Research training and national innovation systems in Australia, Finland and the United States

A policy and systems study supported by 30 case studies of research students in the fields of geospatial science, wireless communication, biosciences, and materials science and engineering.

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RMIT University, Melbourne, Australia

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A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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Statement of original authorship

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; and, any editorial work, paid or unpaid, carried out by a third party is acknowledged.

________________________ (Signature)

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Abstract

Key words: research, research training, research careers, innovation, national innovation systems, mobility, knowledge, human capital.

Reforms to the national research and research training system by the Commonwealth Government of Australia sought to effectively connect research conducted in universities to Australia's national innovation system. Research training has a key role in ensuring an adequate supply of highly skilled people for the national innovation system. During their studies, research students produce and disseminate a massive amount of new knowledge.

Prior to this study, there was no research that examined the contribution of research training to Australia's national innovation system despite the existence of policy initiatives aiming to enhance this contribution. Given Australia's below average (but improving) innovation performance compared to other OECD countries, the inclusion of Finland and the United States provided further insights into the key research question. This study examined three *obvious* ways that research training contributes to the national innovation systems in the three countries: the international mobility and migration of research students and graduates, knowledge production and distribution by research students, and the impact of research training as advanced human capital formation on economic growth.

Findings have informed the concept of a *research training culture of innovation* that aims to enhance the contribution of research training to Australia's national innovation system. Key features include internationally competitive research and research training environments; research training programs that equip students with economically-relevant knowledge and the capabilities required by employers operating in knowledge-based economies; attractive research careers in different sectors; a national commitment to R&D as indicated by high levels of gross and business R&D expenditure; high private and social rates of return from research training; and the horizontal coordination of key organisations that create policy for, and/or invest in research training.

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Chapter 1: Introduction

1.1 Background

The Commonwealth Government of Australia released a White Paper, *Knowledge and Innovation: A policy statement on research and research training*, in December 1999. This White Paper outlined reforms to "make the best use of available resources to ensure that the research and research training undertaken in Australian universities continues to be world class and that the new knowledge it generates is effectively linked to innovation in Australian industry" (Kemp, 1999a, p. iv). These reforms were largely in response to the Government's concern that **research in universities is often disconnected from the national innovation system**. The Government was aiming to extend higher education research to the national innovation system through closer links with industry, thereby leading to stronger local and international connections between the producers and users of research. Universities were expected to conduct research and research training in an entrepreneurial environment characterised by collaborations with partners across the world and with other actors in the national innovation system, a stronger movement of staff and researchers across various research settings, and research students acquiring skills and knowledge in both academic and industrial environments.

Research undertaken by the OECD (1999) around the same time found that the interaction of market institutions (the users) and non-market institutions (the knowledge producers) to achieve collective goals influences "the direction and speed of innovation and technology diffusion" (p. 23). The OECD (1999) identified several examples of interactions among enterprises, universities and public research institutes that facilitate innovation and technology diffusion. These interactions included research contracts, mobility of researchers, licensing, spin-offs, joint labs, co-publications, and informal contacts within professional networks.

Some of the *Knowledge and Innovation* reforms sought to address deficiencies in research training and enhance **"the important contribution of research students to the national research and innovation system"** (Kemp, 1999a, p. 18). This contribution has been described as undertaking cutting-edge research, renewing the research and academic workforces, and transmitting knowledge and skills (Kemp, 1999a; West, 1998). More recently, Nelson (2002a) stated that research training, is "becoming an increasingly important element of the national innovation system" (p. 42) because of its role in building skills and capacity and generating new ideas. However, there has been little research on the impact of research and research training policies and other relevant initiatives (such as those related to international mobility and research careers) in actually enhancing the contribution of research students to Australia's national innovation system. Lundvall (1992) argued that national education and training are missing elements in a national innovation system and called for future research to "integrate education and training systems and innovation systems in one single analytical framework" (p. 15).

Therefore, the purpose of this PhD study was to investigate if and how **research training contributes to Australia's national innovation system**. Australia ranks among the top 10 OECD countries in many of the innovation indicators such the size of its research workforce, publication rates and government funding of R&D. Yet, it remains well below the OECD average for business investment in R&D, employment of business researchers, diffusion and commercialisation of innovations (as indicated by patenting levels), linkages and collaborations, and citations of publications. As a result, this study is also examining the contribution of research training to national innovation systems in Finland and the United States – two contrasting countries which are regarded as world leaders in innovation.

Findings should provide stakeholders such as policymakers, funding bodies, universities and innovation researchers with greater insight about the contribution of research training to the national innovation systems of Australia, Finland and the United States. The key outcome of the study has been the identification of the features of a **research training culture of innovation** that may enhance the contribution of research training to Australia's national innovation system.

1.2 Research problem and justification

The key research question or research problem for the study was as follows: **Does research training (particularly in science and technology fields) contribute to national innovation systems in Australia, Finland and the United States?** The key research question has been addressed in three *ways* represented as elements of a conceptual framework:

- *Element 1: International mobility and migration of research students and graduates, particularly in science and technology fields* – Research students are more likely to contribute to their national innovation system if, after graduating, they continue their research career AND remain in their own country (they are *immobile*); migrate to Australia, Finland or the United States from another country (*brain gain*); return home from another country (*brain circulation*); and/or leave home but maintain professional links and networks that encourage international flows of highly skilled workers and knowledge (*brain circulation*).
- *Element 2: Knowledge production and distribution by research students in a national innovation system* (based on 30 case studies of research students in science and technology fields) – Research students are more likely to contribute to their national innovation system when their research is characterised by a combination of Mode 1 and Mode 2 knowledge production and distribution i.e. their research considers the context of application, involves stakeholders and leads to transdisciplinary results; research results are effectively disseminated to all stakeholders throughout the process of production (beyond the traditional Mode 1 methods of journal and conference papers); and research training equips them with economically-relevant knowledge and the capabilities to work in knowledge-based economies.

- *Element 3: Research training, human capital and economic growth* – Research training represents human capital formation at an advanced level; leads to relatively high private and social returns; and represents a significant investment in R&D activities by countries aiming to build a highly qualified workforce that directly contributes to technological advance and innovation. Therefore, human capital formation through research training may have a positive impact on economic growth and contribute to social benefits that result from human capital investment in education.

The exact level of funding and other resources devoted to research training by Governments, industry, other organisations and individuals in each country is not known. The Commonwealth Government of Australia devotes over $1 billion a year to research and research training schemes. The Academy of Finland and the National Technology Agency of Finland provide annual combined R&D funding of over 600 million euros. The sheer volume of people who complete research degrees in the United States each year (as indicated by recent completions data of 44,200 graduates compared to 1,957 graduates in Finland and 6,321 graduates in Australia) shows that research training is a multi-billion dollar industry. Therefore, these countries are probably interested in ways that can increase the returns from their investment in research training.

The discussion about innovation theories and approaches and the features of a national innovation system in Chapter 3 highlights the importance of a highly skilled workforce, the increasing reliance on scientific knowledge to technological advances, and the need for knowledge producers and users to interact and learn together in order to innovate. A supply of well trained research graduates in science and technology fields is a critical component of any national innovation system. Much of the debate about research training has concentrated on improving the quality of research training (particularly to address high attrition rates and slow rates of completion), providing research students with the capabilities required by employers operating in different sectors, and creating attractive career paths for researchers. There is also a growing expectation that research students are exposed to multidisciplinary research environments. This study is the first of its kind to examine these issues within the bounds of a national innovation system.

Research training systems have an important role in training people to produce new knowledge within economies where knowledge is the fundamental resource driving competitiveness. The students within these systems are responsible for a significant share of a country's new knowledge. This study is also unique by comparing the knowledge produced and distributed by research students against the characteristics of effective knowledge production and distribution in knowledge-based economies - as discussed in element 2 on the previous page. These findings may assist Governments and universities to rethink aspects of research training models in relation to knowledge production, knowledge distribution and capability development.

1.3 Research design

The principles espoused by constructivism and interpretivism provide a foundation for the study's research design. The study sought to address one key research question and eight secondary research questions within a three element conceptual framework. It used a mixed methodology strategy based a complementary relationship between the following qualitative and quantitative research methodologies:

- *Historical research* to source key documents that describe the nature, development and performance of the research training system and national innovation system in each country. Key documents were also examined for any mention of how research students contribute to the national innovation system in their country.
- *Case study research* to produce 30 intrinsic case studies of research students in the science and technology fields of geospatial science, wireless communication, biosciences, and materials science and engineering. These students were from RMIT University (Australia), University of Oulu (Finland) and University of Illinois at Urbana-Champaign (United States).
- Collection and analysis of *statistical data* that complemented the historical research component and two elements of the conceptual framework.

Data was collected in the three countries over a 15 month period: from February to June 2003 in Australia; from July to December 2003 in Finland; and from January to May 2004 in the United States. Document analysis, interviews with innovation and research training experts, and statistical analysis were the main methods used in the historical research component. Case study data collected via semi-structured interviews, short observations and document analysis was presented interactively on a Compact Disc (CD) and analysed within two elements of the conceptual framework. The quantitative research component involved collecting data from the Organisation for Economic Co-operation and Development (OECD) and country sources in relation to: innovation investment and performance; size and outputs of research training systems; international movements of highly skilled people; human capital stocks, investments and returns; and economic and non-economic impacts of human capital investment.

1.4 Outline of the thesis

This thesis contains eight chapters, including the introduction. The purpose and contents of Chapters 2 to 8 is explained in this section.

Chapter 2: Research design describes the research questions, stages and activities in the research process, epistemology, theoretical framework, methodology, methods, and ethics.

Chapter 3: Key concepts draws on key literature to define and/or clarify words or terms that are within, or closely related to the key research question for the thesis i.e. innovation, national innovation systems, research and development (R&D), human resources in science and technology (HRST), and research students and training. This chapter aims to address Research Question 1: *What is meant by innovation, a national innovation system, research training and research students?* and Research Question 2: *What is the role of research training (particularly in science and technology fields) in a national innovation system?*

Chapter 4: Systems in Australia, Finland and the United States describes the structure, strengths and challenges of the research training system and national innovation system in each country. The chapter should provide the reader with a good overview of the context before presenting findings in relation to the three elements of the conceptual framework for each country in chapters 5, 6 and 7. It also aims to address Research Question 3: *What have been the major developments in, and performance of innovation and research training policies/systems in Australia, Finland and the United States?*

The next three chapters each represent an element of the conceptual framework. The format of these chapters is similar, starting with key assumptions based on a literature review followed by an analysis of findings. This structure seemed the most logical as all the information about one particular element is contained in the same chapter which helps the reader to move from theory to analysis and to understand similarities and differences between the three countries.

Chapter 5: International mobility and migration of research students and graduates commences with a discussion about common terms, the importance of mobility and migration to national economies, drivers and obstacles, and measure/indicators of mobility. The chapter then presents findings for each country in the areas of mobility programs and performance, research careers, and mobility activities of 30 research students. This chapter aims to address two research questions: Research Question 4: *What policies have been introduced in each country to support the international mobility and migration of research students and graduates*? and Research Question 5: *How has each country performed in terms of brain drain, brain gain and brain circulation?*

Chapter 6: Knowledge production and distribution by research students (30 case studies) presents a framework for the analysis of case studies based on a literature review of knowledge production and distribution in a national innovation system, and the preferred capabilities of researchers within knowledge-based economies. Findings about how the 30 research students produce and distribute knowledge are analysed against key assumptions generated from the literature review. The case studies aim to address Research Question 6: *Is the R&D work performed by 30 research students likely to contribute to an innovation?*

Chapter 7: Research training, human capital and economic growth examines what is meant by human capital, how it is formed and measured; and the possible economic and non-economic impacts of human capital investment in education. Many studies on the impact of human capital formation through education on economic growth have acknowledged inconclusive results and problems with causality. In addition, there are limited studies on the impact of research training on economic growth. Therefore, a basic approach has been taken in this chapter to address Research Question 7: *Does research training as human capital formation contribute to economic growth in Australia, Finland and the United States?*

Chapter 8: Conclusion summarises findings for Research Questions 1 to 7 to address the key research question for this study: *Does research training (particularly in science and technology fields) contribute to national innovation systems in Australia, Finland and the United States?* The chapter then draws together relevant literature, findings and responses received from interviewees to answer Research Question 8: *What is a research training culture of innovation*? This discussion describes the features of a research training culture of innovation that may enhance the contribution of research students to Australia's national innovation system. Implications of the concept to theory, policy and practice are also presented. Finally, the chapter proposes areas of further research that warrant more debate and research.

1.5 Definitions

Because the following terms are used frequently throughout the thesis, it is worth defining each of them in the introduction. They are presented here in alphabetical order. Most of the terms are clarified further in specific chapters.

Economically-relevant knowledge – Four types of knowledge that are combined in the innovation process in the learning economy: *Know-what* i.e. knowledge about facts or information; *know-why* i.e. knowledge about principles and laws in nature, human mind and society; *know-how* i.e. the ability to do different kinds of things on a practical level; and *know-who* i.e. the social ability to co-operate and communicate with different kinds of people and experts (Lundvall & Johnson, 1994).

Human resources in science and technology (HRST) – People who have either successfully completed their education at the third (university) level in an S&T field of study; or if they are not formally qualified, they are employed in an S&T occupation where these qualifications are normally required. The total number of people who fulfil these conditions at a particular point of time is called the **HRST stock**.

HRST core – People with a tertiary qualification who are currently employed in an S&T occupation.

Human capital – The knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of a personal, social and economic well-being (OECD, 2001b, p. 18).

Human capital formation – A process of further developing the productive capacity of human resources through investment (Wykstra, 1971, p. xv).

Innovation – A technological product or process (new or significantly improved) innovation that has been implemented; or an organisational innovation that has led to a measurable change in output.

International mobility of highly skilled people – People who are employed in year t who go abroad either temporarily or permanently for employment purposes; and people who are employed in year t coming from abroad (Åkerblom, 2001, p. 57). International mobility includes short-term overseas visits, long-terms stays, and permanent stays (Mahroum, 1999). Managers and executives, engineers and technicians, academics and scientists, entrepreneurs, and students are the main *highly skilled* groups (Mahroum, 1999).

Knowledge-based economy – An economy in which the production, distribution and use of knowledge is the main driver of growth, wealth creation and employment across all industries (McKeon & Lee, 2001, p. 1).

Learning economy – A dynamic concept that involves the capability to learn and expand the knowledge base. It refers not only to the importance of the science and technology systems – universities, research organisations, in-house R&D departments and so on – but also to the learning implications of the economic structure, the organisational forms and the institutional set-up (Lundvall & Johnson, 1994, p. 26).

National innovation system – A system of interacting market and non-market institutions that continuously learn how to generate, diffuse and use new knowledge to form product, process and organisational innovations. The role of government is to provide a framework of policy instruments that support systems growth and address problems that restrict the functioning of the system.

Research and development (R&D) – Creative work undertaken on a systematic basis in order to increase the stock of knowledge, including the knowledge of man, culture and society; and the use of this stock of knowledge to devise new applications (OECD, 2002a, p. 30).

Research training (in science & technology fields) – Research training provides research students with a high level of knowledge and skills necessary to work as HRST professionals in and beyond their national innovation system.

Research students – Researchers who undertake independent and novel research to form a thesis or dissertation. When educated and employed in key science and technology fields, they are a core part of the HRST stock and a critical component of a national innovation system.

Science – Knowledge or knowing in the disciplines of natural science, engineering and technology, medical sciences, agricultural sciences and social sciences; but excluding humanities (OECD/Eurostat, 1995, p. 16).

Technology – The application of knowledge, and more narrowly dealing with tools and techniques for carrying out the plans to achieve desired objectives (OECD/Eurostat, 1995, p. 16).

1.6 Delimitations of scope and key assumptions

As explained in section 1.2, this study explored the contribution of research training to national innovation systems in three *ways* which are presented as elements of the conceptual framework: international mobility and migration of research students and graduates; knowledge production and distribution by research students; and research training, human capital and economic growth. The study involved three countries (Australia, Finland and the United States) and 30 research students in science and technology fields from three universities. Key assumptions about the scope of this study in terms of the conceptual approach and participating countries and students are discussed in this section.

Key assumption 1: There are likely to be other factors beyond the three elements of the conceptual framework that impact on the contribution of research students to a national innovation system. The elements chosen were the most obvious and have been broadly analysed in this study. The study aims to raise awareness of the topic with stakeholders and stimulate further research that looks at these elements and other factors in more depth.

Key assumption 2: The study involves three Western countries with well established research training systems and national innovation systems that have been developed over a long period of time and are supported by comprehensive policies. Finland and the United States were chosen because they are world leaders in innovation, as indicated by key innovation measures; yet are very different in terms of size, economic structure and culture. Although the recommendations to build a *research training culture of innovation* in the concluding chapter are relevant to the three countries and other developed countries, they aim to enhance the contribution of research training to Australia's national innovation system.

Key assumption 3: As a highly skilled science and technology (S&T) workforce is a crucial component of any national innovation system, case studies were undertaken of research students in S&T fields. A purposive sampling strategy was used to recruit students who were undertaking cutting-edge S&T research and enrolled in a research training program with an international reputation for innovative outcomes. Even though this strategy produced a small information-rich sample of research students, the differences in research intensity at the three universities will have impacted on their experiences. In addition, the case studies were not representative of all research students within these or other fields, and findings cannot be generalised to the research student population in Australia, Finland and the United States. Therefore, the title of this PhD thesis includes a sub-title that recognises this assumption:

Research training and national innovation systems
in Australia, Finland and the United States

A policy and systems study supported by case studies of research students in the fields of geospatial science, wireless communication, biosciences, and materials science and engineering.

1.7 Chapter summary

This PhD study is largely a response to statements made by the Commonwealth Government of Australia about the need to effectively link knowledge produced in Australian universities to innovation in industry and the importance of research students to Australia's national innovation system – statements that were made as part of the 1999 *Knowledge and Innovation* reforms to research and research training. The study is the first of its kind to examine the role of research training within a national innovation system. It examined three "obvious" ways that research students contribute to a national innovation system, which are represented as elements in the study's conceptual framework. Information presented in this chapter should provide the reader with the necessary foundation to proceed through the rest of the thesis.

Chapter 2: Research design

2.1 Introduction

The research design for this PhD study is summarised in Figure 1. The design aimed to address the key research question: **Does research training (particularly in science and technology fields) contribute to national innovation systems in Australia, Finland and the United States?** Eight secondary research questions supported this key research question:

1. What is meant by *innovation*, a *national innovation system*, *research training* and *research students*?
2. What is the role of research training (particularly in science and technology fields) in a national innovation system?
3. What have been the major developments in, and performance of innovation and research training policies/systems in Australia, Finland and the United States?
4. What policies have been introduced in each country to support the international mobility and migration of research students and graduates?
5. How has each country performed in terms of *brain drain*, *brain gain* and *brain circulation*?
6. Is the R&D work performed by 30 research students likely to contribute to an innovation?
7. Does research training as human capital formation contribute to economic growth in Australia, Finland and the United States?
8. What is a *research training culture of innovation*?

Research questions 1 and 2 are addressed in Chapter 3 through an analysis of concepts that are words or terms within, or closely related to the key research question. Research Question 3 is addressed in Chapter 4 which discusses the structure, strengths and challenges of the research training systems and national innovation systems in Australia, Finland and the United States. Research Questions 4 to 7 are part of a **conceptual framework** consisting of three elements that are presented in Chapters 5, 6 and 7:

- International mobility and migration of research students and graduates.
- Knowledge production and distribution by research students.
- Research training, human capital and economic growth.

The final and concluding chapter draws together all findings in relation to these research questions in order to address the key research question and present the concept of a *research training culture of innovation* (Research Question 8). The remainder of this chapter explains the research design for the study in terms of epistemology, theoretical perspective, methodologies and methods. Section 2.5 discusses ethical requirements and processes that were undertaken.

Figure 1: Research design

Key research questions:

- ❖ Does research training (particularly in science and technology fields) contribute to national innovation systems in Australia, Finland and the USA?

Elements of the theoretical framework:

- ❖ International mobility and migration of research students and graduates
- ❖ Knowledge production and distribution by research students
- ❖ Research training, human capital and economic growth

Research Questions:

❶ What is meant by "innovation", a "national innovation system", "research training" and "research students"?

❷ What is the role of learning, competence building and R&D (in science and technology) in a national innovation system?

❸ What have been the major developments in, and performance of innovation and research training policies/systems in Australia, Finland and the USA?

❹ Do innovation and research training policies/systems in these countries encourage research students to contribute to a national innovation system?

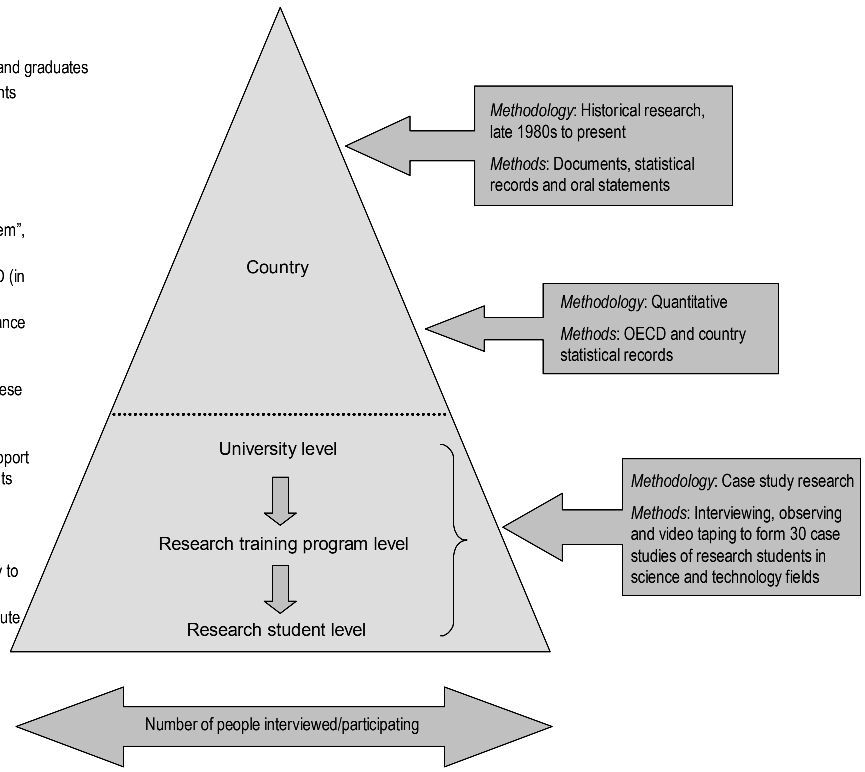
❺ What policies have been introduced in each country to support the international mobility and migration of research students and graduates?

❻ How has each country performed in terms of "brain-drain", "brain-gain" and "brain-circulation"?

❼ Is the R&D work performed by 30 research students likely to contribute to an innovation?

❽ Does research training as human capital formation contribute to economic growth in Australia, Finland and the USA?

❾ What is a research training culture of innovation?



2.2 Research stages and activities

Research activities occurred within **four interrelated stages**: PhD proposal development and approval; data collection in Australia, Finland and United States; data analysis; and thesis writing and verification (Table 1). These stages reflected elements of models advocated by the following authors:

- Crotty (1998) – A scaffolding approach to determine what methods to use, the methodology governing the choice and use of methods, the theoretical perspective behind the methodology, and the epistemology which informs the theoretical perspective.
- Neuman (1997) – An interactive process of seven steps i.e. choose topic, focus research question, design study, collect data, analyse data, interpret data, and inform others.
- Wiersma (2000) – A systematic and ordered process of five overlapping and integrated steps i.e. identify the problem, review information, collect data, analysing data, and draw conclusions.
- Denzin and Lincoln (1998) – Five phases or levels of activity starting with the researcher as a multicultural subject, followed by theoretical paradigms and perspectives, research strategies, methods of collection and analysis, and the art of interpretation and presentation.

Table 1: Stages and activities in research process

Month/year	Stages/activities
March to December 2002	**Stage 1: PhD proposal development and approval**
July 2002	Completed research methods course.
September 2002	Passed First Review presentation.
October 2002	Submitted final PhD proposal and ethics application.
December 2002	Received approval for the PhD proposal and ethics clearance.
February to July 2003	**Stage 2a: Data collection in Australia (based at RMIT University), including initial analysis**
March 2003	Interview questions tested on five students and one supervisor.
May 2003	Attended the seminar *Innovation and Transformation in the Australian Economy* at the National Graduate School of Management (Australian National University).
July 2003	Second Review presentation at the Faculty's Postgraduate Colloquium.
July to December 2003	**Stage 2b: Data collection in Finland (based at the University of Oulu), including initial analysis**
July 2003	Presented a paper at the *Third Conference on Researching Work and Learning* in Tampere, Finland.
October 2003	Attended a two week ETIC European Doctoral Training Programme on *Systems of Innovation and Technology Policy* at the University of Maastricht, The Netherlands.
	Conducted interviews at the OECD (Paris), European Union (Brussels) and University of Aachen (Germany).
	Attended the conference *Institutional Responses to the Changing Research Environment* hosted by Zentrum für Wissenschaftsmanagement/Centre for Science & Research Management and the OECD Programme on Institutional Management in Higher Education in Bonn (Germany).
December 2003	Completed interviews of Finnish innovation and research training experts.
	Completed and distributed interactive case studies of RMIT and University of Oulu research students.
January to May 2004	**Stage 2c: Data collection in United States (based at the University of Illinois at Urbana-Champaign (UIUC)), including initial analysis**
February 2004	Received ethics approval from UIUC.
March 2004	Submitted the first of two reports to the National Technology Agency of Finland (Tekes).
May 2004	Completed interviews of American innovation, research training and human capital experts.
	Completed and distributed interactive case studies of UIUC research students.
August 2004 to March 2005	**Stage 3: Data analysis and verification**
September 2004	Presented findings at RMIT University *Conference on Innovating Research*
March 2005	Reviewed *Chapter 2 Research Design* and *Chapter 4 Conceptual Framework*. These chapters informed the analysis of collected data.
April to October 2005	**Stage 4: Thesis writing and verification**
August 2005	Final report (based on 4 thesis chapters) sent to Tekes for comment and publication.
September 2005	Submitted full thesis to supervisor which incorporated feedback received about draft chapters.
October 2005	Submitted final thesis for examination.

The activities that occurred within the four interrelated stages were informed by the epistemology of constructivism; the theoretical framework of interpretivism – although some aspects of post-positivism were relevant; and the methodologies of historical research, case study research (characterised to a limited extent by ethnography) and quantitative research. The main methods of data collection were document analysis, semi-structured interviews, short observations, and statistical analysis. Overall, this study used a mixed methodology strategy where there was a complementary relationship between qualitative and quantitative research methodologies.

2.3 Epistemology and theoretical perspective

In his discussion on the nature of qualitative and quantitative research, Lancy (1993) referred to epistemology as "…basic assumptions made about how one derives truth, the purpose of inquiry, the role of the scientist/investigator, what constitutes evidence, how one evaluates the quality of a given study, and so on" (p. 8). Crotty (1998) identified three types of epistemological stances that influence how researchers decide on what knowledge is possible and how it can be obtained in an adequate and legitimate way (pp. 5-9):

- *Objectivism* – Things exist as meaningful entities independently of consciousness and experience, that they have truth and meaning residing in them as objects, and that careful research can attain the objective truth and meaning.
- *Constructivism* – There is no objective truth waiting for us to discover it. Truth, or meaning, comes into existence in and out of our engagement with the realities in our world. There is a meaning without a mind. Meaning is not discovered, but constructed … different people may construct meanings in different ways, even in relation to the same phenomenon.
- *Subjectivism* – Meaning does not come out of an interplay between subject and objective but is imposed on the object by the subject … humans are not that creative … meaning is made out of something or imported from somewhere else.

Constructivism was the most logical epistemological position for this study as it provides the flexibility to change the methods as more evidence was uncovered, supports the methodologies selected (particularly historical research and case study research), and allows the researcher to construct his/her own response to the research findings. The research design incorporated the concept of triangulation which is a key characteristic of constructivism validating the use of different data sources, different perspectives of theories, different investigators, or different methods (Sturman, 1997). This approach has allowed the construction of meanings about the contribution of research training to national innovation systems in Australia, Finland and the United States. These meanings were based on what had been written about research training, national innovation systems and the three elements of the conceptual framework; and what was said by participating experts, research students and supervisors.

Constructivism is linked to the theoretical perspective of **interpretivism** which, along with the theoretical perspectives of positivism, post-positivism and critical inquiry, are "competing approaches to social research based on different philosophical assumptions about the purpose of science and the nature of social reality" (Neumann, 1997, p. 82). Guba and Lincoln (1998) refer to these theoretical perspectives as *paradigms* which represent "the basic belief system or worldview that guides the investigator, not only in choices of method, but in ontologically and epistemologically fundamental ways" (p. 195). The interpretivist paradigm informed the collection, analysis and presentation of the case studies of the 30 research students. The case studies relied on responses from participating experts, students and supervisors. Given that the participants were active and conscious human beings who act and behave differently, their interpretation of the questions varied, leading to different responses and viewpoints. The aim of the study was to capture these meanings by seeing through the eyes of the participants.

There are some features of the post-positivism paradigm that were useful and appeared complementary to interpretivism. These features included judging the quality or rigour of the inquiry through internal validity, external validity, reliability and objectivity; ethics are extrinsic to the inquiry process and policed by external mechanisms such as professional codes of conduct and human subject committees; and novices are trained in technical knowledge about measurement, design and quantitative methods as well as qualitative methods (Denzin & Lincoln, 1998).

2.4 Methodologies and methods

Crotty (1993) referred to methodology as a strategy, plan of action, process or design that governs the choice and use of methods. The study used a **mixed methodology strategy** based on a complementary relationship between the qualitative and quantitative research methodologies, which in this case were historical research, case study research and statistical analysis. Lancy (1993) described a complementary relationship as one in which both qualitative and quantitative research have "the potential to contribute vital information bearing on a question or problem" (p. 11). For example, the history of innovation and research training systems obtained from documents and interviews was supported by an analysis of system performance using statistical data. Two elements of the conceptual framework (international mobility and migration of research students and graduates; and research training, human capital and economic growth) relied on a combination of theory obtained from key literature and statistical data. Yet the element relating to knowledge production and distribution by research students was solely based on the qualitative methodology of case study research. Findings generated using both quantitative and qualitative research methodologies were needed to address the research questions. The use of the different data collection methods of document analysis, statistical analysis, interviews and short observations "implies greater validity than if a single or similar methods had been used" (Neuman, 1997, p. 151).

