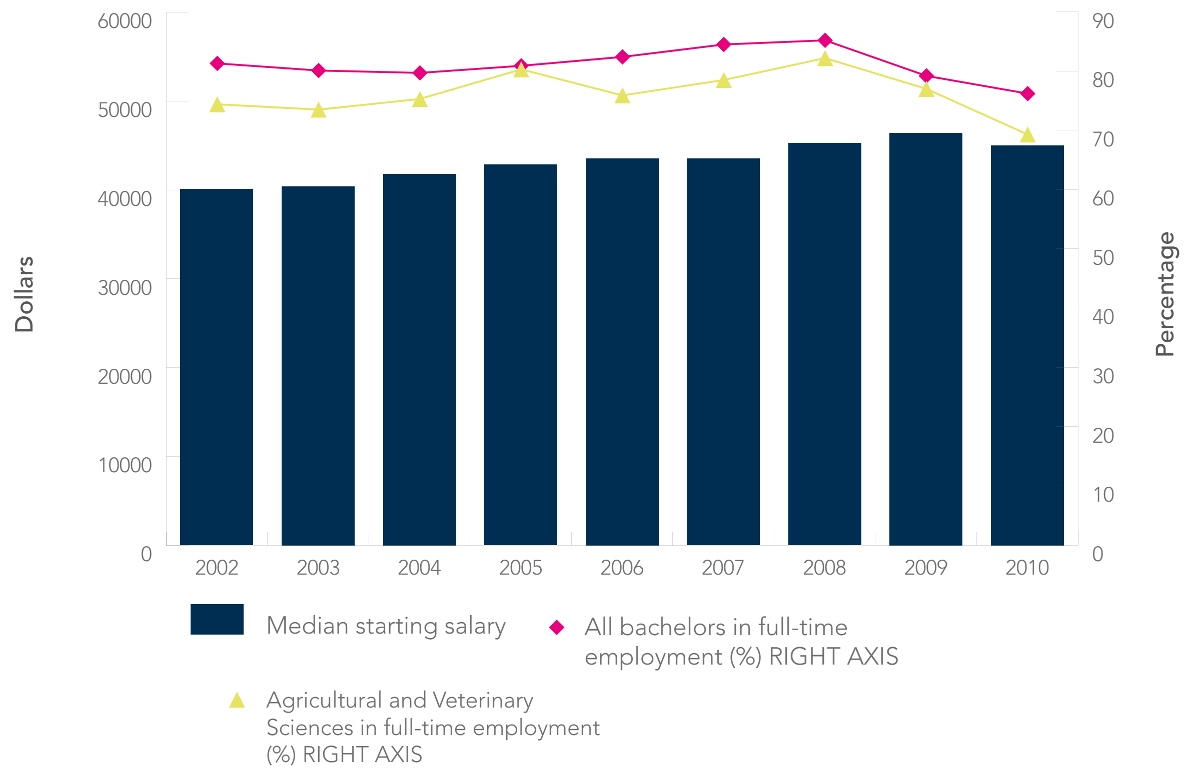
Figure 7.3.26 Teaching at undergraduate level to university students in Agricultural, Environmental and Related Sciences, by narrow discipline group

In contrast, domestic EFTSL in the narrow discipline Agriculture at the higher degree by research level experienced modest growth of 8.8 per cent during the 2002 to 2010 period (see Figure 4.7.15).

The decline in teaching of Agriculture to domestic students at the undergraduate level reflects both a fall in commencing enrolments and considerable attrition among continuing students. These trends cast doubt about the adequacy of the future supply of researchers, scientists and professionals in the field of agriculture.

Demand for graduates in Agricultural Sciences

One measure of the demand for agricultural science graduates is the percentage of bachelor's degree graduates seeking full-time employment that are in full-time employment within four months of completing their degree. Between 2002 and 2010 the employment uptake of agriculture graduates varied between 69 per cent and 82 per cent. The uptake was typically less than that for bachelor's degree graduates generally (see Figure 7.3.27). Median starting salaries rose in real terms by about 16 per cent from 2002 to a peak in 2009, after which they fell about 3 per cent. A recent survey of advertisements for agricultural jobs identified a job market of about 1600 a quarter, which arguably sets the demand for university graduates at about 4500 a year (Pratley & Hay 2010). The current rate of domestic bachelor's completions is smaller than this demand by a factor of 5 (see Section 4.7.1).