2.4.1 Historical research

Historical research is defined as the "systematic and objective location, evaluation and synthesis of evidence in order to establish facts and draw conclusions about past events" (Cohen & Manion, 1989, p. 48). Information sourced from key documents gathered in each country and obtained from interviews of innovation and research training experts was used to identify the major developments in, and performance of innovation and research training policies/systems in Australia, Finland and the United States (Research Question 3). The scope of the methodology was based on two of the four ways identified by Gottschalk (1969) to conduct historical research: *Chronological*, starting from the late 1980s when the national innovation systems approach was conceptualised; and *geographical* i.e. Australia, Finland and the United States.

As stated by Cohen and Manion (1989), historical research is different to other forms of research in that it must deal with data that already exists. Country-specific documents produced by Governments, consultative groups, industry bodies and academics were collected when they described, recommended and/or evaluates policy and system structures, issues, changes and directions. These documents have been supported by well-known global publications that have informed policy and system development and explained relevant concepts – such as OECD studies on national innovation systems, mobility of highly skilled workers and industry-science relationships. These **country-specific and global documents**, together with **statistical data**, are primary sources of data as they were "original to the problem under study" (Cohen & Manion, 1989, p. 55). A smaller number of secondary sources produced in response or related to these key documents also "supplement[ed] primary data" (Cohen & Manion, 1989, p. 55). The majority of documents were located in organisational websites and publication databases, or provided or referred to by innovation and research training experts who were interviewed. The techniques of internal criticism[1] and external criticism[2] were useful in assessing the accuracy and genuineness of the documents.

Key documents, diagrams of national innovation systems (which include supporting agencies) and referrals provided by experts to other experts were the main methods used to identify **innovation and research training experts** to approach for an interview. Some of the experts who were interviewed provided a testimony as an *eyewitness* (Gottschalk, 1969) as they were involved in producing key documents. Other experts interviewed were not eyewitnesses but had expertise in the content of these documents. Table A1 in the appendix contains the names of experts interviewed in Australia, Finland and the United States. Table A2 contains the questions asked of Finnish experts which were slightly revised for the interviews of experts in the United States. These questions suggest a structured interviewing style where "an interviewer asks each respondent a series of pre-established questions with a limited set of response categories" (Fontana & Frey, 1994, p. 363). However, there was a fair degree of flexibility in the

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[1] *Internal criticism* aims to determine the accuracy of the information contained in the documents by asking questions about whether the author was involved in the event he or she is describing, competent to describe the event, emotionally involved in the event, and had any vested interest in the outcomes of the event (Forrest, May 2002, unpublished handout).

[2] *External criticism* refers to the genuineness of any and all documents the candidate uses which is determined by asking questions about who wrote the document, for what purpose was the document written, when was the document written (and is this date accurate), where was the document written, under what conditions was the document written, and do different forms or versions of the document exist (Forrest, May 2002, unpublished handout).

actual interviews which meant not all questions were asked, questions were not always asked in the same sequence, and unexpected questions and comments arose. Therefore, experts were interviewed using a *semi-structured* or *guided* style as there was "ample freedom to formulate questions and to determine the order of the questions" (Sarantakos, 1995, p. 182). Interviews were also *unstandardised* as the questions asked were open, allowing experts to answer each question as they saw fit.

2.4.2 Case study research

Case study research involves investigating "an individual, group or phenomenon" (Sturman, 1997, p. 61). There is a perception that research training is *training* and the contribution of research students to a national innovation system will largely depend on how they enter the labour market after graduation. The 30 **intrinsic** case studies of research students from RMIT University (Australia), University of Oulu (Finland) and University of Illinois at Urbana-Champaign (United States) provided an opportunity to understand the R&D work being undertaken by each student within their research training environment. According to Stake (1995), a case study is intrinsic when the focus is learning about a particular case. The purpose of the case studies was to investigate how research students were producing and distributing knowledge; whether their R&D work was likely to contribute to an innovation (Research Question 6); and the extent of international mobility activities during and after their research training.

A **purposive sampling** approach was used to select research students who were enrolled in research programs in science and technology fields (upon which many innovations rely) and from countries with a strong innovation track record (Table 2). This process provided an "opportunity to focus, without justification and without hesitation, on a small information-rich sample selected to illuminate the research focus" (Green, 2002, p. 11). It is important to note that research students who were selected using this approach were not representative of all research students within their fields or other fields. Therefore, findings cannot be generalised to the research student population in Australia, Finland and the United States. In addition, there were differences in research intensity at the three universities as reflected in different levels of infrastructure and other resources available to research students. RMIT University is regarded as more of a teaching-intensive university whereas the University of Illinois has a long history as a research-intensive university – with the University of Oulu somewhere in between. As a result, the study has avoided comparisons between universities.

Table 2: Research student case studies

University	Centre, Department or Group	No. of students
RMIT University, Australia	Department of Biotechnology and Environmental Biology	5
	Department of Geospatial Science	5
University of Oulu, Finland	Biocenter Oulu	5
	Centre for Wireless Communication	5
University of Illinois at Urbana-Champaign, USA	Department of Materials Science and Engineering	2
	Beckman Institute of Advanced Science & Technology	3
	Department of Crop Sciences	5
Total		30 students

Research students were targeted from two types of programs. Department, centre or program heads (i.e. "gatekeepers") of a bioscience program such as biotechnology, bioinformatics, molecular biology and crop sciences were approached at each university. For the second program, gatekeepers were approached from a program of particular strength in each university: Geospatial science at RMIT University, wireless communications at the University of Oulu, and materials science and engineering at the University of Illinois at Urbana-Champaign. Following a face-to-face interview with gatekeepers that explained the purpose of the study and the involvement of participants from a particular department or centre, gatekeepers usually nominated research students or requested supervisors to nominate research students. Nominated research students were then invited to participate. In some cases, referrals by research students led to the recruitment of other research students from the same program. Names of case study participants are contained in Table A3 in the appendix. As discussed in section 2.5, participants agreed to have their identities disclosed on a Compact Disc (CD) and in the thesis.

The **background interview** with the research students was *semi-structured* (although somewhat closer to structured) and *unstandardised*. Research students were able to formulate their own responses to the questions. The questions that are contained in Table A4 in the appendix were generated from a review of relevant reports that were produced prior to, as part of, or following Australia's National Innovation Summit held in February 2000. Table A5 in the appendix is an extract from a conference paper written for the 3rd International Conference of Researching Work and Learning held in Tampere (Finland) in 2003. The part of the paper that described how the questions were developed is contained in this appendix table. Five students from RMIT University's Department of Biotechnology and Environmental Biology piloted the questions which led to slight revisions to the questions and their sequencing. The interviews with research students aimed to gather as much relevant information as possible about their background, research topic (and whether it was likely to contribute to an innovation), international mobility activities, commercialisation possibilities, intellectual property arrangements, dissemination methods, and any other relevant experiences in their research training program. At the start of the interview, research students were provided with a copy of the questions. Interviews were digitally recorded and later transcribed and sent to students for verification. **Written documents** that described the student's background (i.e. resume) and research topic (i.e. research proposal and publications) were collected during, or soon after the background interview.

Following the background interviews, arrangements were made to observe and film the research students in their natural setting(s) where they usually conducted their research. The laboratory, field and office were the main settings visited. The type of **observation** undertaken can be regarded as *direct* as it involved the objects of the study i.e. the research students; *open* as the research students were fully informed about their participation; and *semi-structured* as the purpose of the observation was disclosed to the research students and the settings for filming were selected by the research students (Sarantakos, 1995). In the second filming session, research students were asked to respond again to four questions asked during the background interview. They were asked to succinctly explain their background, research topic, the likely users of their results, and how their research was innovative. The footage of each research student was edited to create a three to five minute video which included overlays from the first filming session in their natural setting(s).

Interviewing, observing and filming 30 research students from three different countries in their natural setting over one semester suggests some sort of alignment with the methodology of ethnography – especially when writers like Hammersley and Atkinson (1995) state that ethnographers participate "overtly or covertly, in people's daily lives for an extended period of time, watching what happens, listening to what is said, asking questions … collecting whatever data to throw light on the issues that are the focus of the research" (p. 1). Although the approach taken for the fieldwork was influenced by ethnography, it was not characterised by the essential features of an ethnographic study that were identified by Evans-Pritchard (1951): Carefully studying the people of the region before starting the fieldwork; spending sufficient time on the study (he suggested two years); and studying the entire culture and social life of the people studied.

Supervisors of the 30 research students and **industry representatives** in some of the Australian cases participated in a *semi-structured* interview. Some of the questions asked were similar to those asked of the research students, such as the nature of the student's topic, whether the student was involved with users, commercialisation possibilities, dissemination methods, mobility experiences, and if the student's research was expected to contribute to an innovation. Supervisors were also asked about student selection, skills development, and the characteristics of a *research training culture of innovation* – if they believed research students should be encouraged to innovate.

Case studies have been supported by a description of the department and university in which the research students were enrolled. Departmental and university information was mainly sourced through websites and interviews with **university staff** who were research training policy advisors, research training program managers or departmental/centre heads. Interview questions focused on strengths, weaknesses and future directions for research training at the participating department and university.

When composing a case study, Yin (1989) recommended identifying the target audience, developing a compositional structure, and following procedures to analyse and present the case studies. There are a number of audiences for this study: Participants in the case studies, their home departments and universities, policymakers, funding bodies, and the RMIT University thesis committee. Yin (1989) supported the production of more than one version or form of the case study when there are differences among audiences. For this study, case study results were presented interactively on a CD and in written format in this thesis. The purpose of these two formats were to arouse the interest of the different "flocks" of readers (Van Maanen, 1988). The presentation of the case studies in a user-friendly interactive format on a CD allowed relevant audiences to see, hear and read about research students from three different countries. By June 2004, three CDs had been produced and distributed to case study participants as well as innovation and research training experts from the National Technology Agency of Finland (Tekes), OECD, European Union and the U.S. National Research Council. The presentation of the students' work on a CD also assisted in the recruitment of students who could use the CD to further promote themselves and their research.

For the thesis committee and other readers of the thesis, case study findings were included in the discussion on the international mobility and migration of research students in Chapter 5, and analysed within the second element of the conceptual framework i.e. knowledge production and distribution by research students in Chapter 6. This approach represents a combination of two of the seven representational styles proposed by Van Maanen (1998): A *realist style*[3] to present the work and experience of the research students; and a *formal style* to analyse findings in a way that can "build, test, generalise, and otherwise exhibit theory" (p. 130).

2.4.3 Statistical analysis

Statistical data for the study was mainly sourced from OECD publications and its Main Science and Technology Indicators (MSTI) database as well as key country sources and databases i.e. the U.S. National Science Board's Science and Engineering Indicators, Finland's KOTA Online database, and the Higher Education Statistics Collection from Australia's Department of Education, Science and Training (DEST). Chapter 3 explains approaches to measuring national innovation system performance (section 3.3.3), R&D inputs (section 3.4), and human resources in science and technology (HRST) stocks (section 3.5). Chapter 4 includes statistical data relating to innovation investment and performance of Australia, Finland and the United States. Chapter 5 includes available proxy measures that indicate the international mobility and migration of research students and graduates. Chapter 7 includes statistical data on human capital stocks, investment and returns as well as data relating to the possible economic and non-economic impacts of human capital investment in university education.

2.5 Ethics

As part of the ethics applications for RMIT University and University of Illinois at Urbana-Champaign, plain language statements and consent forms were developed and approved by designated committees. Although ethics approval was not required by the University of Oulu, case study participants in Finland also received a plain language statement and consent form. The statement for research students explained that their participation would involve a background interview, observing and filming of their work in a natural setting, a video response to a small number of questions, and providing feedback about their draft case study. Table A6 in the appendix contains an example of the plain language statement and consent form provided to research students from Biocenter Oulu at the University of Oulu. Supervisors received a similar statement which described how they and their student(s) would be involved. Innovation and research training experts who were interviewed also received a plain language statement and consent form.

Although the option of anonymity was offered, all case study participants agreed to have their identity revealed on a CD and in the thesis. Certain commercially confidential information was not included in a

[3] According to Van Maanen (1988), realist tales 'provide a rather direct, matter-of-fact portrait of a studied culture, unclouded by much concern for how the fieldworker produced such a portrait' (p. 7).

small number of case studies, and in one case the author of this thesis signed a legal document to assure the protection of such information. In another case, filming was not permitted in a building designated for military research and an alternative environment was found. To ensure the accuracy of the case studies, participants were asked to check the accuracy of the facts presented in their interview transcript and draft case study – a process known as *member checking* (Lincoln & Guba, 1985).

2.6 Chapter summary

The research design for this study is based on a mixed methodology strategy characterised by a complementary relationship between historical research, case study research and statistical analysis. It has been informed by the principles of constructivism and interpretivism. Eight secondary research questions were formulated to address the key research question: *Does research training (particularly in science and technology fields) contribute to national innovation systems in Australia, Finland and the United States?* Activities within four interrelated stages were undertaken between March 2002 and October 2005: PhD proposal development and approval, data collection, data analysis, and thesis writing and verification. The data collection stage was undertaken in Australia from February to June 2003, Finland from July to December 2003, and the United States from January to May 2004. Case study results were presented interactively on a CD and in written format in two chapters of the thesis. Ethics applications were approved by RMIT University and the University of Illinois at Urbana-Champaign, and the necessary policies and procedures have been followed.

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Chapter 3: Key concepts

3.1 Introduction

The following concepts are defined and/or clarified in this chapter because they are words or terms within, or closely related to the key research question:

- Innovation
- National innovation systems
- Research and development (R&D)
- Human resources in science and technology
- Research students and training

The chapter presents internationally agreed and/or recognised definitions and explanations for these concepts to determine what is meant by *innovation*, a *national innovation system*, *research training* and *research students* (Research Question 1). The chapter also clarifies the role of research training (particularly in science and technology fields) in a national innovation system (Research Question 2). This approach provided a framework to examine the contribution of research training to three national innovation systems in terms of international mobility and migration, knowledge production and distribution, and its possible impact on economic growth.

3.2 Innovation

3.2.1 Definition of innovation

The OECD's Oslo Manual (1997) contains guidelines for collecting and interpreting science and technological data related to innovation. The 1997 version of the manual is based on the testing of concepts and classifications in the earlier (1992) version by many OECD countries, an improved understanding of the innovation, and the existence of a wider range of industries. The manual distinguished between the different types of innovation and those activities that are not regarded as an innovation, as shown in Figure 2. The main type of innovation is **technological product and process (TPP) innovation** defined as "implemented technologically new products and processes and significant technological improvements in products and processes" (p. 31). The word *implemented* means that the TPP innovation has been "introduced on the market (product innovation) or used within a production process (process innovation)" (p. 31).

Technological **product innovation** covers both goods and services, and takes two broad forms. A technologically **new product** has "… technological characteristics or intended uses [that] differ significantly from those of previously produced products. Such innovations can involve radically new technologies, can be based on combining existing technologies in new uses, or can be derived from the use of new knowledge" (p. 32). Examples provided by the OECD (1997) include the first microprocessors and video cassette recorders which used radically new technologies, and the first portable cassette player which combined existing tape and mini-headphone techniques into a new use. Although not stated in the manual, this type of innovation has also been described as *breakthrough* or *radical* innovation. A technologically **improved product** is "an existing product whose performance has been significantly enhanced or upgraded" (p. 32). The OECD (1997) distinguished between improvements to a simple product through higher-performance components or materials; and partial changes to one of the integrated technical sub-systems of a complex product. For example, the use of higher performance components to substitute plastics for metals in kitchen equipment or furniture, and the introduction of ABS braking or other sub-system improvements in cars to partially change one of a number of integrated technical sub-systems. This type of innovation has also been described as *progressive* or *incremental* innovation.

The OECD (1997) defined technological **process innovation** as follows:

> Technological process innovation is adoption of technologically new or significantly improved production methods, including methods of product delivery. These methods may involve changes in equipment or production organisation, or a combination of these changes, and may be derived from the use of new knowledge. The methods may be intended to produce or deliver technologically new or improved products, which cannot be produced or delivered using conventional production methods, or essentially to increase the production or delivery efficiency of existing products. (p. 32)

Figure 2: Types of innovation

			INNOVATION			*Not innovation*
			Maximum	Intermediate	Minimum	
			New to the world	(a)	New to the firm	Already in firm
TPP INNOVATION	Technologically new	Product				
		Production process				
		Delivery process				
	Significantly technologically improved	Product				
		Production process				
		Delivery process				
Other innovation	New or improved	Purely organisation				
Not innovation	No significant change, change without novelty, or other creative improvements	Product				
		Production process				
		Delivery process				
		Purely organisation				

TPP innovation ☐ Other innovation ☐ Not innovation ☐

(a) Could be geographical e.g. new to country or region.

Source: OECD (1997) p. 36

The OECD (1997) defined **worldwide TPP innovation** as "… the very first time a new or improved product or process is implemented" (p. 34), and **firm-only TPP innovation** which occurs "… when a firm implements a new or improved product or process which is technologically novel for the unit concerned but is already implemented in other firms and industries" (p. 34). These terms are referred to as *New to the world* and *New to the firm*. In between these two types is an *Intermediate* category where an innovation could be geographical as it is new to a country or region. Figure 2 also includes *Other innovation* which represents **organisational innovation** described as "… the introduction of significantly changed organisational structures; the implementation of advanced management techniques; or the implementation of new or substantially changed corporate strategic orientations" (pp. 36-37). Organisational innovations lead to a "measurable change in output, such as increased productivity or sales" (p. 37).

The OECD (1997) also identified changes in products and processes that cannot be regarded as TPP innovations:

> These are changes which: are insignificant, minor, or do not involve a sufficient degree of novelty; [and] make other creative improvements where the novelty does not concern the use or objective performance characteristics of the products or in the way they are produced or delivered but rather their aesthetic or other subjective qualities. (p. 37)

The rest of this section discusses the well known models or approaches to innovation that fit into Rothwell's (1994) **five generations of innovation models**: *First generation* (technology or science push), *second generation* (need or market pull), *third generation* (coupling of science, technology and the market), *fourth generation* (integrated), and *fifth generation* (systems integration and networking). The *fourth generation* or *integrated model* involves parallel development with integrated development teams rather than a sequential process; strong supplier and customer linkages with the firm; collaborations between firms (such as joint ventures and strategic alliances); and integration of R&D, manufacturing and marketing functions. The *fifth generation* or *systems and networking model* includes fully integrated parallel development and significantly more networking through strong linkages with leading-edge customers; the use of expert systems and simulation modelling in R&D; strategic collaborations and networking between firms; co-development of new products and linked systems with suppliers; and an efficient and flexible innovation process enhanced by IT technologies (Industry Commission, 1995).

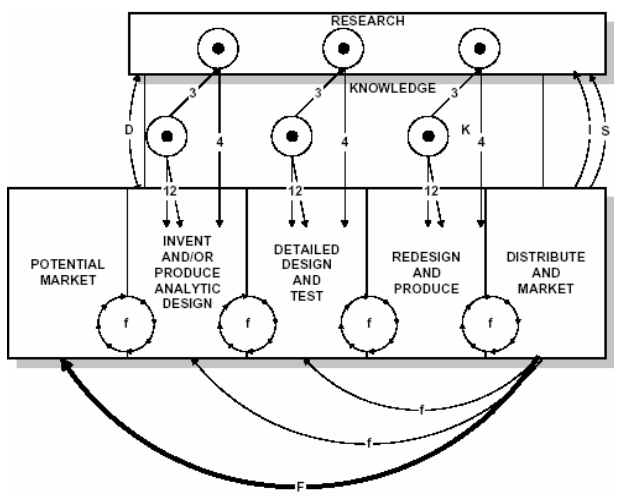
3.2.2 Linear models (post World War II)

The **linear model** of innovation, in which the market reacts to R&D outputs in a simple sequential process, was generally accepted in the period following World War II. In this technology or science push model, knowledge flows smoothly in one direction from basic research to development (design and engineering) to production (manufacturing) to marketing and then sold in the marketplace. Based on his definition of invention as a new combination of pre-existing knowledge which satisfies some want, Schmookler (1966) proposed a demand-induced model of innovation consisting of six critical steps to produce an invention: The existence of inventive potential i.e. the availability of the last bit of knowledge to create an invention; acquisition by the inventor to this last bit of knowledge; desire by the inventor or backer for the effect of the innovation; decision to make the invention; creation by the inventor of the invention's root idea; and reduction of the invention to operable form (pp. 16-17).

3.2.3 Kline and Rosenberg's chain-link model (1986)

Kline and Rosenberg (1986) criticised economists for treating technological innovation as a *black box* of known components and processes, concentrating only on inputs and outputs rather than on what goes on inside the box. They were concerned that technologists were only interested in technological processes inside the box, ignoring market forces and institutional requirements for innovation. Kline and Rosenberg (1986) argued that the linear model of innovation distorted the reality of innovation as it did not include feedback paths between and within events; take into account the real world problems of "inadequate information, high uncertainty and fallible people" (p. 266); or recognise that innovation involves complex and variable processes and systems. Science is not a precondition for innovation (using the bicycle as an example of an innovation that occurred without science) but an important part of the innovation process. Innovation draws on science, and the demands of innovation create new science. The outcome of an innovation is highly uncertain due to "uncertainty not only about technical performance but also the market response and the ability of the organisation to absorb and utilise the requisite changes effectively" (p. 276). These factors, together with significant differences in how innovations are generated from industry to industry, make it difficult to measure the impact of innovation.

Figure 3: Chain-link model of innovation



Source: Kline & Rosenberg (1986) p. 289

Kline and Rosenberg (1986) proposed a **chain-link model** (see Figure 3) consisting of five major paths of activities in the innovation process:

- The first path is the central-chain-of-innovation from design through to development, production and marketing.
- The second path is a series of feedback links between these activities (F and f).

- Science is the third path which is linked to the developmental processes and is called upon by the other stages when information is needed (D and K). The type of science needed depends on the stage in which it is undertaken, such as pure, long-range science at the design or invention phase compared to process research at the production stage.

- The fourth path between research and invention (D) is rare and involves new science leading to a radical invention, such as lasers, semiconductors, atom bombs and genetic engineering.

- The final path is feedback from the products of innovation on the market to science through the support of scientific research of instruments, machines, tools and technology procedures (I); and scientific research about the product area (S).

3.2.4 Dosi's stylised facts (1988)

Dosi (1988) defined innovation as "the search for, and the discovery, experimentation, development, imitation, and adoption of new products, new production processes and new organisational set-ups" (p. 222). Based on contributions by a number of authors to the economics of innovation over the previous decade, Dosi (1988) identified **five stylised facts of innovation** that represented fundamental properties of the innovative process (pp. 222-223):

- Uncertainty about the occurrence of unknown events, existence of techno-economic problems with unknown solutions and consequences of actions.

- Increasing reliance on advances in scientific knowledge for major new technologies.

- Increasing complexity of research and innovative activities leading to formal organisations (such as R&D laboratories in firms, universities and government laboratories) as opposed to individual innovators.

- Many innovations and improvements are the result of *learning-by-doing* and *learning-by-using* when solving production problems, meeting customer requirements, overcoming bottlenecks etc.

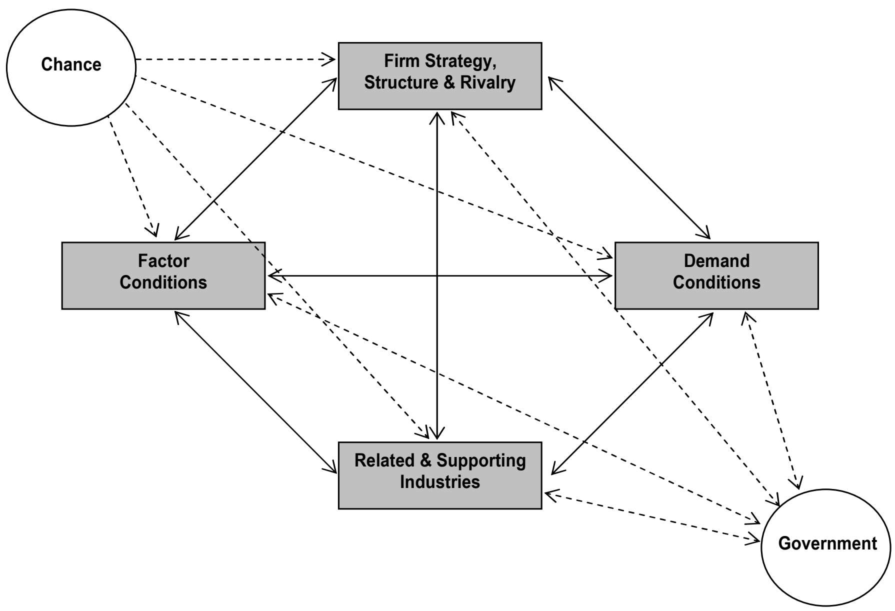
- Technical change is a cumulative activity i.e. technological advances are a function of the technological levels already achieved.

Despite an increasing reliance on scientific progress for technological advances, Dosi (1988) found that links were more direct and powerful in some technologies and sectors and more indirect in others. For example, many innovations in electronics and chemicals industries tend to rely on emerging new technological paradigms made possible by scientific advances. In such cases, innovative activities in these science-based sectors were often formalised in R&D laboratories, undertaken by large firms, and led to product innovations that were taken up by many sectors as capital or intermediate inputs. Dosi (1988) identified the use of science-based equipment and intermediate inputs together with generic science-based knowledge acquired by researchers and engineers during their formal training as examples of indirect links between science and technological advances in other sectors.

3.2.5 Porter's national competitive advantage (1990)

Porter (1990) developed his **national competitive advantage** approach by examining specific industries and industry segments to explain why nations achieved international success in particular industries. He identified the following four broad and interrelated factors within a "diamond" (see Figure 4) that shape the environment in which firms compete: *factor conditions* i.e. access to infrastructure and human, physical, knowledge and capital resources; *demand conditions* i.e. the home market's demand for the industry's product or service; *related and supporting industries* i.e. internationally competitive supplier industries and related industries in a nation; and *firm strategy, structure and rivalry* (Porter, 1990). The government's role is to influence these conditions through subsidies, policies (including education), standards and regulations, and as a major buyer of many of the nation's products. *Chance events* like surges in world or regional demand, changes in financial markets and exchange rates, war, and pure invention were included in the diamond as they cause shifts in competitive advantage.

Figure 4: Determinants of national competitive advantage



Source: Porter (1990) p. 127

Porter (1990) divided factor conditions into *basic factors* such as natural resources, climate, location, unskilled and semi-skilled labour, and debt capital; and *advanced factors* such as highly educated personnel, modern digital data communications infrastructure, and university research institutes in sophisticated disciplines. To achieve higher-order competitive advantages such as differentiated products and proprietary production technology, Porter (1990) argued that countries need advanced factors that require large and sustained investments in human and physical capital. To show how the creation of advanced factors relies on basic factors, he used the example of how the supply of doctoral level biologists is dependent on the pool of talented university graduates in the field.

Porter (1990) also distinguished between *generalised factors* such as highway system, a supply of debt capital, and a pool of well-motivated employees with college educations that can be deployed in a wide range of industries; and *specialised factors* such as narrowly skilled personnel, infrastructure with specific properties, and knowledge bases in particular fields. He concluded that the "most significant and sustainable competitive advantage results when a nation possesses factors needed for competing in a particular industry that are both advanced and specialised" (p. 79). Whereas natural resources or location are basic factors that are inherited, nations must create and continually upgrade advanced and specialised factors. Porter (1999) found that internationally successful national industries were characterised by a significant direct investment by firms, trade associations and individuals in factor creation, and a close coupling of private and public investments.

Because the determinants of national competitive advantage do not occur evenly throughout an economy, Porter (1990) proposed that industries are connected through **clusters**. These clusters draw on "common inputs, skills, and infrastructure [stimulating] government bodies, educational institutions, firms, and individuals to invest in relevant factor creation or factor-creating mechanisms" (p. 135). The impact of industry clusters on factor creation and upgrading is strongest when there is vigorous domestic rivalry and rivals are located in the same city or region.

3.2.6 Systems of innovation approaches

There are four types of innovation systems which serve different purposes but can be regarded as systems and networking models or **systems of innovation** approaches. Innovation systems can be national (which is discussed on subsequent pages), regional[4], sectoral[5] and technological[6]. Their development has been mainly influenced by interactive learning and evolutionary theories of innovation. The process of learning and user-producer interaction are key elements of the interactive learning theory proposed by Lundvall (1992) and the Aalborg Group in Denmark. Edquist (1997) found that the evolutionary theory of technical change first proposed by Nelson and Winter (1982) assumed that technical change is an evolutionary process in which innovations are path dependent (i.e. built on existing technologies), open-ended, time-consuming, involve considerable randomness, and although superior, are not optimal in solving a technical problem. As a result, the system never reaches a state of equilibrium. Edquist (1997) identified nine characteristics that are common to systems of innovation approaches (pp. 16-29):

- Innovation through learning is the key focus of the system.
- Systems aim to be holistic covering all determinants of innovation i.e. economic, institutional, organisational, social and political.
- Innovations, institutions, organisations and the whole system develop cumulatively over time.

[4] Cooke (2001) identified *region*, *innovation*, *network*, *learning* and *interaction* as key, linked concepts in a regional innovation system made up by network organisations and/or members who *associate*. He referred to the Boston biotechnology case as one of the world's leading clustered, regional, sectoral innovation systems.

[5] Malerba (2002) defined a sectoral system of innovation and production as a "set of products and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products. A sectoral system has a specific knowledge base, technologies, inputs and demand" (p. 1).

[6] Carlsson (1997) referred to the definition of technological systems provided by Carlsson & Stankiewicz (1991) as "knowledge and competence networks supporting the development, diffusion and utilisation of technology in established or emerging fields of economic activity. They consist of networks of firms, research and development (R&D) infrastructures, educational institutions and policy-making bodies" (p. 2).

- Systems of innovation differ across countries, regions and technologies due to differences in the structure of production, resources devoted to R&D and innovation, performance of technology development and diffusion, and organisations and institutions in the system – making it difficult to compare systems and define an optimal system of innovation.
- Firms seldom innovate in isolation but interact with other organisations, such as competitors, suppliers, customers, government agencies, universities etc.
- Innovation encompasses technological process innovations, technological product innovations, and organisational innovations.
- Institutions have a crucial role in influencing innovation, and include formal institutions such as R&D laboratories and universities as well as norms, rules and laws.
- Ambiguity about the systems of innovation concept provides openness and flexibility for competing perspectives and solutions but makes the process of selection between alternatives difficult.
- There is no formal theory for the systems of innovation approach but instead it is characterised by conceptual frameworks.

3.2.7 Etzkowitz & Leydesdorff's triple helix of academic-industry-government (1995)

With an interest in how to study innovation systems from different dimensions and subdynamics, Henry Etzkowitz and Loet Leydesdorff proposed in 1995 that the key institutions of university, industry and government form a *dually layered network* in a national innovation system: "One layer of institutional relations in which they constrain each other's behaviour, and another layer of functional relations in which they shape each other's expectations" (Leydesdorff, 2006). They observed that the new environment for innovation is characterised by a strong role of universities and other knowledge producing institutions; active engagement of all levels of government in formulating policies; strategic alliances of firms in developing and marketing new products, product and process innovation within industry which are complemented by techno-scientific innovation; and the emergence of science-based technologies that originated in academia and were encouraged by Government policies (Etzkowitz, 1998). As a result, the three institutional sectors of public, private and academia that previously worked separately are increasingly working together in a spiral pattern to form a **triple helix** with linkages emerging at various stages of the innovation process. There are four dimensions in their model (Etzkowitz, 1998, p. 129):

- Internal transformation in each of the helices, such as the development of strategic alliances among companies or changes in the resource base of universities.
- Influence of one helix upon another, such as the role of the U.S. Federal Government in shifting intellectual property rights and technology transfer for discoveries made from Federally-funded academic research over to universities through the *Bayh-Dole University and Small Business Patent Act of 1980*, and the formulation of policies and programs by State governments to encourage universities to establish industrial ties.

- Creation of a new overlay of three helices, established to generate new ideas and formats for high tech development such as regional industrial clusters.

- Recursive effect of these exchanges among institutional spheres both on the spirals from which they emerged and on the larger society. For example, the effect on science itself as a result of internal changes within academia, strengthened and diffused by government policy.

Etzkowitz (2001) also referred to the *second academic revolution* in which entrepreneurial scientists and universities are transforming the knowledge produced in academia into intellectual property. This revolution has involved faculty members and graduate students assessing both the commercial and intellectual potential of their research. Universities are becoming core institutions in society which contribute more to economic development by combining teaching and research with technology transfer, shifting from an individual to an organisational perspective in their missions, and generating social, intellectual and human capital.

3.3 National innovation systems

3.3.1 Origins and approaches

In his 1987 book, *Technology Policy and Economic Performance: Lessons from Japan*, Christopher Freeman first published the term *national innovation system* (NIS) defining it as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (Freeman, 1987, p. 1). Freeman (1995) attributed the origins of the concept to Friedrich List (1841) and the initial use of the term to Bengt-Åke Lundvall. List (1841) proposed a national system of political economy involving the protection of infant industries and a broad range of policies of learning about, and applying new technology. List (1841) was aiming to enhance industrialisation and economic growth in an attempt "to understand the reasons for British commercial supremacy and enable Germany (and other countries) to catch up" (Freeman, 1995, p. 19).

Awareness of the NIS concept was heightened with the release of a book on technical change and economic theory by Giovanni Dosi in 1988. His book included a four chapter-section on national systems of innovation by Bengt-Åke Lundvall, Christopher Freeman and Richard Nelson. Lundvall (1992) and Nelson (1993) went on to formulate different but somewhat complementary national systems of innovation approaches that have informed the development of national innovation systems in many countries.

Lundvall (1992) defined a national innovation system as follows:

> All parts and aspects of the economic structure and the institutional set-up affecting learning as well as searching and exploring – the production system, the marketing system and the system of finance present themselves as sub-systems in which learning takes place. (p. 12)

Lundvall's definition is based on his **interactive learning approach** that assumes knowledge is the most fundamental resource in a modern economy; the long term competitiveness of firms and national economies depends on their innovative capability; and innovations are cumulative i.e. based on pre-existing knowledge. Acknowledging that globalisation and internationalisation are challenging the *national* approach, Lundvall (1992) argued it is still important to understand how institutional and economic structures impact on the promotion of innovation at a national level. He identified five key elements of a national innovation system that vary from country to country:

- Internal organisation of private firms, including the learning capabilities and information flows required to strengthen innovative capability.
- Inter-firm relationships with competitors and knowledge producers such as universities and research institutes.
- Institutional set-up of the financial sector to provide resources, especially for small and medium enterprises without the sufficient resources to invest in new technologies.
- Role of the public sector and government in supporting innovation through schemes that encourage scientific research, and regulations and standards which influence the rate and direction of innovation.
- Resources, competencies and organisation of the R&D system, referred to as R&D intensity.

Learning is the central activity in the interactive learning approach and is enhanced by shared norms and culture in countries. It is a socially embedded process which involves interactions between people (particularly between producers and users of knowledge), positive feedback, and the reproduction of knowledge. This process leads to "new products, new techniques, new forms of organisation and new markets" (Lundvall, 1992, p. 8). Lundvall and Johnson (1994) found that the three interconnected phenomena[7] in the post-Fordist era of ICT, flexible specialisation, and changes in the innovation process created new constellations of knowledge and learning in the economy. This finding led them to coin the term, **learning economy,** in which firms are regarded as *learning organisations* that first learn how to learn and gradually develop their capacity to learn:

> The learning economy is a dynamic concept; it involves the capability to learn and to expand the knowledge base. It refers not only to the importance of the science and technology systems – universities, research organisations, in-house R&D departments and so on – but also to the learning implications of the economic structure, the organisational forms and the institutional set-up. (p. 26)

[7] The three interconnected phenomena are the development of information communication technologies (ICT) to handle, store and move information, and the cost of the competence required to deal with information efficiently; the movement towards flexible specialisation where organisations respond rapidly to changes in demand and to other external changes (for example, by making minor changes to products in the short term or developing product innovations to meet user needs in the longer term); and changes in the innovation process means that firms must find ways to increase the learning ability at all levels of the firm and enter into cooperation and alliances with other firms both in order to share financial risks and gain access in a more diversified knowledge base. (Lundvall & Johnson, 1994, p. 25)

Lundvall and Johnson (1994) identified four different types of **economically-relevant knowledge** that are combined in the innovation process in the learning economy: *Know-what* i.e. knowledge about facts or information; *know-why* i.e. knowledge about principles and laws in nature, human mind and society which is essential for technological development in certain areas such as chemicals and electronics; *know-how* or skills i.e. the ability to do different kinds of things on a practical level; and *know-who* i.e. the social ability to co-operate and communicate with different kinds of people and experts. Firms gain this knowledge by learning intentionally through education, training, R&D and market research (*learning-by-searching*) and as a by-product of routine economic activities (*learning-by-producing*). Knowledge can also be forgotten when it is not actively used, deteriorates, or is no longer relevant to the context. Innovation can be blocked by old habits of thought, routines and patterns of cooperation. Forgetting is "an essential and integrated part of learning" (Lundvall & Johnson, 1994, p. 38) as the creative destruction of knowledge can lead to radical innovations. The role of government in the learning economy is to support learning processes through the following activities:

- Providing the means to learn i.e. investing in education and training, continually renewing the form of content of these activities, and adapting to new social and technology developments.
- Providing incentives to learn such as systems of salaries and wages and income taxes at the individual level, and patent laws and tax rules at the firm level.
- Ensuring the capability to learn i.e. government studies of best practice programs, diffusion of findings to laggards, and financial support for organisational innovations and experimenting.
- Providing access to relevant knowledge i.e. access to universities, technical institutes and libraries; agents to link knowledge producers and knowledge users; and government programs for projects of cooperation to support network formation.
- Encouraging learning to forget through, for example, a system of redistribution to compensate victims of change that could involve different social security arrangements, active labour market, and retraining policies.

More recently, Lundvall, Johnson, Andersen and Dalum (2002) advised that national innovation systems should be considered from the dimensions of *structure* i.e. what is produced in the system and what competencies are most developed; and *institutional setup* i.e. how production, innovation and learning takes place. Innovation system studies should avoid a narrow focus on the role of science and science-based technologies. They called for a greater focus on the process of learning and competence building; the creation, transformation and passing away of innovation systems; the broadening of the analysis of economic development to include the affects of knowledge production on social and ecological sustainability; and new development strategies together with policy coordination in the areas of social policy, labour market policy, education policy, industrial policy, energy policy, environmental policy, and science and technology policy.

The **institutional approach** proposed by Nelson and Rosenberg (1993) examined how institutional structures and mechanisms in national systems of technical innovation can impact on technological and economic performance of different countries. Similar to the earlier work of Kline and Rosenberg (1986), they found that national innovation systems are strongly influenced by the mix of industries within a nation and the nature of technical change, which differs between industries. Arguing that technology and business were becoming increasingly transnational, they questioned the relevance of the *national* innovation systems concept and clarified each word rather than the concept itself. Nelson and Rosenberg (1993) focused on identifying the factors that influence national technological capabilities rather than understanding the behaviour of firms and institutions to explain innovation. They defined *systems* as "a set of institutional actors that, together, plays the major role in influencing innovative performance" (pp. 4-5).

Institutions involved in industrial innovation include firms and industrial research laboratories, as well as supporting institutions such as universities, government agencies and policies. Science is regarded as both a leader and follower, and intertwined with technology – giving rise to new technology on the one hand, yet undertaken to understand and improve new technologies on the other. Nelson and Rosenberg (1993) found that technological advances in many fields were being made by people who were university trained in science and technology. Universities play a key role in the innovation system, not only as a training ground for scientists and engineers, but "as a source of research findings and techniques of considerable relevance to technical advance in industry" (Nelson & Rosenberg, 1993, p. 11).

In the closing chapter of his book, Nelson (1993) made the following key points about national innovation systems based on findings from 15 country studies:

- It is worthwhile to observe *national* innovation systems. However, internationalisation is making it difficult for national governments to support national industry, and requires people, governments and the public research system to work with firms with overseas headquarters.
- Differences in economic and political circumstances and priorities – such as size of population, income levels, resource endowments, R&D intensity and military R&D – contribute significantly to differences in innovation systems.
- Features common to effective innovation performance include: highly competent firms in their line of business; an education and training system that provides firms with a flow of people with the right skills and knowledge, including universities that are responsive to the training needs of industry; and a package of fiscal, monetary and trade policies that encourage firms to export.
- The effectiveness of government programs for publicly supported research in universities and public laboratories and industrial R&D is debated, and whether publicly funded research helps firms to innovate varies from field to field.

3.3.2 Features of a national innovation system

The European Commission (1995) defined a national innovation system as the "sum total of firms in an industry, the fabric of economic and social activities in a region, or even in society as a whole, whose dynamics are a complex matter" (p. 2). The OECD (1999) used the definition of a national innovation system provided by Metcalfe (1995) that referred to the role of **institutions**:

> A set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provide the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies. (p. 24)

The European Commission (1995) argued that the innovation process is "… not a linear process with clearly-delimited sequences and automatic follow-on" (p. 4). The innovation process involves a system of **interactions** "… between different functions and different players whose experience, knowledge and know-how are mutually reinforcing and cumulative" (p. 4). Similarly, the OECD (1999) found that innovation requires the performance of specific actors like enterprises, research institutes and universities. Interactions between actors are increasingly complex, and are occurring at "… local, national and world levels among individuals, firms and other knowledge institutions" (p. 3). The forms, quality and intensity of the interactions of main actors in a national innovation system are influenced by a variety of factors that vary from country to country. Factors like country size, level of development, industrial specialisation, specific institutional settings, and policy priorities contribute to differences in financial systems, corporate governance, legal and regulatory frameworks, the level of education and skills, the degree of personnel mobility, labour relations, and prevailing management practices. These factors also impact on a country's ability to mobilise political and financial resources to exploit possibilities offered by a technological gap (Villaschi, 2002). Despite these differences, the interaction of market institutions (knowledge-users) and non-market institutions[8] (knowledge-producers) to achieve collective goals "influences the direction and speed of innovation and technology diffusion" (OECD, 1999, p. 23).

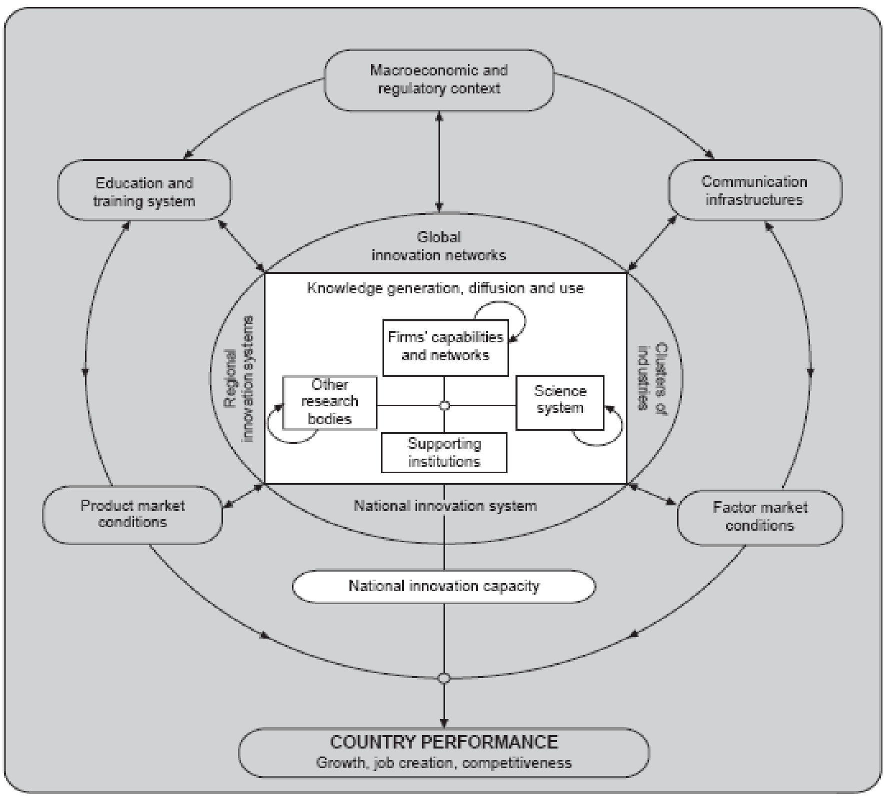
As shown in Figure 5, the role of a national innovation system is to **generate, diffuse and use knowledge**. This role is regarded as critical for a country's economic performance, competitiveness, increased productivity, and improved living standards. At the *micro* level, firms focus on their internal capabilities and interact more intensely with firms with complementary assets (through partnerships) and with other institutions involved in the production process i.e. universities, private and public research laboratories, regulatory bodies, and providers of consultancy and technical services. At the *meso* level, firms with common characteristics cluster by sector (industrial), region (spatial) or function to share a common knowledge base. At the *macro* level, knowledge flows within a network of interlinked sectoral clusters, and knowledge interactions among and between institutions is mapped. The OECD (1999) identified five types

[8] The OECD (1999) acknowledged that non-market, knowledge-producing organisations need adequate resources to "push their investigations beyond what markets can see" (p. 15) to build the stock of knowledge.

of knowledge flows within its functional analysis approach. Of particular importance to this study are knowledge flows that occur due to interactions among enterprises, universities and public research institutes such as joint research, co-patenting, co-publications and more informal linkages.

Acknowledging **human resources** as a crucial NIS element, the European Commission (1995) argued that "… a better-educated, better-trained and better-informed workforce helps to strengthen innovation" (p. 2). Innovation systems demand that individuals have a constantly changing set of skills. A severe lack of flexibility in the structures of education and training establishments and their approach to change, excessive stress on academic knowledge, and too compartmentalised courses were found to impede the ability to adapt and reformulate educational programs to the needs of the changing world.

Figure 5: Actors and linkages in a national innovation system



Source: OECD (1999) p. 23

According to the OECD (2001a), continuous product, process and organisational innovations require organisational learning through intensive information exchange, and interaction within and between organisations (which leads to *structural capital*); as well as the ability of organisations to apply new knowledge (their *absorptive capacity*). Creating new and disseminating existing knowledge involves individual learning which leads to *human capital*. New knowledge created by a PhD student is an example of individual learning in Table 3. The OECD (2002b) explained the role of **learning** within an innovation system as follows:

Effective innovation systems are dynamic and generate capacities for adaptation through learning. The learning process includes typically searching for knowledge internal and external to the firm, experimentation with products, services and strategies, and evaluation. Governments need to continuously adapt through policy experimentation and learning. Experimentation and learning is a partly self-steered process of configuration of the system towards a better alignment between its various components. (p. 80)

Table 3: Categories of learning

	Dissemination of existing knowledge	Creation of new knowledge
Individual learning (resulting in human capital)	A e.g. schooling; vocational training; *learning-by-doing* in the workplace	B e.g. university-based research by PhD students; *learning-by-doing* in the workplace
Organisational learning (resulting in structural capital)	C e.g. building data bases, creation of routines and manuals; appropriation of technological licences from other firms; recruitment of highly qualified staff by firms	D e.g. R&D in universities by research groups; R&D within firms; collaborative R&D between firms and research institutes

Source: OECD (2001a) p. 15

Factors affecting the **performance** of a national innovation system include the quality of the education system; the regulatory, legislative and fiscal framework; the competitive environment and the firm's partners; the legislation on patents and intellectual property; and the public infrastructure for research and innovation support services. The **role of Government** in a national innovation system has been to address blocks[9] in the innovation system and to secure framework conditions[10] that are conducive to innovation. In a report from the National Innovation Systems project, *Dynamising National Innovation System*, the OECD (2002c) recommended against developing a grand design for a national innovation system. Instead it supports a knowledge-based, comprehensive structural policy which includes policy instruments that support systems growth and address problems that restrict the core conditions of a well functioning system. These core conditions are an efficient configuration or structuring of the constituent parts of the systems. For example, the economic structure or the organisation of universities and public labs; and the structure of the innovation process itself, or the particular processes by which knowledge flows in innovation systems and leads to improved economic performance.

According to David and Foray (1995), Governments need to pay greater attention to the processes of **knowledge access and distribution** in their public policies related to the functioning of national innovation systems. The production and acquisition of knowledge or a *knowledge product* in a national innovation system depends on the extent of codification, publicness, disclosure, and how codes, languages and symbols are commonly understood (Foray, 1997). In addition to generating new knowledge, David and Foray (1995) found that innovation systems must aim to increase their *knowledge distribution power* by

[9] Blocks in a national innovation system include institutional rigidity, lack of networking or mobility of human resources, and conflicting incentives between enterprises and the public research sector.
[10] Framework conditions include a stable macroeconomic environment, a supportive tax and regulatory environment, and appropriate infrastructure and education and training policies.

providing institutions with incentive mechanisms and coordination arrangements, including intellectual property rights that encourage the disclosure and pooling of knowledge. Their points are discussed further in section 6.2. Foray (1997) called for the establishment of an efficient knowledge system that generates, distributes and utilises knowledge:

> A knowledge system includes economic agents (or learning entities) that assume the relevant functions of knowledge generation (by means of cognitive exploration and search) such as the codification and reduction of knowledge to information, the monitoring and perception of information (involving encoding, decoding, translation, filtering and compression), the communication and transfer of knowledge, and its storage, retrieval and reconstruction. It also includes the institutions that serve to overcome the market's deficiencies in the production and distribution of knowledge. (p. 65)

The critical role of **scientific knowledge** particularly in the areas of biotechnology, new materials and information technology in many technological innovations is evidenced by the increasing number of references to scientific publications in patents. The increasing intensity of university-industry scientific cooperation in many countries is shown by the expansion of co-patenting and co-publishing activities. In many cases, research students have a significant role in these industry-science relationships by undertaking scientific research and developing the skills required by firms seeking to "… adopt new technologies, new instruments and methods for industrial research" (OECD, 2002d, p. 16). The OECD (2002d) identified a number of areas for policy action that support and encourage industry-science relationships in a national innovation system. These included giving priority to basic and long-term mission oriented research in government S&T programs; ensuring appropriate frameworks for intellectual property rights (IPRs); matching supply and demand for scientific knowledge; improving the governance of universities and public laboratories; safeguarding public knowledge through IPRs; promoting the participation of smaller firms; attracting, retaining and mobilising human resources; improving the evaluation of research; responding to globalisation; and building on existing innovative networks and clusters (pp. 9-10).

3.3.3 Assessing national innovation system performance

To assess the performance of a national innovation system, Lundvall (1992) recommended the use of measures that indicate the "efficiency and effectiveness in producing, diffusing and exploiting economically useful knowledge" (p. 6). The European Trend Chart on Innovation provides information and statistics on innovation policies, performance and trends in all European member countries and other countries in Europe. The **European Innovation Scoreboard (EIS)** was developed to monitor the progress of Europe in reaching its goal set at the Lisbon summit to become the most competitive and dynamic knowledge-based economy in the world within the next decade. The EIS consists of 17 main indicators and three additional indicators divided into four categories: Human resources for innovation, the creation of new knowledge, the transmission and application of knowledge, and innovation finance, outputs and markets. The indicators for the transmission and application of knowledge are based on data collected from manufacturing and services enterprises as part of Eurostat's Community Innovation Survey.

Another useful approach for measuring innovation was included in the European Commission's *Third European Report on Science and Technology Indicators* released in 2003. This report divided indicators into two categories: investment in knowledge production, dissemination and absorption; and performance in knowledge production, exploitation and commercialisation. Many of these and other indicators are contained in two OECD publications: *Main Science and Technology Indicators* and *Science, Technology and Industry Scoreboard*. Key innovation investment and performance indicators from these publications for Australia, Finland, the United States and the OECD are contained in Table 4.

Table 4: Key innovation indicators

Investment indicators	Australia	Finland	USA	OECD
Gross Domestic Expenditure on R&D (GERD) as a proportion of Gross Domestic Product (GDP), also known at R&D intensity	1.54% (2000)	3.46% (2002)	2.6% (2003)	2.26% (2002)
Government financed GERD as a proportion of GDP	0.70% (2000)	0.90% (2002)	0.81% (2003)	0.68% (2002)
Business Enterprise Expenditure on R&D (BERD) as a proportion of GDP	0.78% (2001)	2.41% (2002)	1.79% (2003)	1.53% (2002)
Higher education expenditure on R&D (HERD) as a proportion of GDP	0.41% (2000)	0.66% (2002)	0.44% (2003)	0.41% (2002)
Total researchers per 1000 total employment	7.2 (2000)	16.4 (2002)	8.6 (1999)	6.5 (2000)
Investment in knowledge (R&D expenditure + higher education expenditure + investment in software) as a proportion of GDP, 2000	4.1%	6.2%	6.8%	4.3%
Performance indicators	**Australia**	**Finland**	**USA**	**OECD**
Scientific publications per million inhabitants, 2001	760	983	705	468
Number of triadic patent families per million inhabitants, 2001	16.3	83.1	52.6	37.6

Source: OECD (2003) and (2004a)

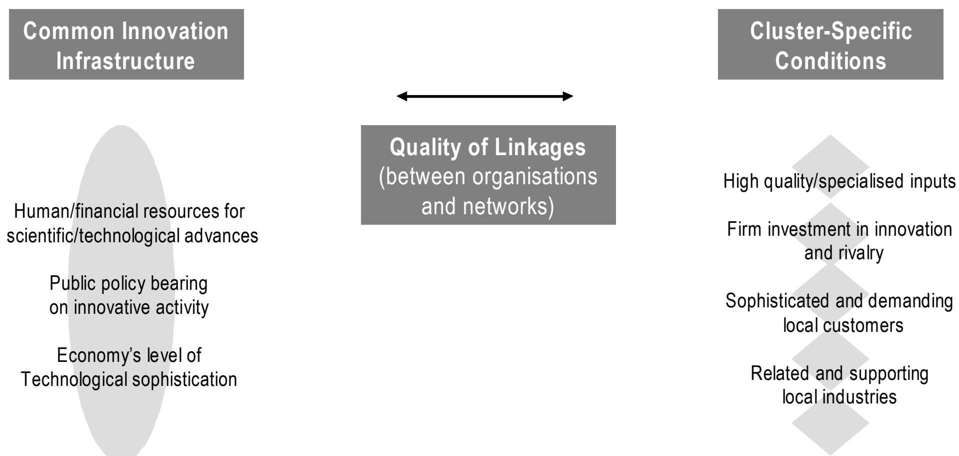
The World Economic Forum's Global Competitiveness Report combines hard data (such as utility patents, tertiary enrolment and internet usage) and findings from the Executive Opinion Survey completed by leading business executives and entrepreneurs to produce two key indexes:

- The **Global Competitiveness Index (GCI)** developed by Jeffrey Sachs and John McArthur aims "to analyse the potential for the world's economies to attain sustained economic growth over the medium and long term" (World Economic Forum, 2003, p. xii). The CGI consists of three indexes which assume that the process of economic growth can be analysed according to the macroeconomic environment (*Macroeconomic Index*), quality of public institutions (*Public Institutions Index*) and technology (*Technology Index*). The *Technology Index* includes an *Innovation Subindex* formulated from patent and tertiary enrolment data, and survey questions about university and industry research collaboration, technological sophistication, firm-level innovation, and company spending on R&D.
- The **Business Competitiveness Index (BCI)** developed by Michael Porter indicates at the micro level "the ability of firms to create valuable goods and services using efficient methods" (World Economic Forum, 2003, p. xviii). Data on patenting and cellular telephone penetration, together with

survey responses, are used to calculate two subindexes: *Company Operations and Strategy Subindex* and the *Quality of the National Business Environment Subindex*.

The Global Competitiveness Report also includes the **National Innovative Capacity Index (NICI)** developed by Michael Porter and Scott Stern to determine the potential of countries to innovate for competitiveness. Survey data is used to calculate the NICI which is the unweighted sum of five subindexes representing "important components of innovation vitality" (World Economic Forum, 2003, p. xxii): *Scientific & Engineering Manpower Subindex*, *Cluster Innovation Environment Subindex*, *Innovation Linkages Subindex*, *Company Innovation Orientation Subindex*, and *Innovation Policy Subindex*. These indexes are reflected in the elements of national innovative capacity as shown in Figure 6.

Figure 6: Elements of national innovative capacity



Source: World Economic Forum (2003) p. 105

Porter and Stern regarded the number of international **patents** granted by the U.S. Patent and Trademark Office (USPTO) as the best measure of national innovative performance (World Economic Forum, 2003). The cost involved is a sign of the innovation's potential economic value and the standard of technological excellence is at or near the global technology frontier. However, the USPTO does not distinguish between those patents that are very minor innovations and patents that represent major, revolutionary innovations. In terms of measuring the success of a national innovation system, Porter and Stern identified four critical factors: the size of the labour force dedicated to R&D and other technically oriented work; the amount of investment directed at R&D; the resources devoted to higher education; and the degree to which national policy encourages investment in innovation and commercialisation (Council on Competitiveness, 1999).

Many Governments assess innovation performance by **mapping** their country's national innovation system. The final report of the Commonwealth Government, *Mapping Australian Science and Innovation*, released in November 2003 defined mapping as the empirical analysis of innovation systems: A map is "… usually not just a description, but an analysis of components, structure and linkages to show how they affect science and innovation performance" (Nelson, 2003a, p. 40). The Commonwealth Government based its mapping framework on the OECD scoreboard publications, European Union's Community Innovation Survey and Trendchart, earlier mapping exercises undertaken in Australia, and mapping exercises carried out in other countries such as Finland, Norway, United Kingdom and Canada. The Commonwealth Government found that mapping projects generally involve some combination of:

- careful institutional descriptions
- data-driven analysis of the structure and flow of R&D resources i.e. funding and expenditure
- statistics-based assessments of science and innovation performance
- university/public sector research agency-industry interactions, including direct collaboration and indirect flows of scientific knowledge into production
- key industrial clusters (dispersed or geographically focused) and related science or research activities
- analysis of the structures and strategies of major players within the system, especially large R&D performers
- analysis of public policy systems in terms of organisational structure and flow of resources.

Godinho, Mendonca and Pereira (2003) found that most mapping exercises have concentrated on the actors and linkages that connect a national innovation system. They argued that it is necessary to consider the resources invested in innovation and the results stemming from the combination of these resources, largely through an analysis of innovation performance. As a result, Godinho et al. (2003) have developed a framework to map a national innovation system based on eight major dimensions which are representative of the multidimensionality of a national innovation system. They used 38 variables to measure innovation performance within these eight dimensions: resources supply, actors and their behaviours, interactivity and linkages, institutional diversity and development, external communication or *absorption*, economic structure, innovation, and diffusion. Researchers per 10,000 labour force is a variable in the *resources supply* dimension. PhDs in science and engineering per 1,000 people in the age group 25 and 34 years is a variable in the *actors and their behaviours* dimension.

3.4 Research and development (R&D)

The OECD Frascati Manual is a technical document that provides internationally accepted definitions of research and development (R&D). The OECD (2002a) regarded this manual as a cornerstone of its efforts "to increase the understanding of the role played by science and technology by analysing national systems of innovation" (p. 3). The Frascati Manual, along with the Olso Manual, belongs to the Frascati family of methodological manuals. Both manuals state that R&D is one of the main activities in the technological product and process (TPP) innovation process. Other activities in the innovation process include: the other acquisition of knowledge such as patents, licences and technical services; acquisition of machinery and equipment incorporating new technology to produce a new product; various other preparations for production/delivery such as tooling up and staff training; and marketing. R&D and the acquisition of machinery incorporating new technology were the only activities treated as *automatically* TPP innovation activities with the remainder included if required.

The OECD (2002a) in its Frascati manual referred to R&D as research and experimental development, which comprises "creative work undertaken on a systematic basis in order to increase the stock of knowledge, including the knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications" (OECD, 2002a, p. 30). There needs to be "an appreciable element of novelty and the resolution of scientific and/technological uncertainty" (p. 34) for an activity to be classified as R&D. If an activity does not meet these conditions, it is regarded as a related activity[11]. R&D is needed when "the solution to a problem is not readily apparent to someone familiar with the basic stock of common knowledge and techniques for the area concerned" (p. 34). Basic research, applied research and experimental development are the three types of R&D assessed in terms of: *institutional classification* i.e. the organisations performing and funding R&D; and *functional distribution* i.e. the nature of the R&D programs. The five sectors within the institutional classification of national R&D effort include business enterprise, government, private non-profit, higher education and abroad. Functional distribution breaks down R&D activities by type, product field, objective and field of science, and also distinguishes between military and civil R&D.

R&D expenditure and R&D personnel are key measures of R&D inputs or "… effort devoted to R&D" (OECD, 2002a, p. 20), and both allow for international comparisons. R&D expenditure is defined as: *intramural expenditure* or "… all expenditures for R&D performed within a statistical unit or sector of the economy" (p. 21); and *extramural expenditure* or "… payments for R&D performed outside the statistical unit or sector of the economy" (p. 21). A country's R&D effort is measured by gross domestic expenditure on R&D (GERD) during a given year, and is usually presented as a percentage of gross domestic product i.e. GERD/GDP ratio.

3.5 Human resources in science and technology (HRST)

The OECD/Eurostat Canberra Manual (1995) also belongs to Frascati family and contains guidelines for the collection, interpretation and analysis of data on human resources in science and technology (HRST). The manual acknowledged the importance of highly skilled human resources to the innovation process, particularly in terms of the development and diffusion of knowledge. It referred to the OECD's 1992 report on *Technology and the Economy: The Key Relationship* that "stressed that an adequate supply of appropriately educated and trained human resources was a critical factor in innovation" (p. 3).