Note: The median starting salary for agriculture bachelor's graduates is also shown (converted to 2010 dollars).
Source: Data from Graduates Careers Australia, http://start.graduatecareers.com.au/Resourcelibrary/GradStatsandGradFiles/index.htm.

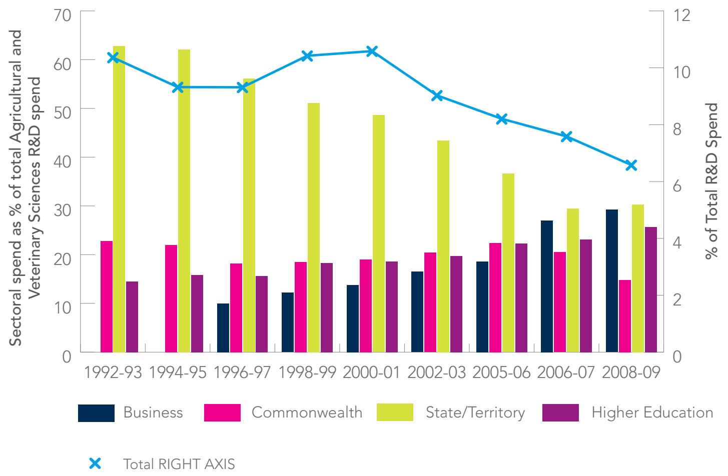
Figure 7.3.27 Proportion of bachelor's degree graduates in full-time employment in Agricultural Sciences four months after completion compared with the proportion of all bachelor's degree graduates in full-time employment

University teaching and research in Agricultural Sciences

The full-time-equivalent staffing profile for the Agricultural and Veterinary Sciences discipline in 2009 was similar to the overall staffing profile, with most staff at level B (see Figure 7.2.1). Staffing profiles for most of the agricultural science sub-disciplines have considerably fewer level A, B and C staff than the overall staffing profile (ARC 2011a). Most sub-disciplines show a sharp drop in relative staff proportions from level B to level C, with minima in staffing at level D. These patterns suggest challenges for maintaining capacity in Agricultural Sciences, especially since there are relatively few level C academics to fill forthcoming gaps left by the retirement of level D and E staff over the next few years.

Research and development spending on Agricultural Sciences

In 1998–99 the total gross expenditure on Agricultural Sciences R&D as a proportion of total R&D for all research disciplines was 10.7 per cent, a value roughly maintained throughout the 1990s. Between 2000 and 2009 this proportion declined to 6.8 per cent, despite a change in accounting to include Veterinary Science and Environmental Sciences in the Agricultural Sciences research category. The largest contributor to gross expenditure on R&D in the Agricultural Sciences—and the sector accounting for much of the recent decline—was the state and territory governments (see Figure 7.3.28).

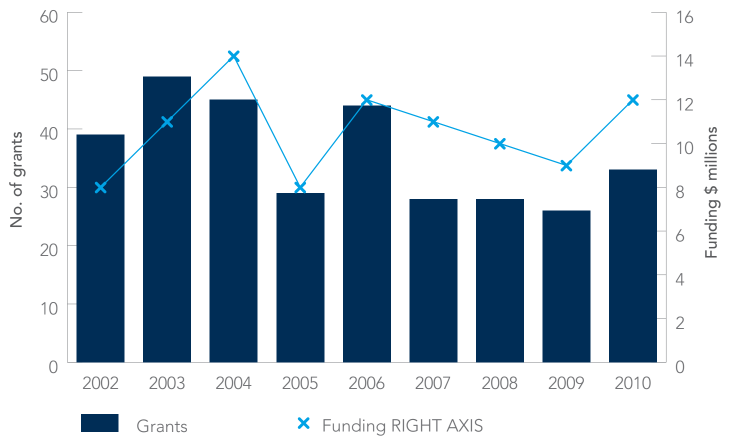


Note: Gross expenditure on R&D by sector, 1992–93 to 2008–09.
Source: Data from Australian Bureau of Statistics.