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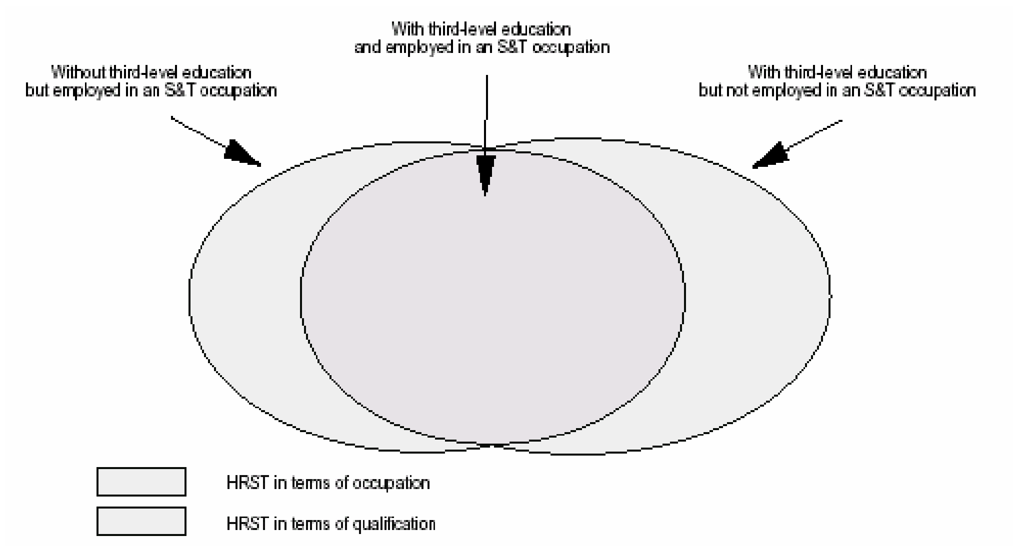
[11] *Related activities* include: education and training; scientific and technical information services; general purpose data collection; patent and licence work; routine software development; industrial production and distribution of goods and services; and the administrative and other support function of raising and managing R&D funds (OECD, 2002a, p. 34).

The manual broadly and cautiously defined *science* as knowledge or knowing in the disciplines within it core coverage: Natural science, engineering and technology, medical sciences, agricultural sciences, and social sciences; but excluded humanities. *Technology* is defined as "the application of knowledge, and more narrowly dealing with tools and techniques for carrying out the plans to achieve desired objectives" (p. 16). People who are regarded as **human resources in science and technology (HRST)** must have either successfully completed education at the third (university) level in an S&T field of study; or if they are not formally qualified, are employed in an S&T occupation where these qualifications are normally required. The total number of people who fulfil these conditions at a particular point of time is called the **HRST stock**. Figure 7 combines the two categories of HRST to form the principle category called the **HRST core** which consists of people with a tertiary education who are currently employed in S&T occupations. **HRST flows** represent the number of people who enter and leave the HRST stock during the time period, as they meet or cease to meet one of the conditions.

Figure 7: Categories of HRST



Source: OECD/Eurostat (1995), p. 17

Given the wide definition of HRST, the manual recommended a framework to modulate the coverage of the data collection in order to reflect education levels, fields and occupations that are central to S&T activities. Table 5 indicates **coverage by field and level of education** based on three categories: *core* (such as a person with a university degree in engineering), *extended* (such as a person with a PhD in English literature) and *complete* (such as a person with non-university, level 5 qualification in graphic art). Categories of **coverage by occupation type** in Table 6, based on the International Standard Classification of Occupations (ISCO), include: *core* (such as chemist, statistician and computer programmer), *extended* (such as university professor, economist and historian), and *complete* (such as school teacher, athlete and estate agent).

Table 5: Coverage for HRST data collection, by field of study and level of education

Field of Study	Level 5A/6	Level 5B
Natural sciences	Core	Extended
Engineering and technology	Core	Extended
Medical sciences	Core	Extended
Agricultural sciences	Core	Extended
Social sciences	Core	Extended
Humanities	Extended	Complete
Other fields	Extended	Complete

Source: OECD/Eurostat (1995), p. 22

Table 6: Coverage for HRST data collection, by occupation

	ISCO-88 groups of occupations	Coverage
122	Production and Operations Department Managers	Extended
123	Other Department Managers	Extended
131	General Managers	Extended
21	Physical, Mathematical and Engineering Science Professionals	Core
22	Life Science and Health Professionals	Core
23	Teaching Professionals	Extended
24	Other Professionals	Extended
31	Physical and Engineering Science Associate Professionals	Extended
32	Life Science and Health Associate Professionals	Extended
33	Teaching Associate Professionals	Complete
34	Other Associate Professionals	Complete

Source: OECD/Eurostat (1995), p. 25

OECD/Eurostat (1995) defined *professionals* as those people in:

> … occupations whose main tasks require a high level of professional knowledge and experience in the fields of physical and life sciences, or social sciences and humanities. The main tasks consist of increasing the existing stock of knowledge, applying scientific and artistic concepts and theories to the solution of problems, and teaching about the foregoing in a systematic manner. (p. 93)

Professionals are usually required to have a *fourth ISCO skill level* which is equivalent to a university or postgraduate qualification. The key functions of the two core groups of professionals in Table 6 (physical, mathematical and engineering science professionals, and life science and health professionals) are to "conduct research, improve or develop concepts, theories and operational methods, or apply scientific knowledge relating to their fields" (p. 93).

3.6 Research students and training

Research students in this study are classified according to educational and occupational classifications specified in the Frascati Manual. The manual refers to research students as postgraduate students who are working towards a PhD. Table 7 shows that a PhD is classified in the International Standard Classification of Education (ISCED) as level 6. At this level, tertiary programs "… lead to the award of an advanced research qualification" and "… are devoted to advanced study and original research and are not based on course work only" (OECD, 2002a, p. 97). Students usually submit "… a thesis or dissertation of publishable quality which is the product of original research and represents a significant contribution to knowledge" (p. 97). Level 6 programs should prepare graduates for faculty and research posts.

Table 7: International Standard Classification of Education (ISCED) levels

ISCED-97 categories		General coverage	OECD personnel categories
6. Second stage of tertiary education – leading to an advanced research qualification		Post-secondary	Holders of university degrees at PhD level
5. First stage of tertiary education – not leading to an advanced research qualification	5A. Theoretically based tertiary programs to qualify for entry to advanced research programs		Holders of basic university degrees below the PhD level
	5B. Practically oriented or occupation-specific programs		Holders of other tertiary degrees
4. Post-secondary, non-tertiary education			Holders of other post-secondary non-tertiary diplomas
3. Upper secondary education		Secondary	Holders of secondary education diplomas
2. Lower secondary or second stage of basic education			Other qualifications
1. Primary education or first stage of basic education		Primary	
0. Pre-primary education		Pre-primary	

Source: OECD (2002a), Table 5.2, p. 96

The manual acknowledged the difficulty of the borderline between R&D and education and training at ISCED level 6. Education and training at level 6 is highly structured and "… the teacher transmits knowledge and trains in research methods" (p. 36), such as in the case of set courses, study schemes and compulsory laboratory work. However, independent study undertaken by students as part of their thesis or dissertation is an R&D activity because it contains "… the elements of novelty required for R&D projects and presenting their results" (p. 36). The manual also stated that students at the ISCED level 6 are often attached or employed by the same university to teach at lower levels or to undertake related activities. As a result, the OECD (2002a) recommended that **research students** should be considered and counted as researchers who are defined as "… professionals engaged in the conception or creation of new knowledge, products, processes, methods and systems, and also in the management of the projects concerned" (p. 93).

Incorporating the definitions for HRST, research students who are undertaking independent research for their PhD thesis or dissertation are therefore regarded as *researchers*. They are a permanent part of the HRST stock given their ISCED category 5A qualification when commencing a level 6 programme. They are also a core part of the HRST stock when these ISCED category 5A qualifications are in the fields of natural sciences, engineering and technology, medical sciences, agricultural sciences, and social sciences. Although the OECD (2002a) referred to researchers as *professionals*, the OECD/Eurostat (1995) stated that HRST professionals in these fields have a "… high level of professional knowledge and experience" (p. 93). Some research students may already have a high level of professional knowledge and experience when they commence a level 6 programme. However, this study assumes that the purpose of **research training** or a level 6 program is to provide students with the necessary knowledge and experience to work as HRST professionals in a national innovation system.

3.7 Chapter summary

This chapter has addressed what is meant by *innovation*, a *national innovation system*, *research training* and *research students* (Research Question 1). The related concepts of Research and Development (R&D) and Human Resources in Science and Technology (HRST) were also defined and/or clarified. The purpose of the chapter was to provide the necessary background before examining the three elements of the conceptual framework in subsequent chapters. As such, the concepts have not been debated or explored in great depth. What has been presented is based on the work of well known innovation researchers and accepted international definitions and classifications contained in the latest manuals from the OECD's Frascati family: Oslo Manual (1997), Frascati Manual (2002) and Canberra Manual (1995). These manuals incorporate UNESCO's International Standard Classification of Education (ISCED).

Based on the literature review in this chapter, key concepts for this study are defined as follows:

- **Innovation** is a technological product or process (new or significantly improved) innovation that has been implemented, or an organisational innovation that has led to measurable changes in output.
- A **national innovation systems** is made up of interacting market and non-market institutions that continuously learn how to generate, diffuse and use new knowledge to form product, process and organisational innovations. The role of Government is to provide a framework of policy instruments that support systems growth and address problems that restrict the functioning of the system.
- **Research training (in science & technology fields)** provides research students with a high level of knowledge and skills necessary to work as HRST professionals in and beyond their national innovation system.
- **Research students** are *researchers* who undertake independent and novel research to form a thesis or dissertation. When educated and employed in science and technology fields, they are a core part of the HRST stock and a critical component of a national innovation system.

Although the literature review of key innovation models and approaches found little direct mention of the importance of research training to the innovation process, it did indicate an increasing reliance on scientific knowledge and a highly skilled workforce. There is now greater university-industry cooperation in many countries where producers (including research students) and users of knowledge interact to learn about and combine economically-relevant knowledge in order to innovate. This *innovation-through-learning* process can be intentional (*learning-by-searching*) or a by-product of routine economic activities (*learning-by-producing*). Research training as an R&D activity is clearly an example of *learning-by-searching* that can contribute to innovation. In some of the case studies presented in Chapter 6, unexpected innovations were occurring as a by-product of the student's research suggesting that research training can also be regarded as *learning-by-producing*.

Therefore, the **role of research training (particularly in science and technology fields) in a national innovation system** (Research Question 2) is to build the competence of research students to produce knowledge by developing their ability to learn about, create and disseminate economically-relevant knowledge; and to interact with research users and other stakeholders. This definition informed the collection and analysis of data on knowledge production and distribution by 30 research students in Chapter 6.

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Chapter 4: Systems in Australia, Finland and the United States

4.1 Introduction

The previous chapter clarified the meanings given to innovation, a national innovation system, research training, and research students in this study. The purpose of this chapter is to describe the research training system and national innovation system that exist in Australia, Finland and the United States to highlight differences in structure, size, current policy initiatives, strengths and issues – factors that impact on the contribution of research training to each country's national innovation system. Through this discussion, the chapter identifies the major developments in, and performance of innovation and research training policies/systems in Australia, Finland and the United States (Research Question 4). Before doing so, a brief description of the social, political and economic structures of each country is provided.

Australia[12] is a westernised country made up of six States and two Territories. The majority of the population of 20.6 million people live in coastal areas and capital cities. Around 2.2% of the population are Indigenous Australians (i.e. Aboriginal and Torres Strait Islanders) and 23.1% were born in other countries such as United Kingdom, New Zealand, Italy, Vietnam and China. The Commonwealth of Australia was formed on 1 January 1901. Under the Australian Constitution, the legislative power is vested in the Parliament of the Commonwealth which consists of the monarch (currently Queen Elizabeth II), the Senate and House of Representatives. There are three levels of Government: Commonwealth, State and Local. Australia is rich in natural resources with its agricultural and mining sectors accounting for 65% of its exports. In recent decades, the services sector has grown significantly and now accounts for 68% of Australia's GDP.

Finland[13] is a bilingual country (Finnish and Swedish) and has a population of over five million people. Finland declared its independence from Russia on 6 December 1917. It has a semi-presidential system made up of a President who is responsible for foreign policy outside of the European Union and a cabinet (headed by the Prime Minister) which has executive power. There are two levels of democratic government: the State consisting of six administrative districts, and 432 Municipalities. Treaties signed with the Soviet Union after World War II led to reparations that to some extent transformed Finland "into a technologically advanced market economy with a sophisticated social welfare system"[14]. The post-war period of rapid economic growth continued until 1991 when Finland experienced a severe recession, due in part to the collapse of the Soviet Union and bilateral trade arrangements. Finland has since recovered and joined the European Union in 1995. The electronics and the electrical industry (in particular, Nokia), forestry, and machinery and transport vehicles dominate the Finnish economy.

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[12] http://en.wikipedia.org/wiki/Australia, http://www.australia.gov.au/about-australia
[13] http://en.wikipedia.org/wiki/Finland, http://virtual.finland.fi/
[14] http://en.wikipedia.org/wiki/Finland

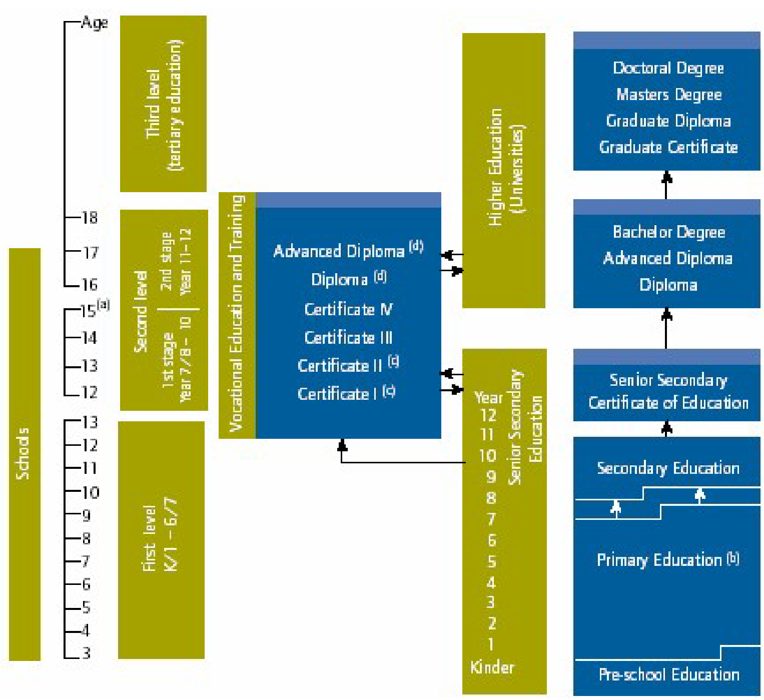
The **United States**[15] has the third largest population in the world at almost 300 million people, with around 10% from 31 ethnic groups. The Second Continental Congress adopted the Declaration of Independence on 4 July 1776 and the Articles of Confederation on 15 November 1777. The Articles were replaced by the United States Constitution which took effect on 4 March 1789. Under the constitution, the Federal Government of the United States operates under a presidential or congressional system consisting of the Legislative (the Congress made up of the Senate and House of Representatives), Executive (President, Cabinet and other officers to help administrative federal law) and the Judiciary. Each of the 50 States has their own unique legal system. The United States has one of the highest per capita GDP and is regarded as the largest and most powerful economy in the world. Although economic activity varies greatly across the country, the service sector employs around 75% of the workforce. Key industries include agriculture, petroleum, steel, motor vehicles, telecommunications, aerospace, chemicals, electronics, food processing, consumer goods, lumber and mining. The United States is a world leader in scientific and technology research, accounting for a large share of Nobel Prizes.

4.2 Australia

4.2.1 Research training system

Research students in Australia are defined as those people enrolled in a theoretically-based advanced research degree i.e. a Doctorate by Research or a Master's by Research. Research training occurs within the higher education sector which is one of three sectors in Australia's education system, along with schooling and vocational education and training (Figure 8).

Figure 8: Australia's education system



Source: Nelson (2003b) p. 30

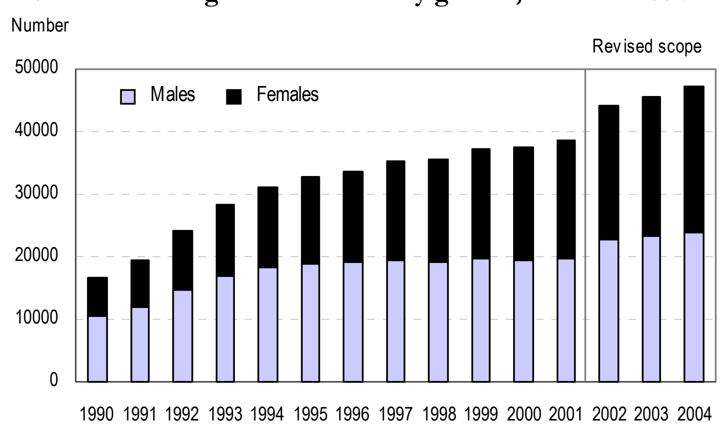
[15] http://en.wikipedia.org/wiki/United_States, https://www.cia.gov/cia/publications/factbook/geos/us.html#Intro

Qualifications awarded in the three sectors are within a national structure called the Australian Qualifications Framework (AQF). This framework was established in 1995 by the Ministerial Council on Education, Employment, Training and Youth Affairs (MCEETYA) to provide a national articulation of awards in the VET and higher education sectors, and to maintain a national register of accredited institutions and courses and authorities empowered by government to accredit post compulsory education and training (Nelson, 2003b).

There are currently 44 universities that are eligible for Commonwealth Government operating grants, and 39 of these universities are autonomous public institutions. Although accountable to government, universities are governed and managed by a Council or Senate; have a high degree of discretion for institutional development; can invest, divest and borrow in respect of property and commercial ventures; can employ their own staff and undertake enterprise bargaining; and are self-accrediting in that they decide on "… what to teach, how to teach it and how learning is assessed" (Nelson, 2002b, p. 6).

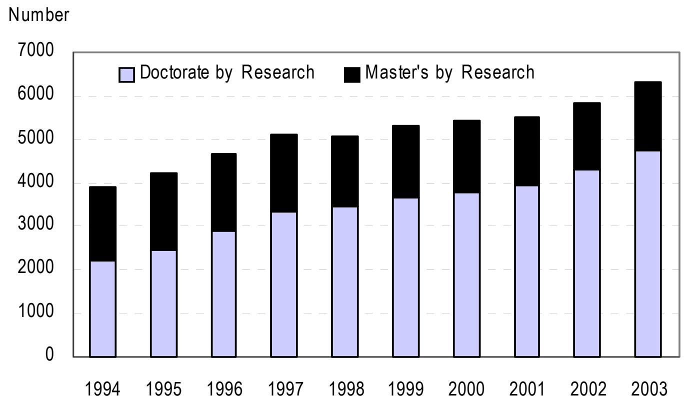
Enrolments in research degrees (Masters and Doctorates) in Australia increased from 16,539 in 1990 to 47,309 in 2004 (Figure 9), representing average annual growth of 7.8%[16] compared to average annual growth in all higher education degrees of 4.1%. Females accounted for 49.4% of research degree enrolments in Australia in 2004 compared to 36.8% in 1990. Research degree **completions** in Australia increased from 2,212 completions in 1990 to 6,321 completions in 2003, which represents average annual growth of 8.4%. In 2003, Doctorates accounted for 74.8% of all research degree completions (Figure 10), females accounted for 46.8% of research degree completions, and almost 36% of research degree completions were in S&T fields.

Figure 9: Research degree enrolments by gender, Australia 1990 to 2004



16 This figure does not include the significantly higher growth recorded in 2002 that occurred because of the change in the scope of enrolments from all students enrolled at the March census date to all students enrolled between September of the year prior to the reference year and August of the reference year.

Figure 10: Research degree completions, Australia 1994 to 2003



Source: Department of Education, Science and Training (2005a), Figures 9 and 10

The current structure of Australia's research training system is largely based on reforms announced by the then Minister for Education, Training and Youth Affairs, Dr David Kemp, in the 1999 White Paper, *Knowledge and Innovation: A policy statement on research and research training*. Many research students in Australia are undertaking their studies through the following schemes:

- The Research Training Scheme (RTS) allocates funds to universities based on successful research student completions (50%), research income (40%) and research publications (10%). Eligible students complete a research degree without incurring fees or a liability under the Higher Education Contribution Scheme (HECS) up to a maximum period of four years full-time equivalent study for a Doctorate by Research and two years full-time equivalent study for a Master's by Research. The Government funded around 22,000 students at a cost of AUD$540.8 million in 2004.

- Australian Postgraduate Awards (APA) and Australia Postgraduate Awards Industry (APAI) provide research students with an annual tax-free stipend (valued in 2005 at AUD$18,837 per annum for APAs and AUD$24,650 per annum for APAIs) as well as relocation and thesis allowances. Research students receiving these awards are also exempt from HECS. Doctoral students receive an award for three years with a possible extension of up to six months. Masters students receive an award for a maximum of two years. There were 1,550 APA awards worth AUD$89.3 million in 2004.

- The International Postgraduate Research Scholarship (IPRS) Scheme provides top quality international postgraduate students with tuition fees and health insurance premiums for three years for Doctoral students (with a possible extension of up to 12 months) and two years for Masters students. There were 330 places at a cost of AUD$17.7 million in 2004.

Many research students are affiliated with **Cooperative Research Centres (CRCs)** which were first established in 1990 to promote long-term strategic links and collaborations between researchers and research users from universities, the public sector and industry. Following the 2004 selection round, there were 72 CRCs operating in six sectors: Environment, agriculture and rural based manufacturing, information and communications technology, mining and energy, medical science and technology, and manufacturing technology. A key function of the CRC Program is to produce research graduates with the skills needed by industry and other research users. Research students are funded through postgraduate scholarships offered directly by a CRC or have received an Australian Postgraduate Award which is topped up by a CRC. For example, in 2004 the CRC for Mining offered postgraduate scholarships starting from AUD$25,000 and top up scholarships of AUD$11,516 to students with an APA. There were 1,599 research students based in CRCs in 2001/2002. Over the ten year period from 1991/1992 to 2001/2002, 1,426 Doctorates by Research and 1,022 Master's by Research were awarded to students from CRCs. PhDs undertaken in CRCs account for about 8% of all PhDs enrolled in science, technology and innovation-related fields of education (Howard Partners, 2003).

Knowledge and Innovation included a **New Competitive Grants Program** administered by the Australian Research Council consisting of *Discovery* grants for fundamental research and *Linkage* grants for applied research. *Discovery* grants can include postgraduate scholarships. Research students who receive an APAI are funded through *Linkage* grants that support industry-oriented research training. In 2004, 426 research students were awarded an APAI, and 50 of these awards were in the priority field of ICT – an initiative from *Investing for Growth* in 1997. The ARC Centres of Excellence Scheme that was established as part of *Backing Australia's Ability* in 2001 funds 11 centres to undertake innovative research within areas of national research priority and provide high quality postgraduate training environments. There are other Commonwealth schemes that also support research training in universities:

- The *Institutional Grants Scheme* (IGS) allocates funds based on research income (60%), publications (10%) and research student places (30%) at a cost of AUD$284.6 million in 2004. Universities make their own strategic judgements on how to use these funds to support their research and research training activities.
- The *Research Infrastructure Block Grants Scheme* (RIBG) meets project-related infrastructure costs at a rate of 20 cents for each competitive research dollar obtained by universities at a cost of AUD$160.3 million in 2004.
- The *Systemic Infrastructure Initiative* funds upgrades to infrastructure to support world class research and research training at a cost of AUD$27.8 million in 2004.

Reforms to research and research training in 1999 were part of the Commonwealth Government's commitment to building a highly skilled research workforce as part of an effective national innovation system. Some reforms sought to address the following deficiencies in research training (Kemp 1999a):

- Research programs were too narrow, too specialised and too theoretical leading to graduates whose communication, interpersonal and leadership skills required further development.
- Opportunities for students to gain experience in appropriate research environments were limited, contributing to a cultural gap between academic researchers and staff in industry.

- Research training environments were associated with poor supervision, inadequate levels of departmental support, and limited access to quality infrastructure.

- There was a mismatch between institutional research priorities and the interests of students.

- High attrition rates[17] and slow rates of completion (over four years for a Masters by Research and nearly six years for a Doctorate by Research) wasted private and public resources.

Findings from recent studies focussing on the state of research training since the *Knowledge and Innovation* reforms indicate that universities have been attempting to address these deficiencies. Research students were more satisfied with their research experience than earlier students – such as those from the 1990 cohort who were generally dissatisfied with supervision and departmental support[18]. Over 82% of respondents to the *Postgraduate Research Experience Questionnaire* (PREQ) agreed or strongly agreed that they were satisfied with the quality of their research experience (Graduate Careers Council of Australia, 2004). The Government's vision for research training to occur within a culture of entrepreneurship remains a challenge given the low ratings for intellectual climate. For example, 52.2% of respondents were dissatisfied with the research ambience in their department.

Ruth Neumann (2002) in *The Doctoral Education Experience* concluded that most research students were positive about their doctoral experience but several issues prevailed: The need for more flexible entry and exit points; lack of induction and career development opportunities; limited opportunities for student feedback; difficulties in attracting suitability qualified students in some hard disciplines; avoidance of part-time students and certain categories of overseas students in hard disciplines; variations across disciplines in the success of industry funded doctoral research; stark resources differences and opportunities for students in hard and soft disciplines; inadequate acculturation opportunities in soft disciplines and for part-time students; variability in the readability and accessibility of university policies and handbooks; and trends toward safe, *bricks in the wall* research in some hard fields.

Postgraduate Research Students and Generic Capabilities: Online directions released by Jill Borthwick and Rod Wissler in April 2003 found that most Australian universities offered research students a broad range of generic capabilities[19] activities, which were gradually being provided online. The generic capabilities of leadership and communication and project management were the focus of many programs. Despite the wide recognition of the importance of these activities in the research candidature, there was concern about how to incorporate them whilst ensuring research projects are completed within the timeframe allowed. There was also uncertainty about the relationship between research skills and workplace related generic capabilities, and the supervisor's role in the development of generic capabilities.

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[17] The attrition rate for research degree programs was 34% in 1997 compared to 20% for undergraduate study and 25% for postgraduate coursework programs (Kemp, 1999b, p.32)

[18] The evaluation of the Australian Postgraduate Awards Scheme in 1996 sought feedback from the 1990 (first) cohort of the Australian Postgraduate Research Awards (APRA) about their research training experience.

[19] Generic capabilities are defined as skills and attributes that have a direct link to postgraduate research students' employability, whatever their research topic and/or discipline base (Borthwick & Wissler, 2003, p. 1).

Mark Sinclair (2004) in *The Pedagogy of Good PhD Supervision: A National Cross-Disciplinary Investigation of PhD Supervision* examined how supervisory influences contribute to the timely completion of PhD candidatures. He found that 64% of doctoral candidates between 1990 and 1997 completed their degree and 43% of these candidates completed their degree in over five years. His findings suggest that attrition and slow rates of completions are still major issues. Completions were found to be higher in natural sciences (75%) than in social sciences (52%), humanities and the arts (54%), and other disciplines (61%) due to a more collaborative research culture in natural sciences. This culture was found to be characterised by a more attainable credential, more collaborative research support, more effective levels of stakeholder investment in candidates' success, safer candidate selection criteria, and a more established supervisory pool.

In April 2002, the then Minister for Education, Science and Training, Dr Brendan Nelson, launched a review of the higher education sector with the release of *Higher Education at the Crossroads*. The package of reforms announced in May 2003 in *Our Universities: Backing Australia's Future* included the intention to evaluate initiatives in *Knowledge and Innovation*. One of the concerns raised in the evaluation report released in March 2004 was that the Research Training Scheme may be a barrier to innovation by directing "students to *safe* topics that can be completed within the time limits, possibly to the detriment of more speculative and adventurous research activity" (Fell, 2004, p. 8) The report contained 18 recommendations, including "that the Government examine ways to build further linkages and collaboration within the national innovation system, including the private sector" (Fell, 2004, p. xi).

4.2.2 National innovation system

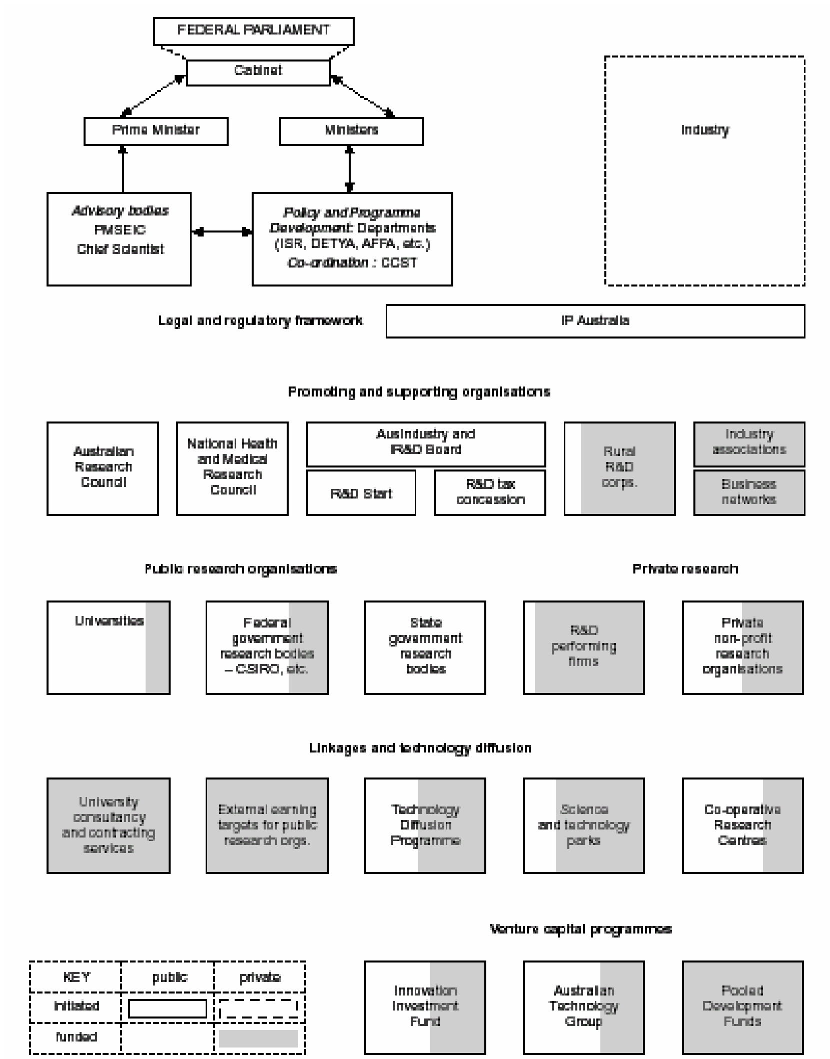
The diagram of **Australia's national innovation system** (Figure 11) was included in the OECD (1999) publication, *Managing National Innovation Systems*, and slightly revised by the Department of Industry, Science and Resources (1999) in its innovation framework paper, *Shaping Australia's Future*. Organisations were grouped into the Australian Commonwealth Government, the legal and regulatory framework, promoting and supporting organisations, public education and research organisations, private research organisations, linkages and technology diffusion, and venture capital programs.

Nelson (2003a) identified five main groups of *players* across the public and private sectors (p. 43):

- Thousands of large and small firms in the business sector in all industries, including firms that are part of multinational corporations.
- A variety of Australian Government and State and Territory government research and science agencies (such as the CSIRO and the Defence Science and Technology Organisation), including units within agencies, which carry out research for the public good (where government is the prime funder or customer) and/or in partnership with businesses and universities.
- 39 higher education institutions (universities) which undertake research to generate new knowledge and train the future research workforce, as well as other research organisations including Cooperative Research Centres and Centres of Excellence.

- Private non-profit bodies, including 29 medical research institutes, most of which are associated or co-located with higher education institutions.
- More than 60 major research facilities in which, principally, universities and government research agencies are jointly involved.

Figure 11: Australia's national innovation system



Source: DISR (1999) p. 37

In 2000, there were 95,710 people working in R&D roles in Australia's national system, with 66,099 people (or 69.1%) employed as researchers. Of these researchers, 39,507 (or 59.8%) were working in higher education, 16,124 (or 24.4%) in business enterprises and 8,972 (or 13.6%) in government. As already stated, research training occurs mainly within universities (as public research organisations) and Cooperative Research Centres (which are regarded as linkage and technology diffusion organisations), with some research students exposed to industry through Australian Postgraduate Awards Industry. In 2004, there were 47,309 research students (32.2% in S&T fields) contributing to, and being trained within Australia's national innovation system.

Kemp (1999b) and West (1998) made explicit statements about the importance of research training to the national innovation system. They believed that research training contributes to knowledge production and transfer, and has a vital role in building a research workforce, which in turn enhances the competitiveness of the national economy. The key role of universities is to develop the capabilities of research students so that they can be part of a highly skilled workforce of researchers involved in R&D work in different national and international settings. Nelson (2002a) also stated that research training is becoming an increasingly important element of Australia's national innovation system because of its role in "the building of skills and capacity, and generation of new ideas" (p. 42). A research training expert from the Department of Education, Science and Training (DEST) described the role of research training as follows:

> They will be the future innovators working creatively in teams or even as individuals but hopefully in the new knowledge paradigm working together in teams so that they will bring a fresh approach, they will bring their particular skills, and they will be willing participants and communicators across the various sectors not just isolating in a little box called academia. Technically, there is also a spin-off from the government's perspective that the investment in the students has a direct benefit for innovation as a result of this. Through industry, new ideas, new knowledge we recognise that the value the investment is the buying power which is being invested for the future, and the benefits to public and private innovation rely upon successive cohorts of these trainees. Additional to that, they will play a role in the development of new products and processes but the main value is the persons themselves and the knowledge and skills they carry, and how our economy and how society at large can benefit from that personnel. The buying power, their capabilities, not just whether they invent a particular widget or gadget, or a particular innovation, it is about the skills that they bring and the interaction across sectors. It is about having people who have the talents to enrich the innovation and knowledge economy.

The Commonwealth Government has implemented a range of initiatives designed to build Australia's capacity to innovate within a national innovation system by addressing system weaknesses and developing features of an effective national innovation system. Australia's current innovation policy is contained in *Backing Australia's Ability, an innovation action plan for the future* – a five year $2.9 billion strategy announced by Prime Minister John Howard in January 2001. This strategy is funding major initiatives to strengthen Australia's ability to generate ideas and undertake research, accelerate the commercial application of these ideas, and develop and retain Australian skills. Policy initiatives from the strategy are contained in Table A7 in the appendix. The Government estimated that the strategy would be underpinned by $6 billion from the private sector and educational and research institutions to further enhance Australia's capacity for innovation. In May 2004, Prime Minister John Howard announced that the Commonwealth Government had further strengthened *Backing Australia's Ability* by $5.3 billion, culminating in a ten year funding commitment of $8.3 billion from 2001 to 2011.

The Minister for Education, Science and Technology, Dr Brendan Nelson, released *Mapping Australian Science and Innovation* in November 2003. Many of the strengths, weaknesses and complementarities in

Australia's national innovation system from this report (see Table A8 in the appendix) have existed for some time and been examined in numerous reports. *Backing Australia's Ability: The Australian Government's Innovation Report 2004-05* found that Australia continued to perform strongly in the areas of R&D expenditure in government and higher education, a highly educated workforce, the share of foreign affiliates in manufacturing R&D, and multi-factor productivity (Howard, 2005). Areas of weak and/or deteriorating performance included patenting levels, business expenditure on R&D, and breadth of international science and engineering collaboration (Table 8). Most of these indicators were not yet reflecting the full impact of additional funding and initiatives in *Backing Australia's Ability*.

Table 8: Australia's innovation scorecard, 2004

Category	Headline indicator	2004 rank	2002 rank	Relative to OECD
Knowledge creation	R&D expenditure in government and higher education sectors as % GDP	6	7	Above
	Scientific and technical articles per million population	9	8	Above
	Number of U.S. patents per million population	18	18	Below
	Business sector R&D expenditure (BERD) as a % GDP	19	19	Below
Human resources	Percentage of workforce with tertiary education	6	5	Above
	Number of science graduates per 10,000 persons in labour force	6	6	Above
	Researchers per 10,000 labour force	8	7	Above
Finance	Investment in venture capital as a % GDP	7	18	Equal
Knowledge diffusion	Investment in ICT as % of business sector gross fixed capital formation	6	3/9*	Below
	Internet users per 1,000 population	6	10	Above
	Investment in new equipment – investment in machinery & equipment as a % of GDP	10	12	Above
Collaboration	Share of foreign affiliates in manufacturing R&D	4	3	Above
	Breadth of international science and engineering collaboration	12	8	Above
Market outcomes	Average annual growth in multifactor productivity between 1997 and 2001	4	4	Above
	Expenditure on innovation as share of total sales in manufacturing %	n/a	16	n/a

* In 2002, data was only available for nine countries
Source: Howard (2005), p. 6

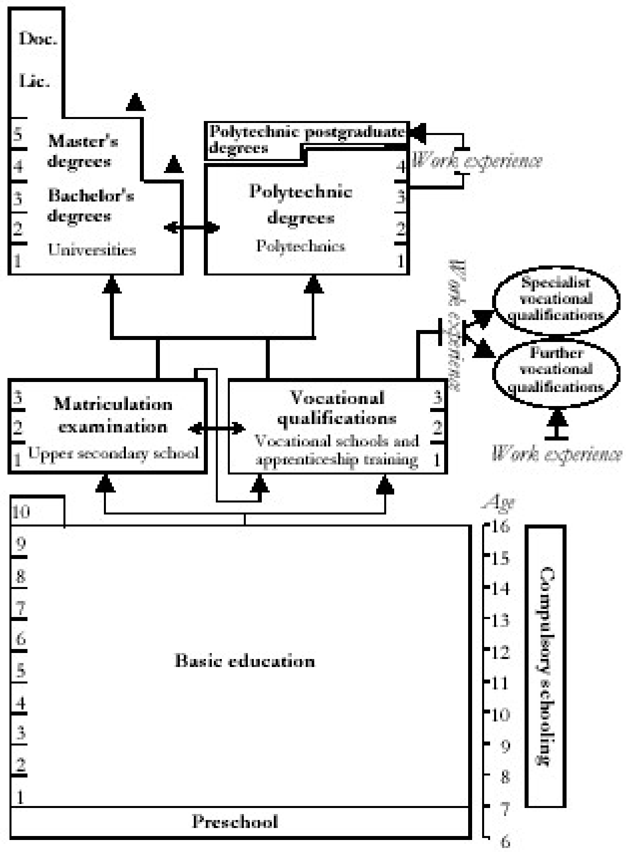
Gans and Stern (2004) used the National Innovative Capacity Index (NICI) to analyse Australia's innovative capacity and found there had been no gain in innovative capacity since 1996. They attributed this finding to declines in R&D expenditure, IP protection and education funding. They believed that Australia has an historic opportunity to establish itself as a leading innovator nation but needs to focus on areas that it has neglected over two decades. Two of these areas were greater investment to ensure a world pool of trained innovators and a university system that is more responsive to the science and technology requirements of emerging cluster areas (pp. 12-13).

4.3 Finland

4.3.1 Research training system

Research training in Finland occurs within an education system that consists of preschool education, comprehensive school, post-comprehensive general and vocational education, higher education, and adult education (Figure 12). Higher education in Finland comprises two parallel sectors: The university sector consisting of 20 universities; and the non-university sector consisting of 29 regionally managed polytechnics (*ammattikorkeakoulut* or AMK) offering vocational education and Bachelor degrees with a professional emphasis like engineering. Ten of the 20 universities in Finland are multi-faculty institutions. The other ten universities are specialist institutions – three are universities of technology, three are schools of economics and business administration, and four are art academies. The Ministry of Defence has a military academy providing university-level education.

Figure 12: Finland's education system



Source: Ministry of Education (2005a)

Finnish universities are state-owned institutions governed by the Universities Act. There are no tuition fees for domestic or foreign students in Finland. The centralised university system was changed in the mid 1980s to allow universities full autonomy in terms of teaching, research, tuition, student intake, number of staff and appropriations, and other internal affairs. The Ministry of Education is responsible for negotiating agreements with universities on target outcomes that link appropriations to performance. Reforms of the early 1990s were aimed at "international equivalence, larger freedom of choice, and comprehensive degrees allowing flexible combinations of study modules from different fields and establishments" (Ministry of Education, 2005b).

Postgraduate degrees include the Licentiate *(lisensiaati)* and the Doctorate *(tohtori)*. Students can commence a doctoral degree after obtaining a Masters degree. The Licentiate is an optional pre-doctoral postgraduate degree which can be completed in two years of full-time study after the Masters degree. Full-time studies for a doctorate take approximately four years following the Masters degree. Students are required to undertake studies in the discipline and in the specific field of research, and to research and prepare a thesis for both the licentiate and doctoral degree. The doctoral thesis must be publicly defended.

Enrolments in postgraduate degrees (licentiates and doctorates) in Finland increased from 10,442 in 1990 to 22,105 in 2004 (Figure 13), representing average annual growth of 5.8% over this period compared to average annual growth for all higher education degrees of 3.2%. Females accounted for 50.7% of postgraduate enrolments in Finland in 2004 compared to 38.5% in 1990. The number of research degrees awarded in Finland rose from 1,128 in 1990 to 1,957 in 2004, representing average annual growth of 5.5%. Most of the growth in research degrees in Finland is due to the significantly larger number of doctoral degrees that have been awarded (Figure 14). Doctoral completions rose from 490 in 1990 to 1,399 in 2004, representing average annual growth of 8.9% over this period. Females accounted for 45.2% of all doctoral completions in 2004 compared to 31.6% in 1990. Over the three year period 2001 to 2003, the S&T fields of natural sciences and technology accounted for 37.8% of all doctorates awarded in Finland.

Figure 13: Postgraduate enrolments by gender, Finland 1990 to 2004

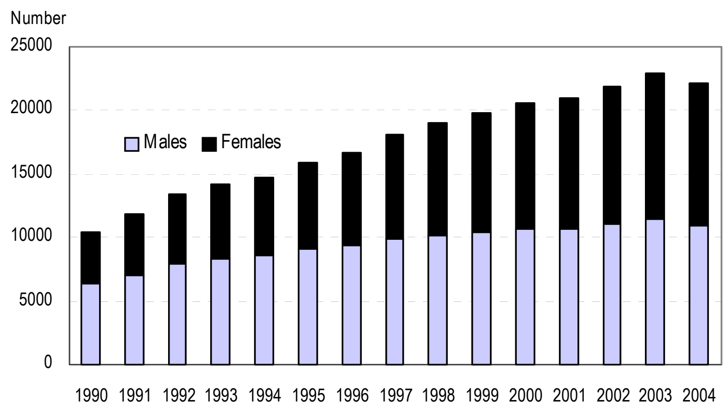
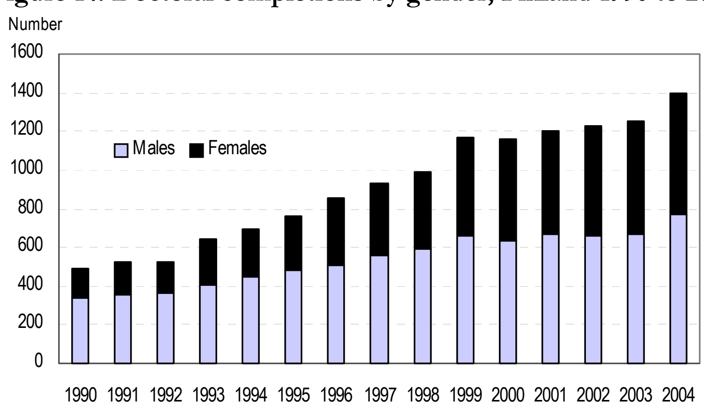


Figure 14: Doctoral completions by gender, Finland 1990 to 2004



Source: KOTA Online (2005) (for Figures 20 and 21)

The **Graduate School (Tutkijakoulu) System** was established in Finland in 1995 to "improve the quality of researcher training and make postgraduate education more systematic, shorten the time taken to prepare doctoral dissertations, lower the average age of new Doctors, improve cooperation in education and research, and increase international cooperation in education and research" (Ministry of Education, 2002,

p. 13). Other concerns included small universities not offering enough research training, too few international contacts, too few researchers seeking training abroad, uncertain entry into research careers, lack of university posts between research training posts and professorships, too much publishing in Finnish and in Finnish scientific journals, too little inter-university mobility among researchers, and few holders of doctorates work in industry (Numminen, 1996). By 2003, there were 114 graduate schools operating in universities and research institutes, most of which were network-type joint projects involving several universities. They provided 1,428 student places funded by the Ministry of Education and a further 2,500 places funded by external sources, such as the Academy of Finland, National Technology Agency of Finland (Tekes), private foundations, and industry. Research students in graduate schools are paid to undertake their studies full-time and encouraged to complete their dissertation in four years.

As stated above, research training in Finland is also supported through external research grants from Tekes and the Academy of Finland's Centres of Excellence in Research Programme. In 2004, Tekes funded 603 public research projects which resulted in the completion of 999 academic theses. The Centres of Excellence in Research Programme launched in the 1990s aims to "develop creative, internationally competitive research and training environments" (Academy of Finland, 2002a). The programme supports 59 centres of excellence over four funding rounds between 1995 and 2007, including the latest six year programme from 2002 to 2007 which is supporting 16 new units.

In 1998, the education ministers of Germany, France, Italy and the United Kingdom started the Bologna process by signing the Sorbonne Declaration concerning the harmonisation of higher education degree systems in Europe. Education ministers of 29 European countries, including Finland, signed the **Bologna Declaration** in June 1999. This declaration aims to create a common European Higher Education Area by 2010 with a view to improving the competitiveness and attraction of European higher education in relation to other continents. Objectives included: a two cycle degree system i.e. undergraduate and graduate; comparable degrees using the European Credit Transfer System (ECTS) and Diploma Supplement; a system of study credits; increased mobility of students, teachers, researchers and administrative staff; quality assurance criteria and methodologies; and promotion of the European dimension in higher education. At the follow up meeting in Prague in May 2001, student participation in the process, lifelong learning, and the creation of joint degrees were added as objectives.

The National Unions of Students in Europe (ESIB) (2003) identified increased mobility, quality improvement and assurance, and improved recognition and flexibility of degrees as the key benefits of the Bologna process. However, ESIB (2003) made several recommendations to address the issues of the trend towards commodification, divergent implementation, and a severe lack of information. A serious issue for doctoral degrees that needs to be explored is whether the strict timeframe for the completion is to detriment of innovation and discovery.

As a result of Finland's commitment to the Bologna process, Finnish universities adopted a 3+2+4 degree structure (3 years Bachelor degree + 2 years Masters degree + 4 years Doctorate) and a national credit unit system that is compatible with the ECTS system on 1 August 2005. An earlier national strategy for the internationalisation of higher education by the Ministry of Education (2001) aims to increase the annual volume of student exchanges to 28,000, of which 15% would be foreign graduate students.

In July 2005, a working group established by the Academy of Finland released the report, *Sustainable and dynamic partnership: Research cooperation and researcher training between universities, research institutes and business and industry*. The working group found that structural reforms, strong commitment, and a change of culture and attitudes were needed to further develop and deepen research cooperation between universities, research institutes and companies. Specific recommendations to achieve this goal were as follows (pp. 8-9):

- Increased R&D investment by the public and private sectors, including a new program for scientific infrastructure to create internationally competitive research environments.
- Greater efforts by universities and research institutes to commercialise research results and encourage researchers to establish their own businesses and work more closely with business companies.
- Provision of competitive funding by the Academy of Finland and Tekes for fixed-term, high profile research and technology units in fields that are important to the national economy.
- Greater collaboration between universities, research institutes and businesses to develop and expand pre- and postdoctoral training that better meets workplace needs. This recommendation included increasing studies that involved interdisciplinarity, international exchange and cooperation, entrepreneurship and business know-how, training in management skills and immaterial property rights, and where relevant, supervision of doctoral students by a steering group including industry representatives.
- New funding instruments and information on existing instruments by the Academy of Finland and Tekes to promote intersectoral mobility at all stages of the research career, particularly at postgraduate and postdoctoral levels. In addition, researchers and businesses should be more active in international programs that support researcher mobility and industry-academia cooperation.
- Increased efforts to attract more foreign researchers and PhD graduates, including the provision of internationally high-quality research environments and fixed-term competitive posts for high profile foreign researchers sponsored by universities and funding agencies.
- Revised criteria and conditions for funding doctoral studies of employed persons by the Academy so that research grants are available not only for the completion of doctoral theses but also for earlier stages of thesis research. This would involve greater integration of employed doctoral students into graduate schools or university research teams, including those people undertaking their thesis in industry.
- Greater involvement of industry in relevant program planning and decision-making by the Academy of Finland and Tekes.

4.3.2 National innovation system

Finland was the first country to adopt the national innovation system approach in its science and technology policy during the recession of the early 1990s. The system is regarded as a sophisticated and coherent model that other countries learn from, performing strongly in terms of growth, competitiveness, and technological sophistication and infrastructure (European Commission, 2004a). The Finnish Science and Technology Service (2005) described Finland's national innovation system as a:

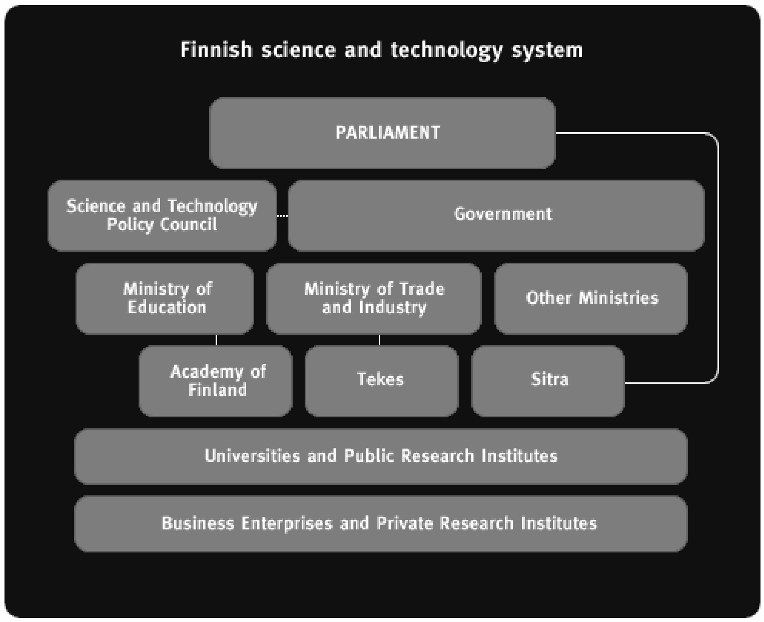
> … comprehensive entity composed of producers of new knowledge, users of knowledge and various interactive relations between them. The major components of the innovation system are education, research, product development and knowledge-intensive business. The system is permeated by wide-ranging international cooperation.

Key organisations in **Finland's national innovation system** (Figure 15) are as follows:

- The Science and Technology Policy Council of Finland coordinates innovation policy activities at a national level.
- The Ministry of Education is responsible for Science Policy and the Academy of Finland.
- The Ministry of Trade and Industry is responsible for Technology Policy, Tekes and VTT.
- The Academy of Finland plans and funds basic research, research training and science policy, providing funding for research of 208 million euros in 2004.
- The National Technology Agency of Finland (Tekes) plans and funds applied technical research and industrial R&D, providing funding for research of 409 million euros in 2004.
- The Technical Research Centre (VTT) is Finland's largest governmental research institute carrying out technical and techno-economic R&D work.
- The network of higher education institutions, technology centres, centres of expertise and other operational players within regional innovation systems.
- The Finnish National Fund for Research and Development (Sitra) was established by the Finnish Government in the late 1960s to finance technical R&D, and today is one of a number of organisations that provide venture capital support.
- Large and increasingly internationalised industrial enterprises particularly in forestry, engineering, manufacturing and electronics.

In 2002, there were 55,044 people in the R&D workforce in Finland's national innovation system of which 38,632 personnel (or 70.2%) were researchers. Of these researchers, 21,283 (or 55.1%) were working in business enterprises, 12,392 (or 32.1%) in higher education and 4,600 (or 11.9%) in government. The system also consisted of 22,105 students enrolled in postgraduate courses in 2004 and around 70% of these students were undertaking doctoral research. Finland recognises the importance of a highly educated and skilled workforce and sufficient level of know-how in its national innovation system. Research training is regarded as a key mechanism to train top-level experts to further develop know-how and innovations in international communities. However, only around 11% of R&D personnel in Finland have Doctorates - in industry this proportion is even smaller at 3% (Academy of Finland, 2005b).

Figure 15: Finland's national innovation system



Source: Finnish Science and Technology Information Service (2005)

Research training and innovation experts who were interviewed were asked about the contribution of research training to Finland's national innovation system. Some responses were based on the role of research training in providing "a direct inter-linkage between innovation, knowledge intensive industries and high level expertise". An expert discussed the importance of research training in "facilitating academic and industry links by providing companies with the most recent knowledge" and "because they are cheap labour for companies. In many cases companies can later employ this person if he is good". Similarly, another expert commented that research students who work in industry "get such a know-how and ability that can be used in industry". One expert referred to the knowledge that research students independently produce: "Whether it is in the form of concrete gadgets that come out, let's stick this thing into a mobile phone or a vaccine check then yes they do greatly contribute to the innovation system". Other experts believe that research students contribute significantly to the national innovation system because they have a "big role in that because they are doing the biggest part of the actual research work" and "they are the workforces. The major part of the work is done by research students". Two other experts discussed the difficulty in assessing the role or contribution of research training: "It very hard to measure which part of Finland's innovation system and how large its role has been" and "there isn't so much information on what is really going on between them".

The current policy framework for science, technology and innovation was released in December 2002 in the sixth triennial review by the Science and Technology Policy Council of Finland, *Knowledge, Innovation and Internationalisation*. Table A9 in the appendix contains the key innovation measures from this review that aim to address challenges facing science and technology policy, enhance the internationalisation of the national innovation system, and further develop innovation in Finland. The national strategy focuses on several areas: social innovation; international science and technology cooperation; national competencies; efficient commercialisation of research; greater resources for the Academy of Finland and Tekes; increased competitive science and technology funding; revised intellectual property legislation to encourage universities to undertake and utilise research; strengthened linkages between research organisations and business; foresight exercises that anticipate societal and technological developments; improving the prospects for research careers; and measures to enhance regional development. Table A10 in the appendix presents the aims and priorities of Finland's science and technology policies that are based on findings from the triennial review. These policies called for increasing the diffusion and utilisation of research results.

As a member of the European Union, Finland reports on its innovation performance as part of the European Innovation Scoreboard (European Commission, 2004a). The SWOT analysis of Finland's national innovation system included in the report for the period covering September 2003 to August 2004 is included in Table A11 in the appendix. Key strengths identified in the report and SWOT analysis were the high number of people with tertiary qualifications, high public and business investment in R&D, high-tech patenting, innovation co-operation, and internet penetration. Weaknesses included innovation expenditures in services, low attractiveness as a location for foreign direct investment, the small number of innovative SMEs, low employment in medium tech industries, diffusion of ICT into traditional industrial sectors and services, and the low level of entrepreneurship. The impact of globalisation and rapid international change on industrial structures, business models and competencies were identified as key challenges for Finland. Table 9 contains strengths and issues of the Finnish innovation system that were identified from interviews with representatives from key players in Finland's national innovation system.

Three recently released documents recommended initiatives to improve the functioning of the national innovation system. The report, *Innovation Policy to Yield More Returns,* identified the structural challenges of the activities of cooperation organisations that promote innovation. These organisations included technology centres, various development companies, business incubators and organisations that tend to the corporate relations of universities. The report recommended that the "Ministry of Trade and Industry should examine how it could adopt a more holistic approach to coordination of the national innovation policy" (Ministry of Trade and Industry, 2004), which could require the restructuring of the public sector. In November 2004, the Science and Technology Policy Council released a strategy for the *Internationalisation of Finnish Science and Technology* that aimed to strengthen knowledge, competence, education, research, and innovation through extensive international cooperation. One of the strategy's objectives was to "enhance the integration of the Finnish innovation system with international science, technology development and innovation" (p. 1). The Finnish Government adopted a *resolution on the structural development of the public research system* in April 2005. The resolution is directed at continually developing the quality and relevance of R&D to ensure it is world class and relevant to the national economy, societal development and citizens' well-being (Ministry of Education, 2005c).

Table 9: Strengths and issues in Finland's national innovation system

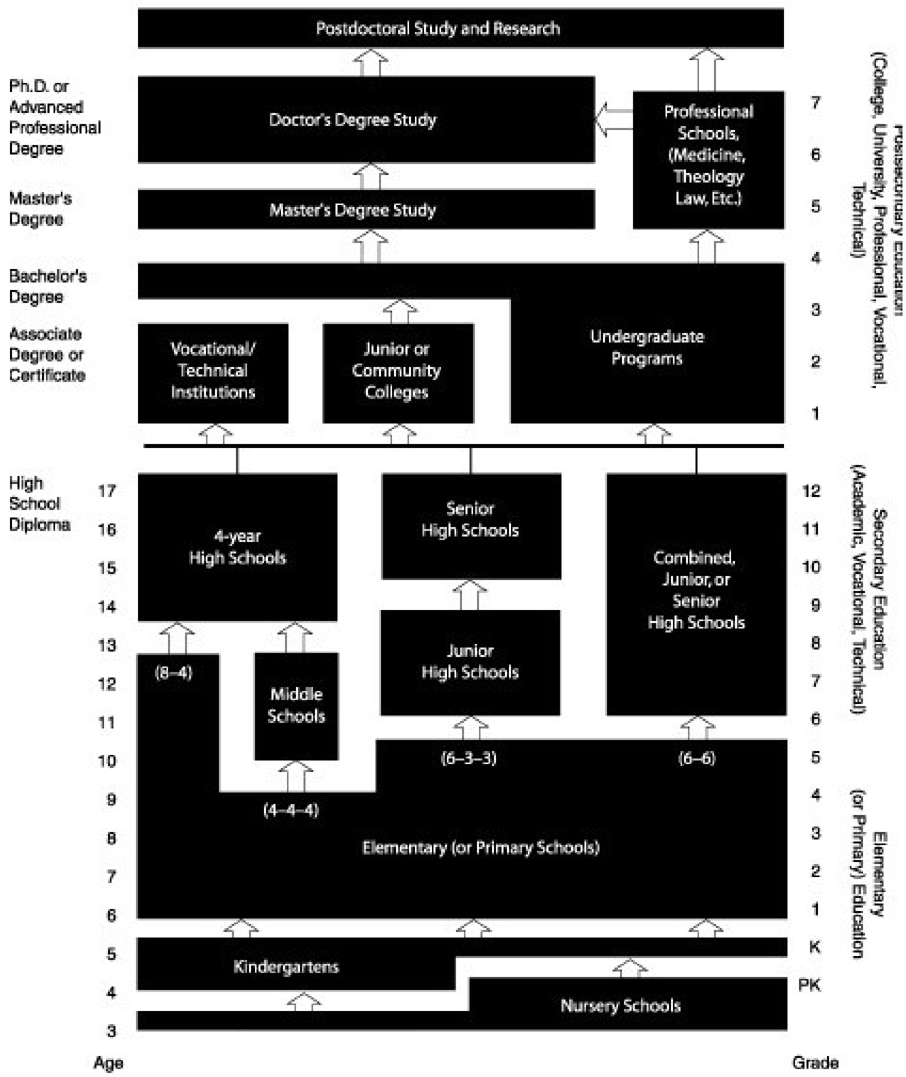
Strengths	Issues
The system is organised. It has efficient and effective supporting agencies with distinct roles, such as the National Technology Agencies of Finland (Tekes), Academy of Finland, Sitra (National Fund for Research and Development), Ministry of Trade and Industry, Ministry of Education, and The Science and Technology Policy Council of Finland. There is continuous evaluation and improvement of these agencies and their programs and priorities.	Impending changes to intellectual property rights legislation aimed at providing greater incentives for universities to exploit research results may jeopardise the trust built up in existing university and industry partnerships, and may discourage new partnerships.
People from agencies, universities, research institutes and industries talk to each other as shown by strong networks and clusters, particularly at regional levels. A small country means it is easier for people moving in similar circles to know each other.	There is pressure on the welfare state due to the ageing population, prevailing high unemployment, and calls to reduce taxation.
Industry involvement in R&D is a part of the normal R&D life, which is due largely to the establishment of Tekes in 1983 which made funding available for university and industry partnerships.	As Finland's innovation system is in itself a unique model, it may have some difficulty in finding inspiration and lessons in other models.
Research on innovation and technology is undertaken from many angles. The current four year research program called *ProAct* consists of 25 to 30 projects to "increase our understanding and knowledge of the effects of technology, research and technology policy on society and the economy, and of the effects of society on technological development" (Ministry of Trade and Industry, 2003). There is also a dedicated research institute called VTT Technology Studies which performs interdisciplinary research on the interface between technology, the economy and society.	Finland does not have critical mass in terms of materials, intellectual resources or customers for major projects or innovations. Similar to other countries with a small population, it is somewhat reliant on the global economy and must move towards global networking to "improve the quality, reduce overlapping knowledge production and help to pool existing resources and allocate them to important targets" (Science and Technology Policy Council of Finland, 2002).
Prior to the recession, Finland set in place an ambitious plan to become a high technology producer and exporter. Finland did not cut back on R&D expenditure or education expenditure during the recession. These smart decisions led to Finland (and in particular, Nokia) to reap the benefits of the technology boom of the 1990s. Some did say there was also an element of luck.	Finland is criticised for its high taxation, strange language and harsh climate - factors which may make it difficult for Finland to complete on the global market for competent researchers.
The businesses that survived Finland's recession in the early 1990s came out tougher and more efficient.	
Finland has always had a strong investment in human capital. In many countries the base degree is the Bachelor degree whereas in Finland the base degree is the Masters degree.	
Greater efforts are now being placed on social innovations to ensure complementarity of societal and social development with economic and technological development.	