Figure 7.3.28 Sectoral spending as a proportion of total spending on Agricultural and Veterinary Sciences R&D and total spending on Agricultural and Veterinary Sciences R&D as a proportion of total spending on all R&D

Funding from ARC schemes for the Agricultural and Veterinary Sciences discipline oscillated around $10 million annually between 2002 and 2010, with some growth during the decade (see Figure 7.3.29). The number of agricultural science grants, however, declined during the decade, from generally more than 35 to generally less than 30 a year. The share of agricultural science funding as a proportional of overall ARC funding declined in ARC schemes (see Section 5.3). As with most fields of research, success rates in agricultural science declined from 2001 to 2008.

The profile of agricultural science shows that about half the funding comes from competitive grants. Agricultural and Veterinary Sciences ranked about fourth among science disciplines in involvement in industry-linked ARC Linkage projects (see Section 5.5). The Cooperative Research Centres program is heavily involved in agricultural science: almost a quarter of currently active CRCs reported activity in this discipline (see Section 5.5.1). The Excellence in Research for Australia assessment showed Agricultural and Veterinary Sciences funding to university researchers as including about 14 per cent from the CRC program and about 15 per cent from Category 3 (Industry) sources (ARC 2011a).



Note: Excludes ARC Centres of Excellence, Co-funded Centres of Excellence and Linkage—Special Research Initiatives. Funding amounts converted to 2010 dollars.
Source: Data from the Australian Research Council national competitive grants data base.

Figure 7.3.29 Trends in funding and grants for Agricultural and Veterinary Sciences: ARC competitive funding schemes, 2002 to 2010

International collaboration and research impacts

The standard and quality of Agricultural and Veterinary Sciences research in Australia, as measured by publications and their impact and the Excellence in Research for Australia assessment (see Table 7.3.4), are rated highly in the global arena (see Figure 7.3.30). This research profile is underpinned by a relatively low number of academic staff nationwide, 1021 FTE (ARC 2011a), suggesting a potential challenge in terms of human capacity to maintaining this research output and quality long-term.

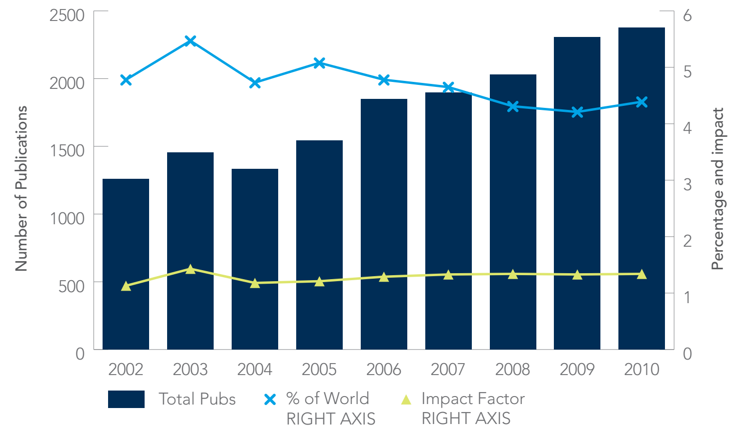
Table 7.3.4 ERA ratings for the broad field of Agricultural and Veterinary Sciences and sub-disciplines, 2006 to 2008

Field of research	Rating
Agricultural and Veterinary Sciences	3.7
Agriculture, Land and Farm Management	n/a
Animal Production	3.7
Crop and Pasture Production	4.1
Horticultural Production	4.7

Source: ARC (2011a).

Australian-authored agricultural science papers account for more than 4 per cent of all global agricultural science papers, although this proportion declined in the past decade. Australian agricultural science publications approximately doubled in total between 2002 and 2010, consistent with the overall growth rate for publications (see Section 6.7).