4.4 United States

4.4.1 Research training system

There is no comprehensive system of education in the United States as the 50 states have freedom in shaping their own educational systems. Figure 16 shows the three levels of education (elementary, secondary and postsecondary) that are common elements in the state systems. The 6-3-3 form is most usual, and consists of six years of elementary or primary school from the ages of 6 to 12, three years of junior high school, and three years of senior high school. There are also a large number of private schools throughout the country. After completing an undergraduate degree, students commence a Masters degree and progress to a Doctorate program. A Masters degree takes at least one year following the completion of an undergraduate degree and a Doctorate takes a minimum of three or four years to complete. Graduates from Professional Schools such as medicine and law also enrol in Doctorate and Post-doctorate programs.

Figure 16: United States' education system

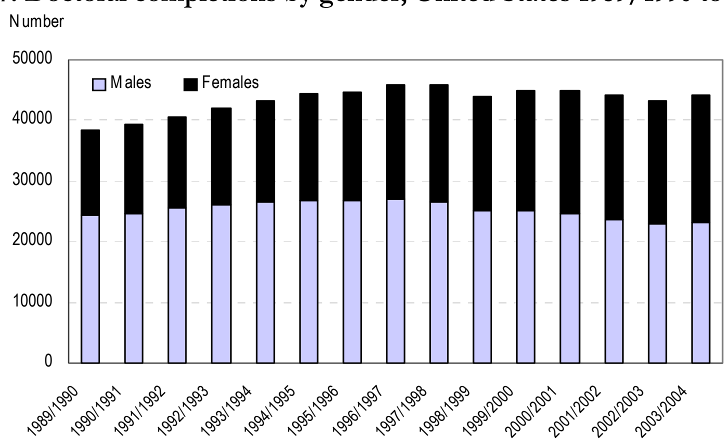


Source: National Center for Education Statistics (2002)

The National Science Foundation (NSF) estimated that there was around 3,700 degree-granting colleges and universities serving 15.6 million students in the U.S. higher education system in the year 2000. Institutions vary in size, type of administrative control (public or private), selectivity and focus. Students have the flexibility in moving between institutions, transferring credits, entering and leaving schools, and switching between full-time and part-time status. The Carnegie Classification of Institutions of Higher Education clusters degree-granting institutions by their purpose and size i.e. Doctorate-granting institutions, Masters Colleges and Universities, Baccalaureate Colleges, Associate's Colleges, Specialised Institutions (such as medical schools, law schools, theological seminaries) and Tribal Colleges. The NSF stated that remaining a leader in generating scientific and technological breakthroughs and preparing workers to meet the evolving demands for skilled workers were the key challenges for the higher education system in the United States.

Data on doctoral enrolments in the United States is included in total graduate enrolments which rose from 1,586,000 in 1990 to 1,904,000 in 2001, representing average annual growth of 1.6% over this period. Females accounted for 58.2% of graduate degree enrolments in the United States in 2001 compared to 53.5% in 1990. In 2003/2004, a total of 44,200 doctoral degrees were awarded in the United States (Figure 17), with 47.3% of degrees awarded to females compared to 36.4% in 1989/90. Almost 24% of doctoral degrees awarded were in the S&T fields of biological sciences/life sciences, engineering, and computer and information sciences.

Figure 17: Doctoral completions by gender, United States 1989/1990 to 2003/2004



Source: National Center for Education Statistics (2004)

Doctoral students may be supported by one or more of the following mechanisms during their studies: research assistantships, teaching assistantships, fellowships, traineeships, and other mechanisms such as work-study programs, business or employer support, and support from foreign governments. Sources of funding include Federal agencies (such as the Department of Defence, United States Department of Agriculture and NASA), higher education institutions, state and local governments, foreign sources, non-profit institutions, private industry, and self-support through loans or personal/family contributions. In 2001, one in five graduate students received Federal financial support, mostly in the form of research assistantships.

The U.S. Committee on Science, Engineering and Public Policy stated in its 1995 report, *Reshaping the Graduate Education of Scientists and Engineers,* that the three areas of primary employment for graduates (i.e. universities and colleges, industry and government) were experiencing simultaneous change. The growth in university positions was slowing and more than half of new graduates with PhDs had found work in non-academic settings. Employers were concerned that PhD graduates were often too specialised, and universities were criticised for training people to work as the next generation of academic researchers. The Committee called for reforms to enhance the educational experience of future scientists and engineers who will work in either academic or non-academic settings. These reforms included offering a broad range of academic options, providing better information and guidance about careers, and devising a national human resource policy for advanced scientists and engineers. Other issues raised by the Committee included the relationship between the supply of, and demand for PhDs in science and technology (in particular, the apparent oversupply at the time); and the rapidly increasing numbers of foreign students who worked in the United States after they graduated. The Committee recommended against across-the-board limits on enrolments in PhDs or limiting the number of foreign students.

Six themes for doctoral reforms were identified in a workshop held in 2000 on *re-envisioning the PhD to meet the needs of the 21st century*: shorten the time to degree acquisition; increase underrepresented minorities among doctoral recipients; improve the use of technology for research and instructional purposes; prepare students for a wider variety of professional opportunities; incorporate understanding of the global economy and international scientific enterprise; and provide doctoral students with an interdisciplinary education. More recently, there have been concerns about doctoral attrition which was estimated at 50%. A study by the Council of Graduate Schools found that completion rates were higher in science and technology fields (at around 75% for those in life sciences) and much lower in humanities (between 30% and 50%). Some of the factors impacting on attrition patterns and completion rates included selection and admission, mentoring, program environment, processes and procedures, financial support, and research mode of the field. In 2004, Pfizer Inc. and the Ford Foundation provided funding to the Council of Graduate Schools to establish the *PhD Completion Program*. This program is providing "awards of up to $100,000 to 15 universities to create intervention strategies and pilot projects, and to evaluate the impact of these projects on rates of doctoral completions and attrition patterns" (Denecke, 2004).

4.4.2 National innovation system

The European Trend Chart on Innovation included annual policy trend reports for Brazil, Canada, Mexico and the United States. The report for the period from September 2003 to August 2004 described the **U.S. national innovation system** as a combined centralised and regionalised system consisting of many Federal agencies with R&D and commercialisation programs, and State and local government agencies with science and technology initiatives. There is no central body coordinating these activities. The report included a sample of key institutions currently operating in the U.S. national innovation system (Table 10).

Mowery and Rosenberg (1993) referred to the gargantuan task in describing the U.S. national innovation system. Their discussion on the changing roles of the three main sectors of industry, universities and the Federal Government highlighted key features of the post war U.S. national innovation system:

- National R&D investment that was more than all other OECD nations combined during most of the post war era. However, U.S. national output devoted to R&D has been flat or declining since the early 1990s. This situation is largely due to disinvestment by the Federal Government in all forms of R&D, falling from nearly 60% of the nation's R&D investment in 1970 to around 30% in 1997 (Council on Competitiveness, 1999).

Table 10: Sample of U.S. national innovation system institutions

Department	Agency	Office/Programme
Department of Agriculture	Agricultural Research Service	
Department of Commerce	National Oceanic and Atmospheric Administration (NOAA) National Telecommunication and Information Administration (NTIA) Patent and Trademark Office Technology Administration	Office of Oceanic and Atmospheric Research Institute for Telecommunications Sciences National Institute of Standards & Technology National Technical Service
Department of Defence	Defence Advanced Research Projects Agency (DARPA)	
Department of Education	Institute of Education Services Office of Innovation and Improvement	National Centre for Educational Research National Research and Development Centres
Department of Energy	National Energy Technology Laboratory National Renewable Energy Laboratory Office of Science	
Department of Health and Human Services	Agency for Healthcare Research and Quality Centres for Disease Control National Institutes of Health	
Department of Labour	Employment and Training Administration Office of Small Business Programmes	
Department of Transportation	Research and Special Programmes Administration	
Executive Office of the President	Council of Economic Advisors Council on Environmental Quality, Executive Office of the President National Economic Council National Science and Technology Council President's Committee of Advisors on Science and Technology (PCAST)	
Independent	National Aeronautics and Space Administration (NASA) National Science Foundation (NSF) Small Business Administration (SBA)	NASA Scientific and Technical Information Programme

Source: European Commission (2004b) pp. 22-23

- Public policies in the areas of antitrust (which increased corporate reliance on industrial research and innovation) and military R&D (which is regarded as an important source of commercial strength in high tech industries).

- The significant increase in Federal Government support for university research during and after World War II (particularly in basic research and defence-related technologies) transformed major U.S. universities into centres for the performance of scientific research. Federal funds also enlarged the pool of scientific personnel, allowed universities to acquire equipment and facilities for high quality research, and reinforced the link between research and teaching.

- The decentralised structure and funding of the higher education system (including the provision of public funding by State Governments) encouraged linkages between academic and industrial research, particularly those that were based on the needs of the local economy and/or involved the agricultural industry that has extensive Federal and State extension programs.

- The importance of new firms in the commercialisation of new technologies within the U.S. economy such as in microelectronics, computer hardware and software, biotechnology, and robotics.
- The scale of the U.S. education system allowed for a broad-based training system for scientists and engineers that aided the diffusion and utilisation of advanced scientific and engineering knowledge.
- Private industry that has retained its dominance as a performer of R&D leading to continued growth in employment within industrial research.
- Strong research performance as indicated by the share of Nobel Prizes and citation of scientific papers.

Two U.S. policy initiatives to strengthen intellectual property rights led to significant increases in patent applications by universities and Federal agencies, significantly enhancing their contribution to the U.S. national innovation system. The *Bayh-Dole University and Small Business Patent Act of 1980* permitted Federal agencies to grant licences to small businesses and non-profit institutions (including universities) for patents based on Federally-funded research. The *Federal Technology Transfer Act of 1986* allowed Federal laboratories to conduct cooperative research and development agreements with private firms (Mowery and Rosenberg, 1998). However, the Council on Competitiveness (2004a) believed that inappropriate and poor quality patents have imposed hidden economic costs and inhibited growth, creating a need for open, global standards that can enhance interoperability, encourage collaboration, and speed up process transformation.

There were 1,261,227 researchers working in the U.S. national innovation system in 1999 of which 1,015,700 were in industry (80.5%), 186,027 in higher education (14.7%) and 47,700 in Government (3.8%). The system included nearly two million graduate students and produced 44,200 doctoral graduates in 2003/2004. A research training expert explained how the graduate education system encouraged independent thinking, creativity and originality, which in turns encourages students to break new ground and innovate. He identified other factors that encourage research students to contribute to the U.S. national innovation system: ongoing efforts to "look at student funding to ensure they have the freedom to innovate"; an emphasis on interdisciplinarity; the decentralised accreditation system of quality review at the program and institutional levels; and the independence of research and higher education from Government. Another expert discussed the contribution of research training to the U.S. national innovation system in terms of ideas generation. He stated that the production of ideas creates substantial social and private rates of return and leads to faster growth and outcomes, particularly in the private business sector where ideas generate economic value. This expert recommended that the Federal Government "substantially increase the production of new ideas in the private sector by subsidising the training of these people and recognising that most of these people will work in the private sector". He criticised institutions for mostly training students for the research track and called for changes to ensure institutions meet the needs of these students, many of whom will eventually create value in the private sector.

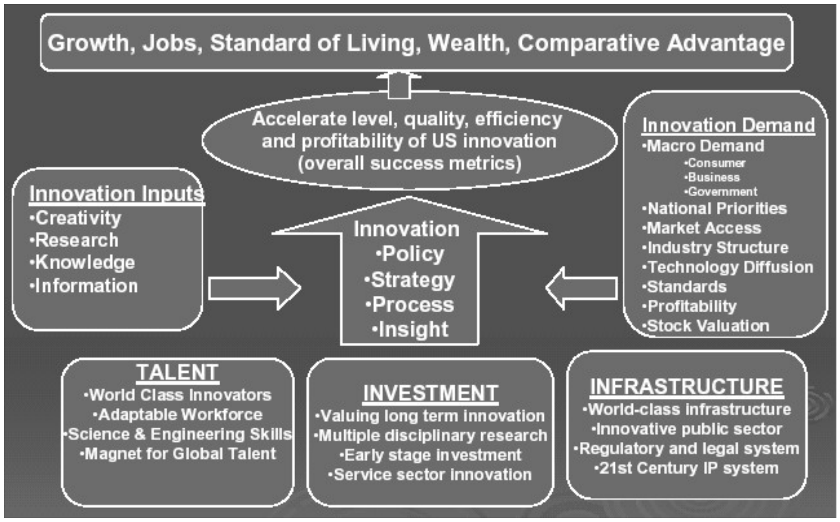
The United States continues to be the largest and most innovative economy in the world, characterised by cutting-edge science research across a wide range of fields, strong capabilities to convert research into applied technology, support for high technology start-ups, extensive venture capital markets, and relatively open labour markets that enable immigration of S&T personnel from other countries. These strengths were included in a SWOT analysis of the U.S. national innovation system that is presented in Table A12 in the appendix. There are a number of issues that are narrowing the gap between the United States and some European Union and Asian countries: a lack of U.S. students entering S&E graduate programs; further declines in the enrolment of international graduate students; insufficient funding for basic science; tighter regulations governing science (such as genetics and stem cell research); shortages of high skilled labour; and coordination problems caused by system decentralisation (European Commission, 2004b).

The American Electronics Association in its 2005 report, *Losing the Competitive Advantage? The Challenge for Science and Technology in the United States*, argued that America's competitive edge in science and technology is slipping. They attributed this situation to U.S. policy makers and industry leaders neglecting the country's technology infrastructure (i.e. skilled labour, R&D and a business friendly environment) and increasing competition from countries (many of which have adopted economic reforms) for foreign talent, innovation, and technology products and services. The Taskforce on the Future of American Innovation (2005) agreed that the United States can no longer take its supremacy for granted, with many nations "on a fast track to pass the United States in scientific excellence and technological innovation" (p. 1). The Taskforce in its report, *The Knowledge Economy: Is the United States Losing its Competitive Edge?,* called for sustained investments and informed policies in the essential areas of education, the workforce, knowledge creation and new ideas, R&D investments, the high-tech economy, and specific high-tech sectors.

In addition to the above issues, there has also been concern about the changing nature of innovation. Prior to the National Innovation Summit of December 2004, the Council on Competitiveness (2004a) released *Innovate America. Thriving in a World of Challenge and Change. National Innovation Initiative Interim Report* which stated that innovation is now a global phenomenon, arises from the intersection of different fields or spheres of activity (i.e. multidisciplinary), sparks innovation in other areas (i.e. an innovation multiplier), spreads through independent activities of many rather than one company or entity (i.e. elements of emergence and openness), and has a transformational force changing not just industries or markets but the way people in society live, work and engage with each other (pp. 5-6). The Council of Competitiveness' (2004b) final report, *21st Century Innovation Working Group Final Report for the National Innovation Initiative,* recommended creating a National Innovation Leadership Network, establishing innovation learning centres within a national support network, developing an aggressive public policy strategy to energise the environment for innovation, changing education to prepare students to become leaders and innovators, and introducing new mechanisms to encourage collaborative investments in innovation other. Table A13 in the appendix contains policy recommendations in relation to these themes. The Council of Competitiveness (2004b) proposed that policy initiatives occur within a *National Innovation Ecosystem* (Figure

18) in which innovation is considered primarily in terms of customer value creation, leading ultimately to broader economic and social benefits.

Figure 18: U.S. national innovation ecosystem



Source: Council on Competitiveness (2004b) p. 22

4.5 Comparison of performance

So far this chapter has presented findings from documents that describe the nature and performance of each country's research training system and national innovation system. This section has used statistical data to compare the innovation performance of Australia, Finland and the United States. Section 3.3.3 in Chapter 3 explained common approaches to assess national innovation system performance. The level of **investment in innovation** by a country is typically indicated by Gross Domestic Expenditure on R&D (GERD) and Business Enterprise Expenditure on R&D (BERD) as a proportion of GDP, the number of researchers, and investment in knowledge as a proportion of GDP. The **innovation output** of a national innovation system is indicated by triadic patents, publications and citations. Investment and output data in this chapter is supported by country rankings from the World Economic Forum's *Global Competitiveness Report.*

4.5.1 Innovation investment

Finland and the United States invest in R&D at rates well above other OECD countries (Figure 19). **GERD as a proportion of GDP** has grown significantly in Finland (rising from 1.17% in 1981 to 3.46% in 2002) and increased slightly in the United States (rising from 2.34% in 1981 to 2.6% in 2003). Average annual growth rates of GERD during the 1990s were 8.7% for Finland, 5.4% for Australia, 3.5% for the United States, and 3.3% for the OECD (Figure 20). Despite increasing from 0.95% in 1981 to 1.54% in 2000, GERD as a proportion of GDP in Australia continues to lag behind other OECD countries. Investment by OECD countries increased from 1.95% in 1981 to 2.26% in 2002.

Figure 19: GERD as a percentage of GDP, 1981 to 2003

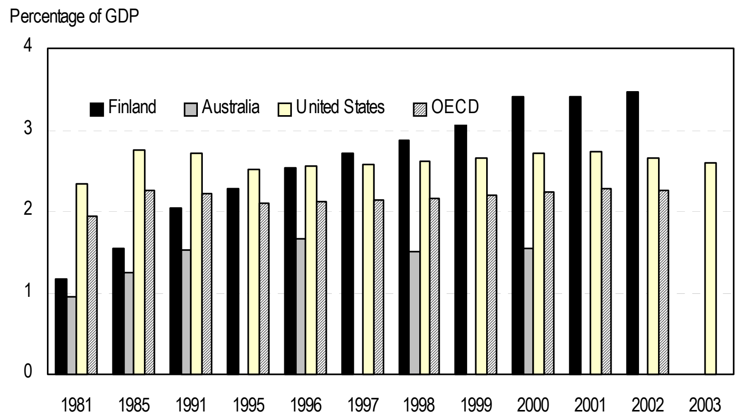
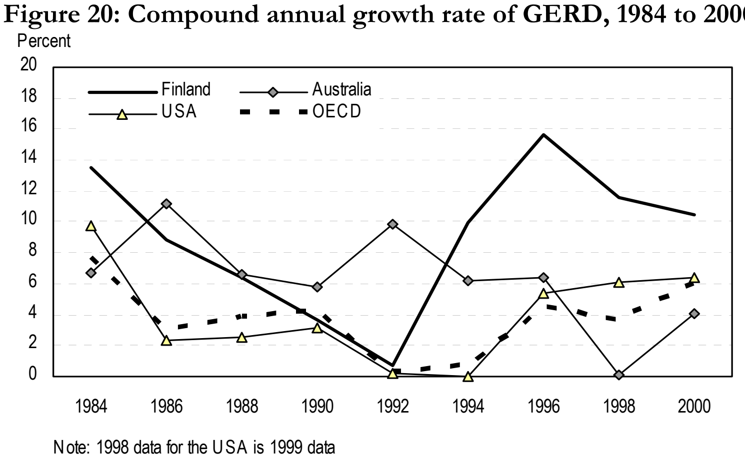
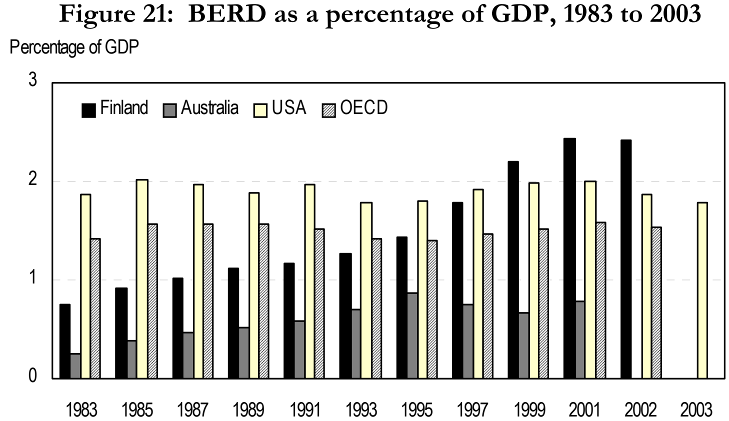


Figure 20: Compound annual growth rate of GERD, 1984 to 2000



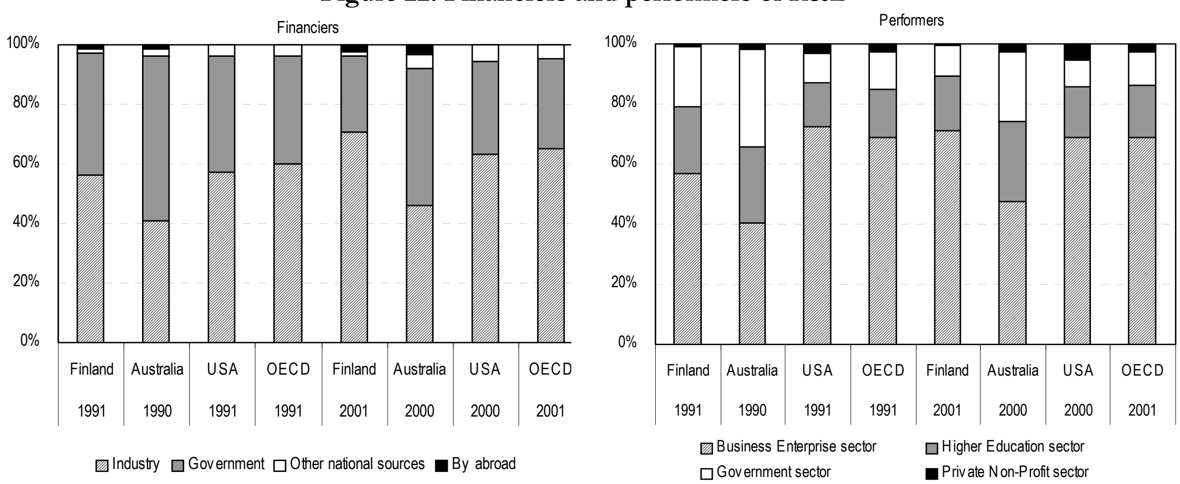
BERD as a proportion of GDP increased significantly in Finland during the 1980s and 1990s, exceeding that recorded for the United States since 1999. In 2002, BERD as a proportion of GDP was 2.41% for Finland, 1.79% for the United States and 1.53% for the OECD. Despite steady increases until 1995, BERD as a proportion of GDP in Australia remains low at 0.78% in 2001 (Figure 21).

Figure 21: BERD as a percentage of GDP, 1983 to 2003



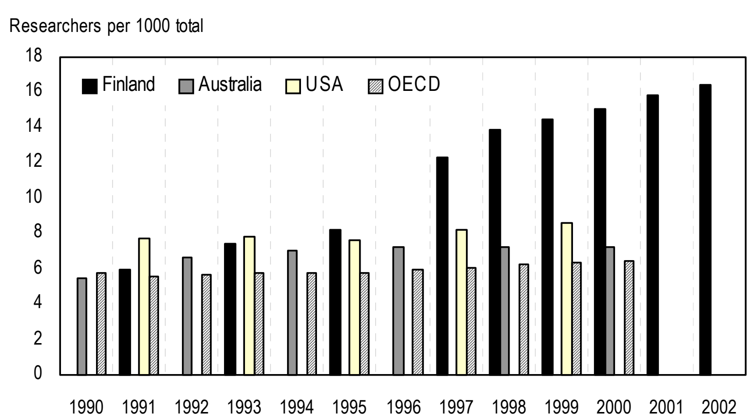
The proportion of R&D financed and performed by the four difference sectors (business enterprise, higher education, government and private non-profit) has varied, due largely to the increased role of the business enterprise sector (Figure 22). The proportion of R&D **financed** by industry has increased in Australia (from 41.1% in 1990 to 46.3% in 2000), Finland (from 56.3% in 1991 to 70.8% in 2001), the United States (from 57.2% in 1991 to 63.1% in 2000), and the OECD (from 58.8% in 1991 to 63.2% in 2001). The proportion of R&D **performed** by business enterprises rose in Australia (from 40.2% to 47.5%), Finland (from 57% to 71.1%) and the OECD (from 68.9% to 69%). The business sector in the United States is performing less R&D, falling from 72.5% in 1991 to 68.9% in 2000.

Figure 22: Financiers and performers of R&D



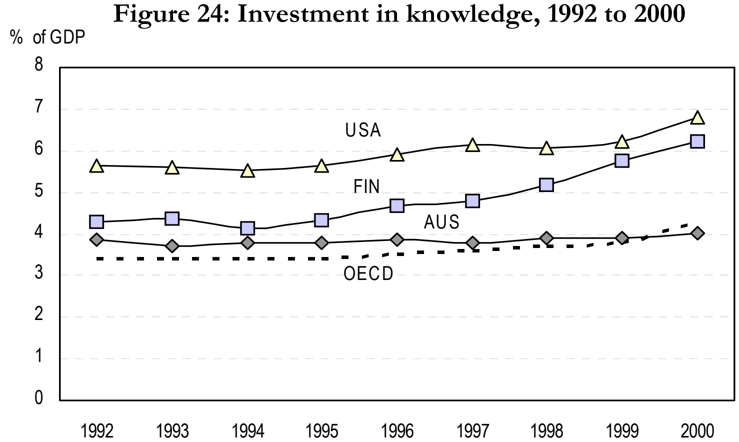
All three countries and the OECD as a whole have experienced an increase in the number of **researchers** as a proportion of total employment. Finland experienced the largest increase, from 6 out of every 1,000 people employed as researchers in 1991 to 16.4 people in 2002, compared to Australia (rising from 5.5 in 1990 to 7.2 in 2000), the United States (from 7.7 in 1991 to 8.6 in 1999) and the OECD (from 5.8 in 1990 to 6.5 in 2000) (Figure 23). The proportion of researchers employed by the business sector has expanded in Finland (from 36.8% in 1991 to 55.1% in 2002) and the United States (from 79% in 1991 to 80.5% in 1999) but has fallen in Australia (from 29.2% in 1990 to 24.4% in 2000) and for the OECD (from 64.9% in 1991 to 63.8% in 2000). The research workforce in the three countries is discussed further in Section 5.7 Research Careers in Chapter 5.

Figure 23: Total researchers per thousand of total employment, 1990 to 2002



Investment in knowledge (R&D expenditure + higher education expenditure + investment in software) as a proportion of GDP in the United States and Finland has been consistently above that for Australia and the OECD. In 2000, investment in knowledge as a proportion of GPD was 6.8% for the United States, 6.2% for Finland, 4% for Australia, and 4.3% for the OECD.

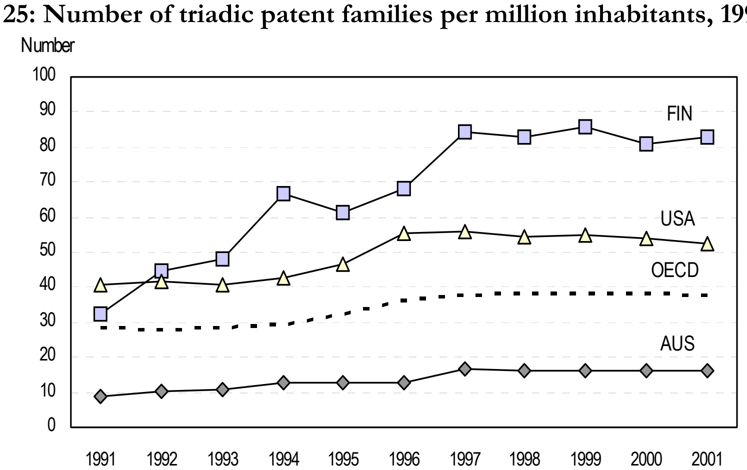
Figure 24: Investment in knowledge, 1992 to 2000



4.5.2 Innovation output

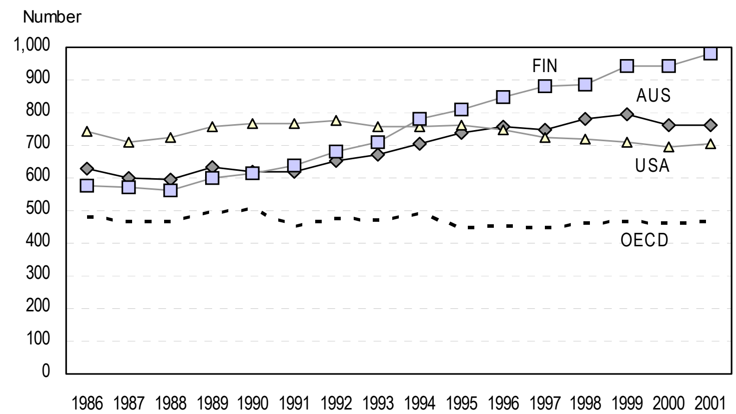
On a per capita basis, **patent data** indicates that Finland continues to diffuse and/or commercialise innovations at a rate well above that for Australia, the United States and the OECD (Figure 25). The number of triadic patents filed by Finland at the European and Japanese Patent Offices and granted by the U.S. Patent & Trademark Office (USPTO) was 83.1 patents per million inhabitants in 2001 compared to 52.6 patents for the United States, 16.3 patents in Australia, and 37.6 patents for the OECD. In terms of high tech patents, the United States performs very strongly in the ICT sector (at 120 patents per million inhabitants compared to 51.7 patents for the OECD in 1999) and the biotechnology sector (at 12.3 patents per million inhabitants compared to 4 patents for the OECD in 1999). Finland performs strongly in ICT patents at 60 patents per million inhabitants in 1999 (however this is lower than the 1998 peak of 78.4 ICT patents) but does not perform strongly in the biotechnology sector as indicated by 2.1 patents per million inhabitants in 1999. Australia's performance in high tech patents remains low at 11 ICT patents per million inhabitants and 1 biotechnology patent per million inhabitants in 1999.

Figure 25: Number of triadic patent families per million inhabitants, 1991 to 2001



Finland, Australia and the United States continue to produce significantly more **science and engineering (S&E) publications** as a proportion of the population than the OECD as a whole (Figure 26). The number of publications per million inhabitants produced in 2001 was 983 in Finland, 760 in Australia, 705 in the United States, and 468 publications for the OECD.

Figure 26: S&E publications per million inhabitants, 1986 to 2001



Source: OECD (2005a), Figures 19 to 26

Although falling over the past decade, the United States accounted for nearly one third of the world's S&E publications and almost 44% of the world's S&E citations in 2001 (Table 11). Because the citation of U.S. S&E publications was well above its publication rate, its relative citation index (i.e. share of cited literature adjusted for its share of published literature) was 1.35 in 1999 - which represents a world ranking of 2. Finland and Australia accounted for very small shares of world S&E publications and world S&E citations. However, Finnish publications are cited at a greater rate than Australian publications as indicated by a relative citation index of 1.02% (and a world ranking of 7) compared to 0.87% (and a world ranking of 14). The United States leads the world in the citation of publications in clinical medicine. Finland leads the world in the citation of publications in health.

Table 11: S&E publication and citation rates

	FIN			AUS			USA		
	1992	1996	2001	1992	1996	2001	1992	1996	2001
Share of world publications	0.63%	0.73%	0.78%	2.09%	2.34%	2.28%	36.31%	34.0%	30.91%
Share of world citations	0.55%	0.65%	0.79%	1.86%	1.81%	2.05%	51.75%	48.85%	43.63%
	1990	1994	1999	1990	1994	1999	1990	1994	1999
Relative citation index	0.89%	0.94%	1.02%	0.94%	0.84%	0.87%	1.36%	1.36%	1.35%

Source: National Science Board (2004)

4.5.3 World competitiveness rankings

Finland and the United States have retained their world rankings of 1 and 2 respectively in the Growth Competitiveness Index (GCI) (Table 12). Finland fell behind the United States in the Business Competitiveness Index (BCI) due to a decline in its company operations and strategy ranking from 2 to 7. Australia's performance deteriorated between 2001 and 2004, leading to a shift from 5 to 14 in its CGI ranking and 9 to 13 in its BCI ranking. The National Innovative Capacity Index (NICI) indicates a country's potential to innovate for competitiveness based on innovation output (mainly patenting) and innovation drivers like infrastructure, clusters and linkages. The United States and Finland retained their NICI world rankings of 1 and 2 respectively. Australia's ranking declined from 7 in 2001 to 15 in 2003.

Table 12: World competitiveness rankings

Index	World ranking					
	FIN	AUS	USA	FIN	AUS	USA
		2001			2004	
Growth Competitiveness Index	**1**	**5**	**2**	**1**	**14**	**2**
Macroeconomic Index	10	17	7	3	14	15
Public Institutions Index	1	8	12	3	12	21
Technology Index	3	5	1	3	17	1
Business Competitiveness Index	**1**	**9**	**2**	**2**	**13**	**1**
Company Operations and Strategy	2	24	1	7	19	2
Quality of the National Business Environment	1	7	2	1	12	2
		2001			2003	
National Innovative Capacity Index	**2**	**7**	**1**	**2**	**15**	**1**
Proportion of Scientists and Engineers Index	7	8	6	3	11	4
Innovation Policy Index	4	10	1	2	4	3
Cluster Innovation Environment Index	2	9	1	3	21	2
Innovation Linkages Index	3	5	1	2	10	1
Operations and Strategy Index	n.a.	n.a.	n.a.	8	22	1

Source: World Economic Forum (2002), (2003) and (2004)

4.6 Chapter summary

This chapter provided an overview of the major developments in, and performance of innovation and research training policies/systems in Australia, Finland and the United States (Research Question 3). The contribution of research training to the national innovation system in each country is significantly influenced by the nature and performance of the policies and systems for research training and national innovation. Variations reflect, for example, differences in national history and culture, population size, and investments levels of government and industry. All three countries have sought to improve the functioning of their research training systems to ensure that their national innovation systems have highly skilled S&T people to generate and diffuse new knowledge.

The United States is a large and highly developed country with markets of advanced customers and opportunities to reap economies of scale while maintaining diversity in R&D activities. A strong commitment by the Federal Government to university research after World War II, decentralisation of universities, and the enormous scale of the higher education system have enabled the United States to create a large pool of well qualified research graduates in science and technology. There is concern that the United States is losing its competitive edge in scientific excellence and technological innovation due to increased competition from many countries and insufficient funding for infrastructure and basic science.

As a small high income country, Finland can more easily capture and benefit from technology inflows but needs to internationalise more rapidly and concentrate on a narrow range of fields to reap these benefits. Another issue is the proportionally higher costs in maintaining educational institutions across a broad range of areas needed by industry. Efforts to create a coherent and efficient national innovation system characterised by a high level of R&D expenditure and a well educated population has transformed Finland into a leading innovating nation. The Graduate School System and other research training funding arrangements have succeeded in expanding the pool of research graduates within Finland's national innovation system. The greatest challenge for Finland is internationalising its research training system and national innovation system.

The statistical analysis on innovation performance in section 4.5 shows that research training in Finland and the United States is occurring within national innovation systems that have a strong research culture. These cultures are supported by a strong investment in R&D (as a proportion of GDP), an ability to diffuse and/or commercialise their innovations, and a recognition of their scientific expertise in terms of citations of publications. Both countries are ranked as leaders in the Global Competitiveness Index, Business Competitiveness Index and National Innovative Capacity Index.

Policy initiatives have improved the performance of Australia's research training system and national innovation system. However, insufficient R&D investment (particularly by industry), low patenting levels and a lack of scientific recognition by the world (as indicated by citation data) are serious and persistent issues for Australia. Although Australia has a relatively high level of researchers and a good S&E publications record, research students are being trained in a national innovation system that is not performing well enough according to OECD data and world competitiveness rankings.

The four chapters presented to this point – Chapter 1: Introduction, Chapter 2: Research design, Chapter 3: Key concepts, and Chapter 4: Systems in Australia, Finland and the United States – should have provided the reader with a clear understanding of a) the purpose of, and approach taken for this study; and b) the context for the study in terms of its central concepts and participating countries. The next three chapters have examined how research training contributes to the national innovation systems in Australia, Finland and United States in terms of international mobility and migration, research production and distribution, and its impact on economic growth.

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Chapter 5: International mobility and migration of research students and graduates

5.1 Introduction

This chapter begins with a literature review to define the common terms of transnational/international mobility, brain drain, brain gain, brain circulation; and identify reasons why countries want to improve their mobility performance, why people work or study abroad (drivers), the obstacles people face or prevent them from working or studying abroad, and the types of, and issues associated with mobility indicators. This information provides a foundation to assess policies and programs in Finland, Australia and the United States that encourage the international mobility and migration of research students and graduates (Research Question 4). This analysis is supported by available data on brain gain, brain drain and brain circulation for each country (Research Question 5), and case study findings in relation to the mobility experiences of the 30 research students who participated in this study.

This first element of the conceptual framework assumes that research students are likely to contribute to a national innovation system in Australia, Finland or the United States if, after graduating, they continue their research career i.e. they are a core part of the human resources in science and technology (HRST) stock, and they:

- remain in their own country i.e. they are *immobile*
- migrate to Australia, Finland or the United States from another country i.e. *brain gain*
- return home to Australia, Finland or the United States from another country i.e. *brain circulation*
- leave Australia, Finland or the United States but maintain professional links and networks that encourage international flows of highly skilled workers and knowledge i.e. *brain circulation*.

Given the above key assumptions, the analysis of mobility policies and programs must be supported by a discussion on research careers. The nature and extent of research opportunities available in Australia, Finland and the United States have a significant impact on the international mobility of research graduates by encouraging graduates to remain in their home country or migrate from other countries, or *pulling* or *pushing* graduates out of their home country to other countries with better opportunities.

5.2 Defining mobility

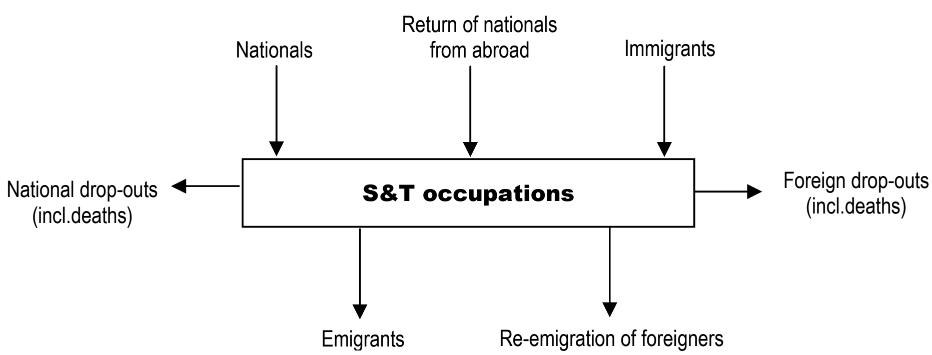
The European Commission established the High-Level Expert Group on Improving Mobility of Researchers in 2000 as part of its efforts to increase the mobility of researchers and enhance research careers in Europe[20]. The Group's final report released in April 2001 identified two types of mobility of researchers, the first of which is the focus of this element: **Transnational mobility** is the movement of

[20] The European Commission (2000) estimated that an additional 700,000 researchers will be needed as part of its target to raise the proportion of GDP devoted to R&D in the European Research Area to 3% by 2010 (Communication adopted on 18 January 2000 called *Towards a European Research Area.)*

researchers between countries and is also known as **international mobility**; and **intersectorial mobility** is the movement of researchers between industry and academia, and between the private and public sectors. Åkerblom (2001) defined the international mobility of highly skilled people as "people employed in year t who go abroad either temporarily or permanently for employment purposes; and people employed in year t coming from abroad" (p. 57). International mobility includes short-term overseas visits, long-terms stays, and permanent stays (Mahroum, 1999). Managers and executives, engineers and technicians, academics and scientists, entrepreneurs, and students were found to be the main highly skilled groups (Mahroum, 1999).

After reviewing available literature on the migration of highly skilled people, Salt (1997) identified two key concepts. The first is the concept of **brain exchange** or the "two-way flow of expertise between origin and destination" (p. 5). The terms of **brain gain** and **brain drain** are used when the net flow is heavily in one direction. **Brain circulation** occurs when researchers return to their home country bringing back knowledge and capacities acquired from abroad, which may dampen or even reverse the negative effects of brain drain (Cervantes, 2004). The second concept, which is also related to the attractiveness and availability of research careers, is **brain waste** whereby highly skilled workers are deskilled when they migrate into employment where they don't use their skills and experience. It should be noted that not all research graduates who pursue careers outside of the HRST workforce are necessarily working at a lower skill level and may in fact be contributing to their national innovation system in a different way. The above concepts are presented in Figure 27 as flows in and out of S&T occupations or the HRST stock.

Figure 27: Main flows in and out of S&T occupations



Source: Auriol and Sexton (2002) p. 25

Mahroum (1999) believes that the inflows and outflows of highly skilled people can be significantly affected by the nature and structure of national innovation systems. He found that foreign scientists and research students are usually attracted to national innovation systems that revolve around universities that undertake cutting-edge national activities in science and technology or where science and technology is largely situated in industrial research or large public research organisations. Stanford University in California and MIT in Massachusetts are examples of powerful centres of excellence having a global attractiveness to researchers. More recently, Mahroum (2001) argued that "from the perspective of science and innovation policy, country specificities in national innovation systems should be taken into consideration in investigating issues of international mobility, brain drain and circulation" (p. 220).

5.3 The importance of international mobility and migration

The STRATA-ETAN Expert Working Group (2002)[21] found that the international mobility of scientists can substantially impact on countries' performance in the field of science and technology, and therefore growth. Nås et al. (1998) argued that the circulation of knowledge is crucial to national economies generating and adopting new technologies effectively. The mobility of highly skilled people is a key vehicle for knowledge flows[22], representing knowledge transfer and a common knowledge base between two NIS institutions. The higher education sector and R&D sector are important NIS institutions that enable knowledge flows. Mobility also helps researchers to keep up-to-date with developments in their field, and can lead to new fields of knowledge when researchers from different disciplines work together (OECD, 2002b). Cervantes (2004) identified stimulating innovation capacity, increasing the stock of available human capital, and internationally disseminating knowledge as key net positive effects of international mobility. Guellec and Cervantes (2002) identified the possible positive and negative impacts of international migration of highly skilled workers on countries as well as the possible global effects (Table 13), providing an insight into why countries want to improve their international mobility efforts.

Table 13: Possible economic effects of international migration of highly skilled workers

Sending countries: possible positive effects	Receiving countries: possible positive effects
Science and technology: ➢ Knowledge flows and collaboration, return of natives with foreign education and human capital, increased ties to foreign research institutes ➢ Export opportunities for technology ➢ Remittances and venture capital from diaspora networks ➢ Successful overseas entrepreneurs bring valuable management experience and access to global networks *Human capital effects:* ➢ Increased incentive for natives to seek higher skills ➢ Possibility of exporting skills reduces risks/raises expected return from personal education investments ➢ May increase domestic economic return to skills	*Science and technology:* ➢ Increased R&D and economic activity due to availability of additional highly skilled workers ➢ Entrepreneurs in high growth areas ➢ Knowledge flows and collaboration with sending countries ➢ Immigrants can foster diversity and creativity ➢ Export opportunities in technology *Higher education systems:* ➢ Increased enrolment in graduate programs/keeping smaller programs alive ➢ Offset ageing of university professors and researchers *Labour market:* ➢ Wage moderation in high growth sectors with labour shortages ➢ Immigrant entrepreneurs foster firm and job creation ➢ Immigrants can act as magnets for accessing other immigrant labour (network hiring effects)
Sending countries: possible negative effects	**Receiving countries: possible negative effects**
Human capital effects: ➢ *Brain drain* and lost productive capacity due to (at least temporary) absence of higher skilled workers and students ➢ Lower returns from public investment in tertiary education (waste of national public resources)	*Higher education systems:* ➢ Decreased incentive of natives to seek higher skills in certain fields, may crowd out native students from best schools *Science and technology:* ➢ Technology transfer to foreign competitors and possible hostile countries
Possible global effects	
➢ Better international flows of knowledge, formation of international research/technology clusters e.g. Silicon Valley, CERN. ➢ Better job matches, including greater employment options for workers, researcher's ability to seek the work most interesting to them, and greater ability of employers to find rare/unique skills sets. ➢ International competition for scarce human capital may have net positive effect on incentives for individual human capital investments.	

Source: Guellec and Cervantes (2002) p. 86

[21] The European Commission established the group in 2001 to examine human resources in research and technical development.

[22] Other knowledge transfer mechanisms include co-operations, temporary exchanges and placements of staff, various types of networks, buyer-supplier relationships, R&D collaborations etc. There are other applicable indicators such as co-authorships, co-citations, co-patenting, number of external contracts and co-operations, branch specific common activities etc (Nås et al, 1998).

Any loss of research talent in key research fields to foreign countries is of concern to sending countries as they have lost their investment in human capital. Foreign students who do not return to their home country after their studies also represent *brain drain*. The STRATA-ETAN Expert Working Group (2002) believed that such losses would impact on competitiveness of the European Union in the knowledge-based economy. Returning migrants and networks that facilitate skilled worker circulation between sending and receiving countries can offset any loss of human capital (OECD, 2002b). Similarly, home countries benefit from students who train and then work abroad when they return home and transfer knowledge to their home country – also an example of *brain circulation* (Mahroum, 1999). However, Cervantes (2004) argues that a strong out-migration of research staff could lead to an underinvestment in education among nationals and have severe impacts on the R&D and wider innovation system. Therefore, countries must invest in science and technology infrastructure and develop their own opportunities for teaching, research and entrepreneurship.

5.4 Drivers and obstacles

Countries with internationalised higher education and research systems/environments that are conducive to entrepreneurship, innovation and financial opportunity (such as the United States) tend to attract a greater pool of foreign research talent in science and technology. Nås et al. (1998) found that social and cultural forces, political initiatives, economic cycles, and magnetic effects like attractive regions also impact on mobility. In the case of academics and scientists, institutions with a reputation for scientific openness, excellent quality and prestige in excelling in research are key factors (Mahroum, 1999). These **drivers of researcher mobility** are very similar to those identified by the OECD (2002e, p. 240):

- Economic opportunities abroad are better than those at home, especially when there are insufficient job opportunities for S&T graduates due to low business R&D spending and few job openings in the public sector.
- Migration policies in destination countries i.e. the propensity to migrate and choice of destination.
- Non-economic factors, such as host country conditions for excellence in teaching and research – an opportunity to enhance a scientist's prestige and reputation.
- Climate for business start-ups, self-employment, and presence of innovative high-technology industry and centres of excellence.

Government immigration policy can respond to market shortages, increase the stock of human capital, and encourage knowledge circulation embodied in highly skilled people as a means of promoting innovation (OECD, 2002e). As a result, the OECD (2002e) called for the coordination of science and innovation policies with migration policies to enhance the attractiveness of receiving countries, and to develop a scientific, technological and business environment that encourages highly skilled people to stay in their home countries or to return from abroad. Cervantes (2004) believes that migration policies must differentiate between the different types of highly skilled migrants who respond to different incentives.

For example, researchers and academics may be influenced to migrate due to factors such as support for research, demand for R&D staff, and desire to work in global centres of excellence. The innovation climate, in particular business start-ups and self employment, may be drivers for entrepreneurs. Students are usually influenced by the quality of the education system and job opportunities after they graduate. These are examples of **pull factors** that act as incentives for international migration. In some cases, people are **pushed** to leave their home country because of a lack of opportunities and poor working conditions for researchers and a lack of capital for entrepreneurs. Mahroum (1999) argued that push and pull factors influence the volume, frequency, length and direction of mobility in various channels.

The High-Level Expert Group on Improving Mobility of Researchers (2001) identified the main **obstacles** to international mobility of researchers in Europe within the categories of general; legal and administrative; social, cultural and practical; and obstacles to a European dimension in research careers (Table 14). The impact of these obstacles on researchers was found to be dependent on the length of stay and the stage of the career of the researcher, with mid-career researchers in medium-term stays facing the most obstacles.

Table 14: Obstacles to the international mobility of researchers in Europe

General	➢ Lack of comprehensive statistics about mobility of researchers. ➢ Women researchers face more serious obstacles than male researchers, such as maternity leave.
Legal and administrative	➢ Immigration restrictions and regulations for third country researchers (i.e. no EU citizens) and their families, even for short visits. ➢ Different social security systems and levels of taxation. ➢ Mobile persons having to pay contributions for benefits they cannot enjoy nor receive compensation for, such as unemployment insurance. ➢ Missing bilateral taxation agreements in some EU countries and outside the EU, introducing a risk of double taxation and double taxation of pensions.
Social, cultural and practical	➢ Lack of one-stop information sources about rules, regulations, funding opportunities, and vacancies for researchers and administrators dealing with mobile researchers. ➢ Lack of personal assistance for researchers with legal and practical problems. ➢ Lack of knowledge of the local language which may hamper social integration and cause difficulties in everyday life. ➢ For researchers with families, barriers of the partner's careers, children's education or daycare, suitable accommodation and obligations in home country such as mortgage payments and care of elderly parents.
Obstacles to a European dimension in research careers	➢ Danger of shortage of young researchers in the future as a scientific career is not perceived as attractive. ➢ Researchers who have been away from their national research system for some years often have difficulties in obtaining a position upon return. ➢ For researchers with permanent positions, longer stays abroad may be a disadvantage for careers at home if mobility is not recognised for seniority accreditation and/or career advancement. ➢ Intellectual value of a research period abroad is often insufficiently recognised. ➢ Inadequate funding hampers mobility i.e. too few positions or fellowships or too little research project funding. Very little funding is available to specifically encourage mobility at mid-career and senior researcher levels. ➢ Age limits in some mobility schemes may limit possibilities for mobility, especially at the later stages in the career and for women researchers on maternity leave. ➢ Researchers from outside the country may have difficulties to compete with researchers already in the country for research funding or positions due to limited advertising, nationally or locally orientated decision procedures, excessively strict language requirements, and preference for local candidates. ➢ Non-recognition of qualifications i.e. training obtained is insufficient and further training has to be undertaken.

Source: High-Level Expert Group on Improving Mobility of Researchers (2001)

As the literature tends to focus on migration in the academic sector and brain drain, Salt (1997) argued that there is a need to examine **migration associated with the acquisition of tertiary education** for a number of reasons. Firstly, the international movement of students represents the internationalisation of knowledge and is the most effective vehicle for creating a global migratory elite. Secondly, the provision of tertiary education internationally is a major business, providing a source of income to destination countries and establishing links. Thirdly, foreign students (especially postgraduates) who remain in the receiving country are a relatively cheap source of skills. Fourthly, the volume of international student migration is enormous. Tremblay (2002) suggested that student migration, where students become increasingly well qualified through their studies, is a kind of HRST migration when they join the workforce and contribute to the host country's production. This combination of student and HRST migration is particularly the case for research students studying at ISCED level 6 who are participating in R&D activities in another country through their dissertation.

With over 80% of international students based in five countries[23], the STRATA-ETAN Expert Working Group (2002) sought to identify factors that influence **student mobility**. Those factors identified included: larger country populations with greater diversity of educational systems and fields of study seem to reduce outward mobility; linguistic proximity/language used in the education system; institutional proximity supported by policies on freedom of movement, recognition of degrees, existence of exchange programs, and geographical and cultural ties; geographical remoteness which acts as a brake on inward mobility; and economic considerations such as tuition fees, costs of living and salary rewards (p. 40). Mahroum (1999) found growing evidence that foreign postgraduate students are mainly influenced by the quality of higher education institutions and opportunities in the host country that exist after their training.

In 1998, the Italian National Research Council (CNR) surveyed doctoral students and coordinators from six Italian universities who had participated (and not participated) in an international mobility experience between 1995 and 1997. The choice of overseas destination was largely based on the type of research being carried out (with preference given to foreign universities with academic excellence and prestige) and the web of personal relations established by the student (Avveduto, 2001). In the majority of cases, it was easier for students to choose a university which had a tradition of research with their home university i.e. alma mater. Most students preferred to go abroad during the second year of their study as this is the point when they have finished any coursework and developed a program of research. The optimal duration of time for many respondents was six months. The period away was regarded by some as a consolidation of an established piece of research work and by others as part of an ongoing study and research activity. The preferred destinations of the PhD students were the United States (33.5%), United Kingdom (22.6%), France (18.5%), and Germany (11%).

[23] Tremblay (2002) in STRATA-ETAN (2002) found that over 80% of inflows of international students are to five countries – United States (34%), the United Kingdom (16%), Germany (13%), France (11%) and Australia (8%).

Avveduto (2001) found that the benefits of a study period abroad fell into two categories. The first category related to a new scientific and cultural context which resulted in a broader professional and human experience, and therefore improved competence. This category also included the capacity to cope with new situations, acquisition of greater flexibility and tolerance towards others, and willingness to accept mobility. The second category was training-related benefits such as the opportunity to learn new research methodologies and gain familiarity with avant-garde techniques and instruments. Although many of those surveyed did not experience problems whilst studying abroad, for those that did language was a major barrier, and to a significantly lesser extent, cultural differences, different teaching methods and accommodation were issues. For those PhD students who were unable to study abroad, the main obstacles were insufficient funds, personal commitments (family/work), lack of information, lack of time, and inadequate knowledge of the scientific opportunities abroad. In terms of the impact of the study abroad experience on their employment, over half of the students surveyed believed it would be easier to find work as they have a wider labour market, both in content and geographically. However, one third of students surveyed believed that they could miss out on local opportunities if the absence was long. Avveduto (2001) concluded by stressing the key role that universities play in international mobility:

> The universities can play a key role in fostering international mobility. Their primary aim should be to help students cover the expenses incurred during the study period and to ensure that information is disseminated widely throughout the university community. International experience is highly relevant to research training, and universities and research institutions must ensure that the opportunity to partake in such projects is open to all PhDs and will not turn out to be an illusion for the vast majority. (p. 240)

5.5 Measures/indicators of mobility

Mobility or movement indicators are useful in mapping important linkages in innovation systems and evaluating the effects of different policy measures (Nås et al., 1998). The OECD and Eurostat developed the Canberra Manual to measure human resources in science and technology (as discussed in Section 3.5). The *OECD International Conference on New Science and Technology Indicators for the Knowledge-based Economy* held in June 1996 focussed on the lack of specialist studies and data on the mobility of highly skilled people. To be able to compare national and international mobility data, there was a call for an overall unified approach that tracks the original nationality of scientists, their field of scientific specialisation, and reasons as to why they moved. Similarly, Åkerblom (2001) recommended that indicators on international mobility be broken down by qualification (field and study) and/or occupation and country of origin/destination; together with indicators of flows to address issues of brain drain, brain gain and brain circulation. Such data is regarded as important for four reasons (Rosengren, 1998, p.4):

- Human mobility is a proxy for knowledge flows, especially when it concerns the highly educated.
- Mobility indicators would help to evaluate effects of different policy measures in the areas of education, research, labour market, regional development etc.

- Indicators involving human resources, particularly in natural sciences and engineering, complement traditional R&D statistics.

- Stock data on human capital becomes more meaningful if inflows and outflows can be measured, such as the effects of educational specialisation.

Despite work by the OECD and Eurostat to develop a system of stocks and flows of HRST and the 1998 Nordic study about the possibilities of using register-based statistical systems to measure mobility, international comparable indicators on the mobility of highly skilled people were still limited in 2002: "In general, the information available on students', but especially researchers' and other migrants' lengths of stay, emigration flows, return rates and alternate forms of mobility is patchy and inadequate" (STRATA-ETAN Expert Working Group, 2002, p. 39). Åkerblom (2001) believed it is unlikely that international comparable flow indicators would be available in the near future. Despite these data limitations, Salt (1997) found that although the volume of migration of highly skilled people and their dependents is small compared to total international migration (excluding asylum seekers), stocks of highly skilled foreign workers are nevertheless considerable and growing, and flows of highly skilled workers are increasing at a fast rate. Table 15 contains examples of available proxy indicators of international mobility and migration for Australia, Finland and the United States.

Table 15: Proxy indicators of international mobility and migration

	Australia	Finland	United States
Foreign students as a percentage of all students, 2002	17.7%	2.2%	3.7%
Student exchange: net intake of foreign students from other reporting countries (% of tertiary enrolments), 2002	8.1%	-2.3%	1.6%
Foreign PhD students as a percentage of total PhD enrolments	24% (2002)	6.4% (2002)	26.3% (2001)
Total net movement of S&T professionals, 1995/1996 to 2002/2003	38,119	n.a.	n.a.
Net loss of domestic residents with a PhD attained between 1996 and 2001	700	n.a.	n.a.
Permanents visa issued to immigrant in S&T occupations, 2001	n.a.	n.a.	33,900
Temporary entry of foreign students (F-1), scholars (J-1) and skilled workers (H-1B)	n.a.	n.a.	606,514
Stay rates of foreign PhD graduates in S&T, 1998-2001	n.a.	n.a.	54.1%
Stay rates of foreign PhD students and researchers, 2004 (sample only)	n.a.	47.6%	n.a.
Foreign-born U.S. residents with S&E doctorates, 1999	n.a.	n.a.	192,000

Source: OECD (2004a), OECD (2004b), Birrell et al. (2004) and National Science Board (2004)

5.6 Mobility programs and performance

5.6.1 Australia

The Commonwealth Government has a history of supporting programs that encourage the international mobility of research students and graduates. In the early 1990s, specific initiatives included the Overseas Postgraduate Research Scheme, International Reciprocal Fellowship Program, and internationally collaborative research projects funded by the Australian Research Council. These programs still exist today in some form or another. Key mobility programs are currently funded by Commonwealth Government through the Australian Research Council (as part of Linkage International), the Department of Education, Science and Training (as part of the Endeavour Programme), and in partnership with other organisations.

The final report of the National Innovation Summit Implementation Group, *Innovation: Unlocking the Future,* released in August 2000 recommended that Australia builds its competitiveness through knowledge of, and access to overseas science and technologies. This recommendation included ensuring the accessibility of technology developed in Australia and overseas, research and business mobility and exchanges, and science and technology agreements with other nations. One of the outcomes was the establishment of **Linkage International,** replacing the International Researcher Exchange Scheme (IREX)[24]. Since 2002, the program has funds two grant types: Fellowships under international agreements for the reciprocal exchange of postdoctoral and senior researchers from Germany, France and South Korea; and awards to build links between research centres of excellence in Australia and overseas by funding extended collaborations. From 2005, Linkage International included a new cooperative program between the ARC and the U.S. National Science Foundation (NSF) to help stimulate enhanced collaborations among materials science researchers and create networks linking individuals and centres in Australia and the United States. Despite the above initiatives, the number of international research fellowships and awards available to postdoctoral researchers has declined after peaking in 2000. The Australian Research Council funded 11 fellowships and 39 awards in 2004 at a cost of $1.6 million, compared to 18 fellowships and 89 awards at a cost of $2.5 million in 2000 (Table 16).

Table 16: Number and value of international fellowships and awards, Australia 1999 to 2004

International Researcher Exchange Scheme (IREX)				Linkage International Program		
	1999	2000	2001	2002	2003	2004
Fellowships	15	19	17	12	16	11
Awards	28	89	86	54	24	39
Funding $million	n/a	$2.5	$2.1	$1.5	$1.5	$1.6

Source: Australian Research Council (2001), (2003) and (2005a)

In May 2003, Dr Brendan Nelson announced a four year $113 million package of Commonwealth initiatives for the international education industry (Nelson, 2003d). The package included funding of $7.9 million for the **Endeavour Programme** that includes scholarships and fellowships to attract high performing students from around the world to Australia. Table A14 in the appendix contains the new and existing postgraduate and postdoctoral awards offered within the Endeavour Programme. Over 400 awards will be offered in 2006, with the long standing **International Postgraduate Research Scholarships (IPRS)** scheme accounting for 330 of these awards. Whereas most of the fellowships and scholarships in the Endeavour Programme aim to attract overseas research students and graduates to Australia, the Commonwealth Government also contributes funding to major awards that enable Australians to undertake research overseas. For example, the Commonwealth Government contributed $4.8 million between 2004 and 2009 to the General Sir John Monash Postgraduate Awards and $550,000 a year to the Fullbright awards through the Australian-American Fullbright Commission. In 2005, eight postgraduate students were awarded the General Sir John Monash Award and 19 Australians received an

[24] In 1999, the Commonwealth Government replaced the International Reciprocal Fellowships Program with the International Researcher Exchange Scheme (IREX). This scheme is similar to Linkage International as it funded the movement of researchers between Australian research institutions and centres of research excellence overseas. The scheme also consisted of bi-national agreements for reciprocal exchange of postdoctoral and senior researchers (i.e. France, Germany, South Korea and the United Kingdom) as well as awards to build links between researchers.