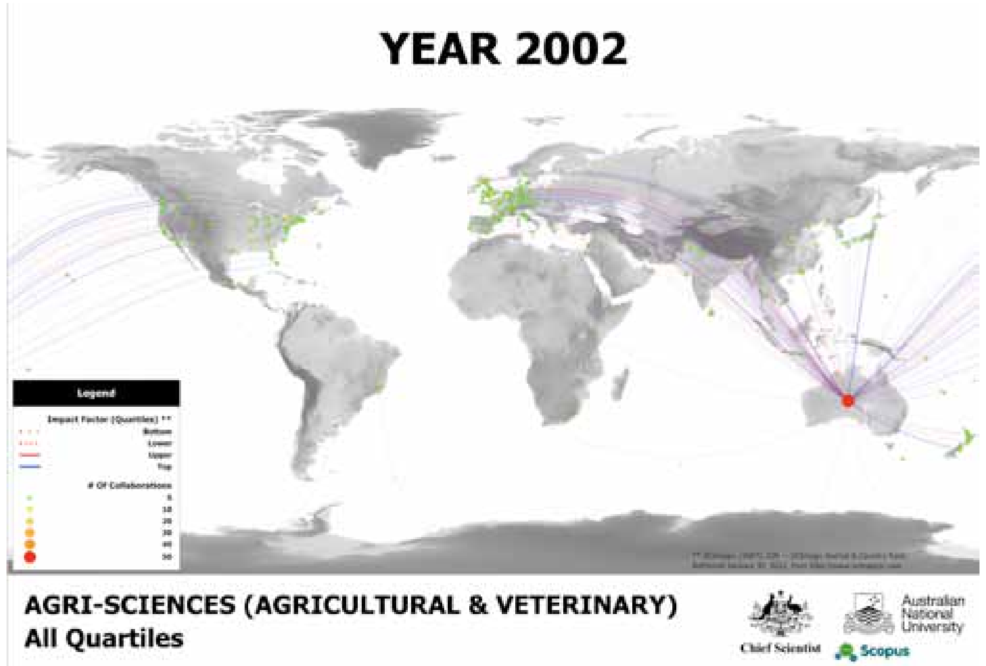
The impact of agricultural science publications (as measured by citation impact factors of journals in which the papers are published) is higher than that for most other science fields by global norms. The growth in relative impact does, however, appear to have levelled off since 2008. Australia's ranking in agricultural science publications, as measured by publication output, dropped after 2003 but rose when measured by citation impact (see Figure 7.3.30).



Note: Relative impact = Australian papers' average impact factor over global impact factor. For this analysis Agricultural and Veterinary Science is an aggregation of AJSC codes 1102, 1104, 1107, 1108, 1111, 3402, 3403; to best overlap with ANZSRC Code 07, 'Agricultural and Veterinary Sciences.'
Source: Data derived from Elsevier–Scopus and analysed by Australian National University Research Office.

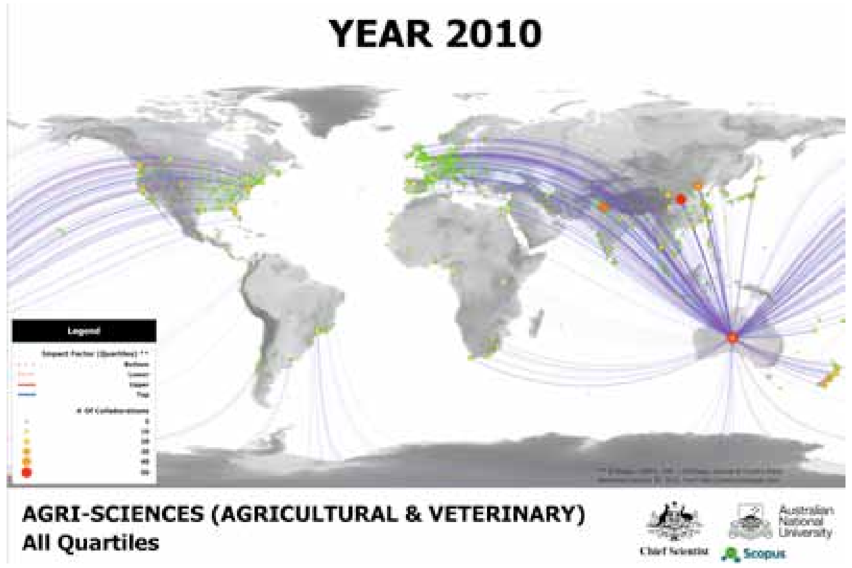
Figure 7.3.30 Publication outputs and relative impact in Australian Agricultural and Veterinary Sciences

As in many other areas of science, research in Agricultural Sciences is increasingly carried out through international collaboration. Agricultural science has a high rate of international co-authorships: about 45 per cent of papers published by Australians have international co-authors. Compared with other fields of science, however, agricultural science has a relatively low number of grants with international partners (ARC 2011b). Again as with many other science fields, collaboration through publication has historically been concentrated in North America, Japan and Europe, but it is increasingly moving towards collaboration with emerging Asian centres of scientific activity, especially China (see Figures 7.3.31 and 7.3.32). China is now Australia's second-highest national source of collaboration in agricultural science: Australia–China co-authorship grew about eightfold between 2002 and 2010 (see Section 6.7). There is also striking growth in collaboration in this discipline with South America and Africa. The increase in international collaboration is accompanied by increased impacts for collaborative publications.



Note: The 'geodesics' or paths between Australia and locations of overseas collaboration represent instances of co-authorship. In cases of multiple-country collaboration, one publication can be represented by more than one path. The paths are colour-coded by journal impact factor; indicated by bottom, lower, upper and top quartiles of ranked journal impact factors for journals in the field, with 2010 as the reference year. The size and colour of symbols represent number of collaborations with a mapped location. For this analysis Agricultural and Veterinary Science is an aggregation of AJSC codes 1102, 1104, 1107, 1108, 1111, 3402, 3403; to best overlap with ANZSRC Code 07, 'Agricultural and Veterinary Sciences.'
Source: Analysis and mapping carried out by Australian National University Research Office, using Elsevier–Scopus data.

Figure 7.3.31 Australian international collaboration in Agricultural and Veterinary Sciences, 2002



Note: Symbols and data sources as for Figure 7.3.31.

Figure 7.3.32 Australian international collaboration in Agricultural and Veterinary Sciences, 2010

7.4 Summary

A general analysis of Australian science suggests a mosaic of strengths, vulnerabilities and opportunities between and within fields and between and within sectors.

An important area of strength lies in Australia's research productivity: most fields of the natural and physical sciences show research performance at or above international standard. Australia produces a high and growing proportion of global publications relative to its population, with higher than global average impacts. The Australian research community is increasingly connected to the global science community through collaboration in relation to grants and large-scale international projects, co-authorship on papers, and other forms of interaction (international visits, student enrolment, symposia, and so on), and this involvement presents opportunities for building on the nation's strengths by complementing them with overseas strengths and capabilities.

Vulnerabilities lie in the trends associated with students taking up science at secondary and tertiary levels of the education system. Participation rates in the enabling sciences of mathematics, chemistry and physics have been declining in Australian secondary schools, and participation in enabling sciences at the tertiary level has been experiencing long-term decline, despite expansion of the higher education sector as a whole. An opportunity exists because there is considerable scope for increased recruitment of secondary and tertiary students to science and mathematics.

A strong trend in higher education science is the growing number, and proportion of the student cohort, of international students. This development presents opportunities for expanding the research workforce and for building on the growth in international involvement. Vulnerability could emerge, however, if the higher education sector becomes overly dependent on international enrolments for sustaining tertiary science education.

Another area of potential vulnerability arises from the age profiles of the research workforce. Relative peaks in the proportions of level E researchers could present challenges for maintaining capacity in research if shortages of senior researchers occur as a result of retirements; particularly if there is also relatively fewer researchers at the immediately lower academic level to follow through.

Women are under represented at senior academic levels of the enabling sciences. This means there is a potentially large and talented pool of scientists that is untapped, thus offering opportunities if greater numbers of female students can be encouraged into the enabling sciences.

The amount of funding to support basic research is increasing, but at the same time there is increased competition for grants and fellowships, especially for younger researchers. In competitive funding schemes, declining success and funding rates suggest an opportunity for more high-quality science to be carried out. On the other hand, the increased funding pressure could cause a bottleneck in efforts to build on Australia's research output.

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GLOSSARY

Term	Definition	Shortened version used in this report
Applied research	Applied research is also original investigation undertaken in order to acquire new knowledge. It is directed primarily towards a specific practical aim or objective.	
Australian Research Council	The main Australian Government organisation providing competitive funding to basic and applied research and research training in all fields of science, social sciences and the humanities, with the exception of clinical medicine and dentistry.	ARC
Bachelor's pass and graduate entry	The standard post–Year 12 tertiary qualification awarded by Australian higher education institutions. Also called an undergraduate degree. Included in this group are bachelor's (graduate entry) courses.	bachelor's (pass and grad. entry); bachelor's
Basic research	Basic (pure) research is experimental or theoretical work undertaken primarily to acquire new knowledge about the foundation of phenomena and observable facts, without any particular application or use in view.	
Commencing student	Students enrolled at an institution for the first time at a particular course level. Commencing status applies for only one calendar year.	First year student
Continuing student	In the years after a student's 'commencing' year they are considered to be continuing.	Later year student
Completion	When an enrolled student is deemed by their institution to have met the requirements of their course they are counted in the completions data.	
Course level	Courses are offered at different levels, such as bachelor's, honours, master's and PhD. Students typically are required to complete a tertiary course at a lower course level before being admitted to a higher level. For example, a bachelor's course is typically required for entry to postgraduate courses. A bachelor's course with honours is typically required for entry to a PhD.	Degree level
Discipline group—broad, narrow	A means of classifying subjects according to the content being studied or researched. Examples of broad disciplines are Natural and Physical Sciences and Health. Narrow disciplines are subsets of the broad disciplines; examples are chemistry and biology, which are narrow disciplines in the broad discipline group Natural and Physical Sciences.	Broad discipline, narrow discipline
Discovery (schemes)	A range of ARC funding schemes mainly aimed at supporting basic research through support for individual projects, fellowships and early career researcher awards and support for Indigenous researchers.	

Term	Definition	Shortened version used in this report
Discovery projects	An ARC funding scheme providing funding for basic and applied research projects by researchers or research teams.	
Experimental development research	Experimental development is systematic work drawing on existing knowledge, gained from research and/or practical experience, that is directed at producing new materials, products or devices, to installing new processes, systems and services, or improving substantially those already produced or installed.	
Field of education (broad)	A classification of a course according to the vocational intent or the principal subject matter.	FoE
Higher degree by research	This group of courses includes PhDs, master's by research and higher doctorates.	HDR
Honours	Honours is awarded to bachelor's students who have achieved beyond the standard of a regular bachelor's pass degree. For some fields of educations honours is awarded on the basis of an extra year, during which a research thesis is completed. This typically applies to Natural and Physical Sciences courses. For other fields of educations, such as Engineering and IT, honours might be awarded on the basis of academic performance during the pass degree.	Hons
H-index	The 'h'-index expresses the number of papers (*h*) that have received at least *h* citations. The index measures both publication output and scientific impact.	
Impact factor	The impact factor of a journal is the average number of citations received per paper published in that journal during the two preceding years. Impact factor as used in this report reflects the impact factors of the journals in which publications appeared in the years in which they were published.	
Indicative completion rate	In this report the indicative completion rate simply compares completions in one year with commencing enrolments from some earlier time (the time shift used depending on the course level). The rate provides a rough estimate only of the proportion of students who commence a particular course level then go on to complete it. See Section 4.3.1 for a full explanation.	

Term	Definition	Shortened version used in this report
Linkage (schemes)	A range of ARC funding schemes, including projects and fellowships, mainly aimed at supporting collaborative research through projects and shared infrastructure, linking educational institutions and other bodies, including industry.	
Linkage projects	An ARC funding scheme supporting collaborative research and development projects between higher education and other parts of the national innovation system. This scheme requires the participation of partner organisations from outside the higher education sector.	
Linkage International	An ARC funding scheme, active until 2009, that supported collaborative research among Australian and overseas researchers and centres.	
Linkage Infrastructure, Equipment and Facilities	An ARC funding scheme providing support for research infrastructure, equipment and facilities to be shared between higher education organisations as well as with industry.	
National Competitive Grants Program	The main funding umbrella under which the Australian Research Council funds research through a range of funding schemes for researchers and institutions.	NCGP
National Health and Medical Research Council	The main Australian Government organisation funding health and medical research.	NHMRC
Participation rate	A commonly used index to monitor the uptake of each subject by Year 12 students. It is calculated as the number of students enrolled in a specified subject (data provided by the Department of Education, Employment and Workplace Relations) divided by the total number of students in Year 12 (data provided by Australian Bureau of Statistics, Cat. no. 4221.0).	
Postgraduate (coursework)	Postgraduate courses typically offered to students who have completed a minimum of a bachelor's pass degree. The course levels include doctorate and master's by coursework, graduate certificate, and various postgraduate diplomas.	Postgraduate
Pedagogy	The method and practice of teaching, including instructional strategies and style of teaching.	

Term	Definition	Shortened version used in this report
Primary course	Students enrolled in a single degree program are enrolled in a 'primary course'. Those enrolled in a double degree will have both a 'primary course' and a 'supplementary course'.	
Pure research	*See* Basic research	
Relative citation impact	Ratio of average citations per paper divided by the global average citations per paper (usually within a discipline).	RCI
Science/s	Natural and Physical Sciences—the broad field of education and broad discipline group	N&PS
Service teaching	Teaching of subjects in one broad discipline to undergraduate students enrolled in a different field of education. For example, teaching of mathematics to students enrolled in Engineering courses.	
Student load	A measure of subject or study load where 1 equivalent full-time student load, or EFTSL, is what a standard full-time student would take in a calendar year.	Load
Subject	An individual unit taken to give credit towards a course of study. An example is Mathematics 1A, which might count towards the degree of Bachelor of Science.	
Supplementary course	*See* Primary course	
Research intensity	A country's gross expenditure on research and development as a proportion of its gross domestic product.	
Research and development	Creative work undertaken on a systematic basis in order to increase the stock of knowledge, including of humans, culture and society and the use of this stock of knowledge to devise new applications.	R&D
Translational research	Research aimed at translating basic health and medical research into clinical practice.	
Transmission model of teaching	A paradigm of teaching characterised by teaching through imparting knowledge and learning through absorbing knowledge.	
Undergraduate student	A student who is taking a course at the bachelor's level—including pass, graduate entry and honours.	

Note: The definitions used for research are those used by the OECD and the Australian Bureau of Statistics. They are taken from: OECD 2002, Frascati Manual: proposed standard practice for surveys on research and experimental development, Organisation for Economic Cooperation and Development, Paris, p. 255.

APPENDIX

Representatives of the following organisations were consulted as part of this Health of Australian Science project:

- Australian Bureau of Statistics
- Australian Council of Deans of Agriculture
- Australian Council of Deans of Science
- Australian Mathematical Sciences Institute
- Australian Nuclear Science and Technology Organisation
- Australian Research Council
- Bureau of Meteorology
- Commonwealth Scientific and Industrial Research Organisation
- Defence Science and Technology Organisation
- Department of Agriculture, Forestry and Fisheries
- Department of Climate Change and Energy Efficiency
- Department of Health and Ageing
- Department of Immigration and Citizenship
- Department of Industry, Innovation, Science, Research and Tertiary Education
- Department of Resources, Energy and Tourism
- Geoscience Australia
- National Health and Medical Research Council
- Skills Australia

Fields of education/Broad discipline group			Narrow discipline group		
Two-digit code	Name	Shortened form	Four-digit code	Name	Short name
01	Natural and Physical Sciences	Science/s, N&PS	0100	Natural and Physical Sciences, nfd	
			0101	Mathematical Sciences	Mathematics
			0103	Physics and Astronomy	Physics
			0105	Chemical Sciences	Chemistry
			0107	Earth Sciences	
			0109	Biological Sciences	Biology
			0199	Other Natural and Physical Sciences	Other NP&S
02	Information Technology	IT	0200	Information Technology, nfd	
			0201	Computer Science	
			0203	Information Systems	
			0299	Other Information Technology	Other IT
03	Engineering and Related Technologies	Engineering	0300	Engineering and Related Technologies, nfd	
			0301	Manufacturing Engineering and Technology	
			0303	Process and Resources Engineering	
			0305	Automotive Engineering and Technology	
			0307	Mechanical and Industrial Engineering and Technology	
			0309	Civil Engineering	
			0311	Geomatic Engineering	
			0313	Electrical and Electronic Engineering and Technology	
			0315	Aerospace Engineering and Technology	

Fields of education/Broad discipline group			Narrow discipline group		
Two-digit code	Name	Shortened form	Four-digit code	Name	Short name
05	Agriculture, Environmental and Related Studies	Agriculture and Environment	0500	Agriculture, Environmental and Related Studies, nfd	
			0501	Agriculture	
			0503	Horticulture and Viticulture	
			0505	Forestry Studies	
			0507	Fisheries Studies	
			0509	Environmental Studies	
			0599	Other Agriculture, Environmental and Related Studies	
06	Health		0600	Health, nfd	
			0600	Medical Studies	
			0603	Nursing	
			0605	Pharmacy	
			0607	Dental Studies	
			0609	Optical Science	
			0611	Veterinary Studies	
			0613	Public Health	
			0615	Radiography	
			0617	Rehabilitation Therapies	
			0619	Complementary Therapies	
			0699	Other Health	

nfd:Not further defined