Australian Fullbright Scholarship to undertake research in the United States. In addition, 20 Americans received a U.S. Fullbright Scholarships in 2005 to undertake research in Australia. There are many other scholarships and awards funded by State and Territory governments in Australia, students' home country governments, Australian education institutions, and private organisations that enable Australian research students and graduates to undertake research overseas and for overseas research students and graduates to do the same in Australia. For example, each year the Australian Academy of Science awards several travelling fellowships. Victoria Fellowships are an initiative of the Victorian Government providing travel grants of up to $18,000 for early career researchers.

Information about such opportunities is available from different sources. SPIN-Australia is a database that provides information on research funding opportunities in Australia and overseas. The Joint Academic Scholarship Online Network (JASON) is a search engine for postgraduate scholarships. The Commonwealth Government recently launched the **Science Portal** at www.science.gov.au to provide information to the research community, investors and industry, including research grants and programs. IDP Education Australia (2005) provides international education and development services in 27 countries, and this role includes providing information about postgraduate research scholarship opportunities. IDP Education Australia's website states that "the majority of international students in Australia are full-fee paying students not covered by any scholarship. Prospective students should be aware that the number of scholarships available for international students is limited and the competition is intense".

The analysis of the international mobility of research students and graduates for Australia is based on data from two sources: Research degree enrolments and completions by overseas students compiled by the Department of Education, Science and Training (DEST) as part of its higher education statistics collection; and migration data on the movement of S&T professionals and the estimated movement of people who attained a PhD between 1996 and 2001 contained within *Skilled Movement in the New Century: Outcomes for Australia* by Birrell, Rapson, Dobson, and Smith.(2004). Migration data on the movement of S&T professionals does not include detailed data on the qualifications of people, making it difficult to analyse the movement of highly skilled people with PhDs.

Research degree enrolments of overseas students rose consistently between 1988 and 2004 (Figure 28). There were 7,695 overseas students enrolled in a research degree in Australia in 2004, which represented 16.3% of all research degree enrolments. Many students were from the Asian countries of China, Hong Kong, Singapore, India and Indonesia. There has also been an increase in research degree completions by overseas students, rising from 894 in 1994 to 1,050 in 2003 (Figure 29), which represents 16.6% of all completions in 2003. As a proportion of all overseas students enrolled in higher education institutions, overseas research students accounted for 3.4% in 2004 compared to 14.8% in 1988 (Figure 30). Growth in research degree enrolments by overseas students has been significantly lower than growth in enrolments by overseas students in lower degrees. Compared to domestic students, overseas students are more likely to enrol in a Doctorate by Research (83.6% compared to 78.9% for domestic students) and an S&T research degree (39.4% compared to 30.8% for domestic students), and undertake their studies in the field of engineering and related technologies (17.5% compared to 9.9% for domestic students).

Figure 28: Enrolments of overseas research students, Australia 1990 to 2004

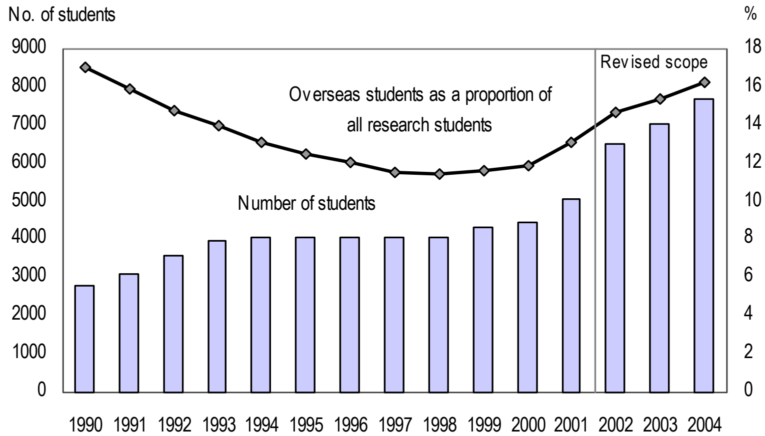


Figure 29: Completions of overseas and domestic research students, Australia 1994 to 2004

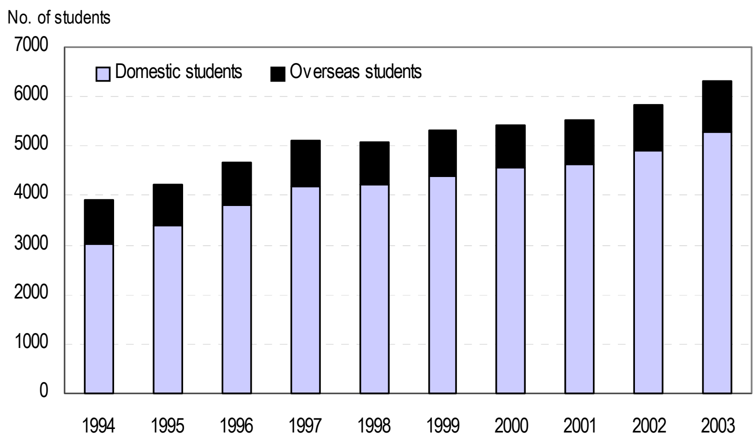
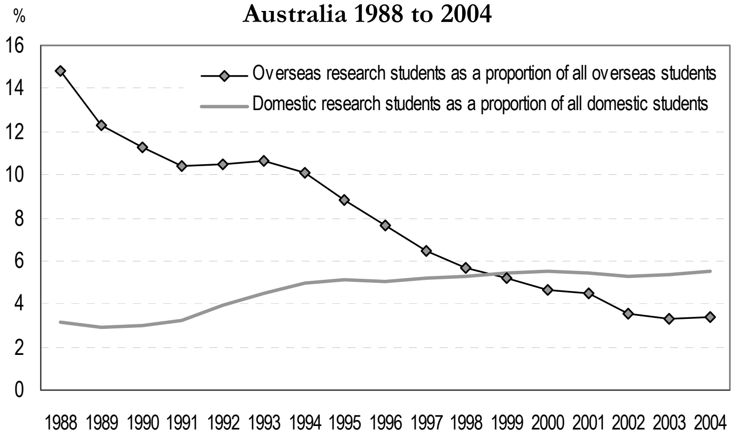


Figure 30: Overseas and domestic students as a proportion of research students, Australia 1988 to 2004



Source: Department of Education, Science and Training (2005a), Figures 32 to 34

Table 17 shows three streams of **international movements of S&T professionals** from 1995/1996 to 2002/2003: Permanent residents of Australia whether Australian or overseas born; settlers who arrive in Australia for the first time, hold a permanent resident visa and indicate that they possess an occupation; and visitors who hold temporary resident visas with work rights in Australia and intend to stay for one year or more. Australia experienced increasing net losses of residents in S&T occupations until recently. Over this eight year period 35,268 residents left Australia and 23,116 residents returned, resulting in a net loss of 12,152 people in S&T occupations. Birrell et al. (2004) found that Australian residents who go overseas and return home, spend on average two years overseas.

Table 17: International movement of S&T professionals, Australia 1995/1996 to 2002/2003

	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	8 year totals
S&T residents departing									
Scientists	712	769	1,386	1,521	1,529	1,757	1,685	1,447	10,806
Engineers	796	875	1,421	712	512	489	369	291	5,465
Computing professionals	1,488	1,940	2,369	2,814	2,193	2,446	3,040	2,707	18,997
Total S&T departing	**2,996**	**3,584**	**5,176**	**5,047**	**4,234**	**4,692**	**5,094**	**4,445**	**35,268**
S&T residents returning									
Scientists	523	543	892	752	872	979	901	975	6,437
Engineers	660	638	999	358	344	295	328	391	4,013
Computing professionals	1,195	1,360	1,676	1,250	1,377	1,284	2,009	2,515	12,666
Total S&T returning	**2,378**	**2,541**	**3,567**	**2,360**	**2,593**	**2,558**	**3,238**	**3,881**	**23,116**
Net S&T residents									
Scientists	-189	-226	-494	-769	-657	-778	-784	-472	-4,369
Engineers	-136	-237	-422	-354	-168	-194	-41	100	-1,452
Computing professionals	-293	-580	-693	-1,564	-816	-1,162	-1,031	-192	-6,331
Total S&T net residents	**-618**	**-1043**	**-1609**	**-2,687**	**-1,641**	**-2,134**	**-1,856**	**-564**	**-12,152**
S&T settler arrivals									
Scientists	908	809	705	779	937	808	583	629	6,158
Engineers	1,333	1,144	1,190	1,221	1,327	1,365	1,055	1,079	9,714
Computing professionals	1,183	1,288	1,248	1,430	1,778	3,705	4,661	3,338	18,631
Total S&T settler arrivals	**3,424**	**3,241**	**3,143**	**3,430**	**4,042**	**5,878**	**6,299**	**5,046**	**34,503**
Net S&T visitors									
Scientists	144	263	206	635	454	519	495	486	3,202
Engineers	237	270	620	611	525	582	574	530	3,949
Computing professionals	362	337	570	1,533	1,325	1,514	1,433	1,543	8,617
Total S&T net visitors	**743**	**870**	**1396**	**2,779**	**2,304**	**2,615**	**2,502**	**2,559**	**15,768**
Net S&T movement									
Scientists	863	846	417	645	734	549	294	643	4,991
Engineers	1,434	1,177	1,388	1,478	1,684	1,753	1,588	1,709	12,211
Computing professionals	1,252	1,045	1,125	1,399	2,287	4,057	5,063	4,689	20,917
Total S&T net movement	**3,549**	**3,068**	**2,930**	**3,522**	**4,705**	**6,359**	**6,945**	**7,041**	**38,119**

Source: Birrell et al. (2004) pp. 17-18

The net loss of Australian residents in S&T occupations was offset by continuing increases in settlers and visitors in S&T occupations. Between 1995/1996 and 2002/2003, there were 34,503 settlers and 15,768 visitors. As a result, Australia recorded a net movement (or gain) of people in S&T occupations of 38,119. Birrell et al. (2004) found this overall net gain to be understated as it does not include the onshore factor of people who applied for permanent residence while on some other visa category in Australia. These people include temporary workers and working holiday makers who successfully applied for permanent residence under the Employment Nomination Scheme, and overseas students who completed certain courses in Australia and successfully applied for skill migration visas without leaving Australia. Over the two year period ending 2002/2003, skilled visas were issued to 136 medical scientists, 709 engineers, and 6,501 computing professionals.

Birrell et al. (2004) used PhD completions data from DEST and 2001 census data on PhD holders from the Australia Bureau of Statistics[25] to investigate the **movement of people with a PhD** in response to concerns that Australia had experienced losses of highly qualified residents i.e. those with a PhD. Because of data limitations they were only able to analyse movements of recently qualified PhDs. Birrell et al. (2004) found that Australia experienced a very small loss of residents of 700 people who were awarded a PhD in Australia between 1996 and 2001. This loss was offset by the inflow of 1,710 PhD qualified migrants and 480 PhD qualified Australians returning from overseas. As a result, they estimated a gain of 1,730 PhD qualified people over this period (Table 18). Birrell et al. (2004) partly attributed this gain to the substantial expansion in the number of research positions in Australian universities over the 1990s. By field, there were overall net losses in education (260 people), management & commerce (240 people) and IT & engineering (220 people); and net gains in science & health (1,420 people) and arts & design (1,060 people).

Table 18: International movement of PhDs attained between 1996 and 2001, Australia

		Science & Health	IT & engineering	Education	Management & Commerce	Arts & Design	Total
A	DEST domestic student completions	7,840	2,200	1,200	940	3,840	16,020
B	Reported in 2001 that they lived in Australia 1996	7,510	1,580	860	610	4,280	14,840
C	Difference (potential loss/gain) (A-B)	-330	-620	-340	-330	440	-1,180
D	Australian residents returning to complete Australian PhD	260	50	20	10	140	480
E	Estimate of domestic PhD students remaining in Australia (B+D)	7,770	1,630	880	620	4,420	15,320
F	Revised loss/gain domestic students (C+D)	-70	-570	-320	-320	580	-700
G	Migrants who were overseas students	120	60	10	10	50	240
H	Migrants bringing overseas qualification	1,110	240	30	60	290	1,710
I	Estimate of Australian residents returning with overseas PhD	260	50	20	10	140	480
J	Gains from sources other than domestic completions	1,490	350	60	80	480	2,430
	Overall loss/gain	**1,420**	**-220**	**-260**	**-240**	**1,060**	**1,730**

Source: Birrell et al. (2004) p. 45

[25] Data gathered in the 2001 census on educational activity was based on the new Australian Standard Classification of Education (ASCED) developed by the Australian Bureau of Statistics (ABS). ASCED replaced the Australian Bureau of Statistics Classification of Qualifications, and includes two component classifications: Level of Education and Field of Education. Within the broad postgraduate degree level, Doctorates by Research and Master's by Research are regarded as detailed levels within the narrow levels of Doctoral degree level and Master's degree level, respectively (ABS, 2001).

Birrell et al. (2004) argued that the movement of Australian residents abroad was largely due to the long-standing keenness of young Australians to see the world. They also believed that departing residents may be *pulled* by higher material rewards and research opportunities (particularly in the case of highly trained people in science and technology) to first world countries, such as the UK which has historical ties to Australia; and *pushed* because of scarce jobs in some scientific fields in Australia. Birrell et al. (2004) disputed the lack of research opportunities in Australia because of the increasing numbers of researchers in higher education. Expansion of the skilled migration program, the ability of graduating overseas students to apply for permanent residence without leaving Australia, fewer restrictions on temporary entry work visas, and demand for certain occupations such as computing professionals were regarded as major *pull* factors that contributed to increases in settler inflow and temporary residents in Australia from the late 1990s. Birrell et al. (2004) attributed the slowdown in movements in 2002/03 to security scares following on from 11 September 2001 and the Bali bombing in October 2002.

Three other major studies examining Australia's performance in international mobility support many of findings by Birrell et al. (2004) and highlight other issues. The main focus of the report by Wood and Boardman on *International Networks and the Competitiveness of Australia's Science and Technology* (February 1999) was the availability of opportunities for early career researchers in the sciences to obtain overseas research training and career development. Their findings were presented within a framework where knowledge is central to economic growth and international competitiveness. They regard Australia as having a well developed but relatively small science base. Australia must be able to access global networks, leading researchers and latest developments in knowledge to ensure research and research training at international standards and the visibility of its research and researchers. These activities usually occur because of personal networks that are supported by various governmental and non-governmental structures. As such, they believe that young researchers should have the opportunity to spend a sufficient amount of time in postdoctoral training and career development overseas (including the world's leading research laboratories) to allow them to establish and bring back networks and linkages.

Wood and Boardman (1999) identified a number of **obstacles** to the international mobility of young researchers. Funding opportunities that support international linkages and access to major overseas facilities were limited, short term in nature, varied substantially between fields, highly competitive (forcing young scientists to compete with established researchers for funds), and inadequately funded (i.e. not accounting for the full range of relocation and living costs). They were also concerned about limited funding for young scientists (particularly PhD students) to participate in overseas conferences; conditions under which Australian scientists could participate in European Union framework programs; and the ability of universities to adequately inform staff students about funding opportunities especially given the many sources of information. Possible obstacles or disincentives to attracting high calibre international researchers to Australia included the distance of Australia from the world's leading research centres, visa application procedures, taxation issues, perceived quality by leading overseas researchers of the facilities and equipment at Australian universities and research institutions, and the Australian dollar combined with the high cost of living and working in industrialised countries.

A Legal and Constitutional References Committee was formed by the Australian Senate in October 2003 to examine the experience of Australia expatriates. The Committee stated in their final report, *They still call Australia home: Inquiry into Australian expatriates*, released in March 2005 that they were concerned about the brain drain of Australia's best and brightest workers on the one hand and evidence of net brain gain of skilled workers on the other hand. Their report referred to a survey by Hugo, Rudd and Harris (2003) which identified pull factors of better employment opportunities, professional development and higher income as the prime motivations for emigration (Table A15 in the appendix). Of the 2,072 people who responded to the survey, almost 50% stated that they were not intending to return to Australia or were undecided. Hugo et al. (2003) found that older respondents and those from the United States and Canada were less likely to return. Key reasons given by those not intending to return or who were undecided were better employment opportunities, established in current location, career and promotional opportunities, and higher income. Marriage/partnership was the key reason given by females for not returning. Respondents were more likely to return home if offered a better job or salary, or for family reasons.

Some of the push and pull factors given by academic researchers in their submissions to the Committee included the opportunity to work in leading overseas research establishments, with the top professionals in the field and significantly superior infrastructure support; few openings in their chosen fields in Australia and that overseas offered their only genuine employment opportunities; the need for overseas experience to pave the way for career advancement; the challenge of testing their abilities in a complex working environment in a different culture; scale of opportunities awaiting abroad; the proximity to other vibrant economies; tax rates in Australia that are too high and not internationally uncompetitive; and the perception that their intellectual endeavour was undervalued.

5.6.2 Finland

Key researcher mobility programs funded by the Academy of Finland and other Finnish and international organisations are summarised in Table A16 in the appendix. The **Academy of Finland** supports international mobility through grants to Finnish research students and postdoctoral agreements, participation of Finnish students in research training at the European University Institute, bilateral agreements for research cooperation and researcher mobility with 38 partners in 26 countries, grants for foreign researchers to work in universities or research institutes in Finland, and subsidies for Finnish researchers to return home. A large number of scholarships to Finnish and foreign research students and graduates are funded by the **Centre for International Mobility (CIMO)**. Foundations, Nordic organisations, and many other European and international organisations also provide funding to support the international mobility of researchers. Finland has recently established the **European Researcher's Mobility Portal Finland** at www.aka.fi/eracareers, a joint initiative with the European Union. The site is linked to the European portal and provides researchers with information about research and job opportunities in Finland as well as advice about practical, legal and administration matters.

Data on the movement of research students and graduates to and from Finland is collected by KOTA Online, the Academy of Finland and CIMO. The Academy provided funding of 1.7 million euros in 2004 as part of bilateral agreements which attracted 464 foreigner researchers to Finland and 175 Finnish researchers to work abroad. In 2004, CIMO provided 1,082 grants to postgraduate students including 704 foreign postgraduate students coming to Finland mainly from Russia, Hungary and Estonia (Finnish Science and Technology Service, 2005).

The number of visits to Finland by **foreign researchers** (Figure 31) has continued to exceed the number of overseas visits by **Finnish teachers and researchers** (Figure 32). In 2004, a total of 1,739 foreign researchers visited Finland (1,060 stayed for over one month and 679 stayed for less than one month) and 1,291 teachers and researchers from Finnish universities made overseas visits (633 stayed for over one month and 658 stayed for less than one month). Finnish teachers and researchers visited for an average of four months (compared to 5.1 months in 1994) and foreign researchers visited for an average of 5.2 months (compared to 4.7 months in 1994). Figure 31 and Figure 32 show a declining trend in inward and outward movements, particularly in the case of overseas visits by Finnish university teachers and researchers.

Figure 31: Visits to Finland by foreign researchers, 1994 to 2004

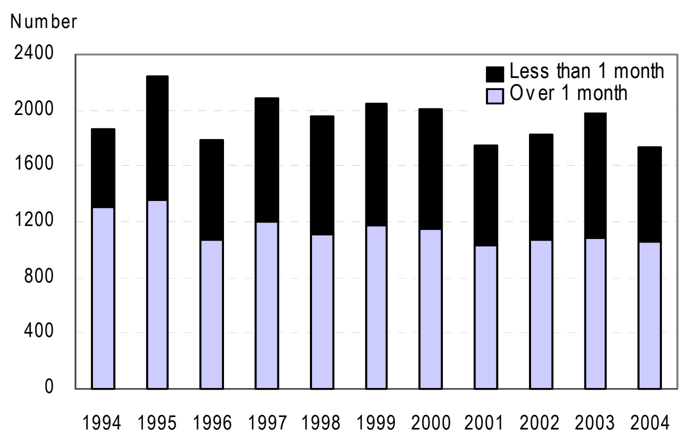
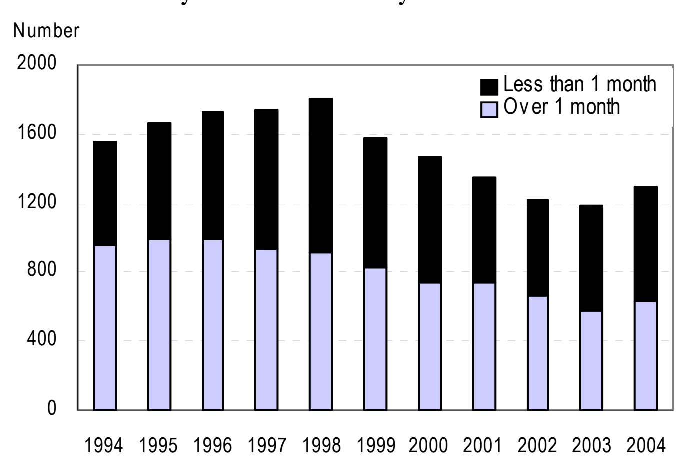
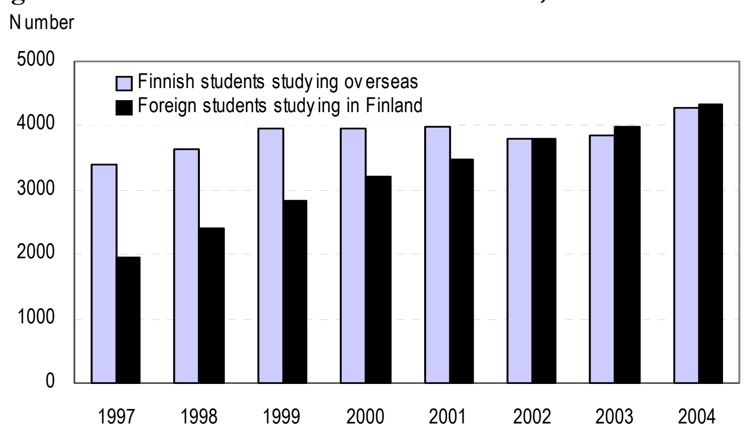


Figure 32: Overseas visits by Finnish university teachers and researchers, 1994 to 2004



The number of **foreign students** studying in Finland has increased significantly. In 2004, there were more foreign students in Finland than Finnish students abroad (Figure 33). Although foreign students continue to account for a small share of all tertiary students in Finland, data from Eurostat shows their share has increased from 1.73% in 1998 to 2.38% in 2002. In 2004, 4,279 Finnish students were studying overseas for an average of 5.9 months and 4,341 foreign students were studying in Finland for an average of 6.1 months. The report on *International Mobility in Finnish Higher Education 2004* by Mira Jortikka and Pirjo Zirra found that postgraduate students accounted for a very small share of these *credit* students who take "part of his/her studies abroad, in the form of study or practical training" (Jortikka & Zirra, 2004, p. 2). There were only 163 Finnish postgraduate (credit) students studying abroad and 73 foreign (credit) postgraduate students studying in Finland in 2004. Data from the OECD (2004b) shows that foreign PhD students account for a small share of PhD enrolments in Finland (6.4% in 2002) compared to Australia (24% in 2002) and the United States (26.3% in 2001).

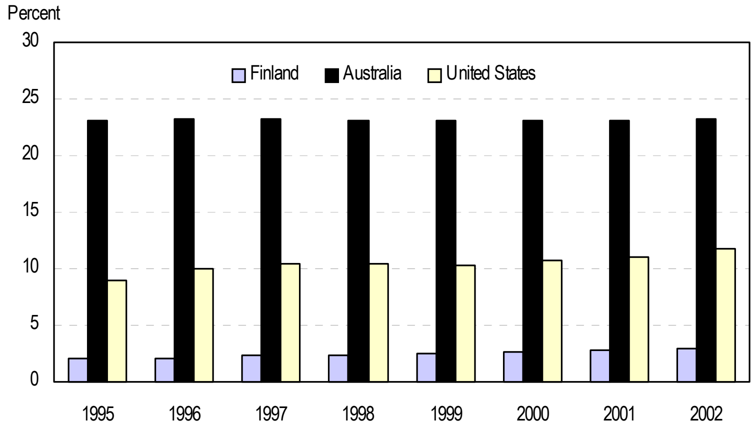
Figure 33: International movements of students, Finland 1997 to 2004



Source: KOTA Online (2005), Figures 31 to 33

The share of **foreign human resources in science and technology** in overall HRST employment is also low in Finland at less than 2% in 2001 compared to between 3% and 3.5% in other European countries (OECD, 2003). A report by Taru Rastas and Candice Stevens provided to the OECD in 2004 on *Developing Highly Skilled Workers: Review of Finland* also found that Finland has relatively low migration rates of highly skilled workers. As shown in Figure 34, only 2.9% of the Finnish population was foreign born in 2002 compared to 23.2% for Australia and 11.8% for the United States. Rastas and Stevens (2004) attributed low migration to language and integration difficulties, and blamed high marginal tax rates for the country's inability to attract more highly skilled workers. They were also concerned about the increasing number of Finnish students (including doctoral students) and researchers being attracted to the United States. They called for an increase in repatriation that could include financial and work-related incentives.

Figure 34: Foreign-born people in the population, Finland, Australia and United States 1995 to 2002



Source: OECD (2005b)

In 2001, the Ministry of Education released an *International Strategy for Higher Education*. The strategy aims to double the number of foreign teachers, experts and researchers working in higher education institutions in Finland by 2010. The Ministry of Education (2001) estimated an increase in the annual volume of student exchanges to around 28,000 students, with foreign students to account for 15% of graduate school students. Despite increases in student exchanges, data on overseas researcher visits, foreign postgraduate students, foreign HRST and the size of the foreign born population suggests that these targets are unlikely to be met.

As part of efforts to further internationalise Finland's national innovation system, the Science and Technology Policy Council of Finland (2002) called for greater investment in all levels of education, particularly research training and increased researcher mobility. These measures would require enhancing individual competencies for international activities and addressing **barriers to mobility**. The Council's internationalisation strategy released in November 2004 included a SWOT analysis (contained in Table A17 in the appendix) that provided some of the reasons for the small number of foreign students and researchers in Finland. These reasons were Finland's remoteness from global market centres, language, severe climate, limited economic and intellectual resources (and therefore, cutting-edge research in only a few fields), and the movement of businesses including R&D-intensive operations to abroad. To remove obstacles to international co-operation and mobility, the Science and Technology Policy Council (2004) recommended legislative measures in the areas of immigration and work permits, the internationalisation of universities and their educational services, payments by foreigners, and taxation. The Council also believed that greater efforts to advance researcher careers, attract foreign researchers, and internationalise research training would involve ensuring high quality research infrastructure of international standard.

The report, *Mobile Minds, Survey of foreign PhD students and researchers in Finland,* prepared by Kaisu Puustinen-Hopper on behalf of the Academy of Finland (as part of the European Commission funded project CONNECT-Finland) was released in early 2005. The purpose of the survey was to identify and address the needs of foreign researchers in Finland. Over 850 people were surveyed and/or interviewed in the spring of 2004. About 60% of respondents were undertaking a PhD in Finland and two thirds of respondents were from the fields of natural sciences and engineering and technology. Most respondents were funded by a Finnish university salary (31%), Academy of Finland (22%), Finnish university grant/scholarship (14%), Tekes (13%), or European Union (10%). On average, respondents had been in Finland for 4.5 years, indicating that many respondents were more permanent and "not just on researcher exchange" (Puustinen-Hopper, 2005, p. 14). Table 19 shows that 47.6% of respondents intended to stay in Finland, with senior researchers more likely to stay due largely to the nature of their contract i.e. permanent versus temporary.

Table 19: Intended residence of foreign PhD students and researchers by career stage, Finland

Career stage	Intending to stay permanently	Not intending to stay permanently	Total N
Postgraduate (PhD) student	45.0%	55.0%	471
Postdoc	42.0%	58.0%	100
Senior Researcher	64.5%	35.5%	93
Professor	54.1%	45.9%	37
Total	47.6%	52.4%	701

Source: Puustinen-Hopper (2005) p.17

Puustinen-Hopper (2005) found that the key motivating factor that attracted foreign researchers to Finland was the **high level research environment**, particularly for postdoctoral researchers who were also establishing their own networks. Other motivating factors in order of importance were career development, experience of living abroad, high standard of living, wife/husband/girlfriend/boyfriend in Finland, learning the language (Finnish, Swedish), hardship in home country, and family members in Finland (p. 15). Many foreign students and researchers were also attracted to Finland because of its free university education (including PhD studies), the flexibility of the Finnish work culture (particularly for women), low rates of crime and corruption, and the open and liberal social atmosphere. Many foreign researchers decided to come to Finland because of "the recommendation by a relative, friend, colleague or superior. Friendships and professional contacts that are established during exchange periods and contacts made in conferences can lead to long-lasting co-operation between individuals and research groups" (p. 21).

Respondents were generally satisfied with the **quality of information and guidance** they received on housing and accommodation, health care, immigration formalities, social security, taxation, language learning, IPR and research ethics issues, and family matters. The report included four recommendations to improve services available to foreign PhD students and researchers arriving and living in Finland (p. 33):

- Improving recruiting practices - A more focused and proactive approach in offering information and guidance services for incoming and present foreign researchers and PhD students. The Researcher's Mobility Portal is a good tool for this purpose, but effective guidance also involves the possibility for personal communication with an advisor. Developing human resources in Finnish research environments should involve a more systematic approach for the recruitment of foreign researchers and PhD students. Staff members responsible for the recruitment of researchers must be well aware of the various possibilities to fund researcher mobility.

- Compiling information on researcher mobility – There are no comprehensive statistics of the number of foreign researchers in Finnish universities and research institutes. Universities should annually compile personnel statistics identifying their faculty with citizenship. The KOTA Online database could be developed to provide information on foreign researchers (visiting and permanent) working in Finland and foreign PhD students in Finnish researcher training programs. This would enable the analysis of developments in the number of foreign researchers in Finnish universities.
- Finnish universities should further enhance international co-operation.
- Further strengthening the collaboration of governmental agencies by continuing the network of Finnish governmental agencies that was established in 2004 to improve co-operation on issues that concern foreign researchers and students coming to Finland.

5.6.3 United States

The United States also has many programs supporting the international mobility of research students and graduates. Foreign research students seeking to study in the United States can access financial assistance from different sources including home government scholarships, U.S. government assistance, private U.S. sources and international organisations, U.S. universities, and loans. These sources are further explained in Table A18 in the appendix. Just over 78% of foreign doctoral students in 2001 were supported by U.S. universities through research assistantships (44.7%), teaching assistantships (17%) and fellowships (16.4%) (Table 20). Only 6.1% of foreign students who were temporary residents used personal savings to undertake their doctorate compared to 24.5% for U.S. citizens. Table A18 also includes the different ways that foreign research graduates can participate in academic visits and exchange programs in the United States, as well as the range of U.S. and international organisations that are funding research students and graduates from the United States to undertake research abroad.

Table 20: Funding sources for S&E doctorate recipients, United States 2001

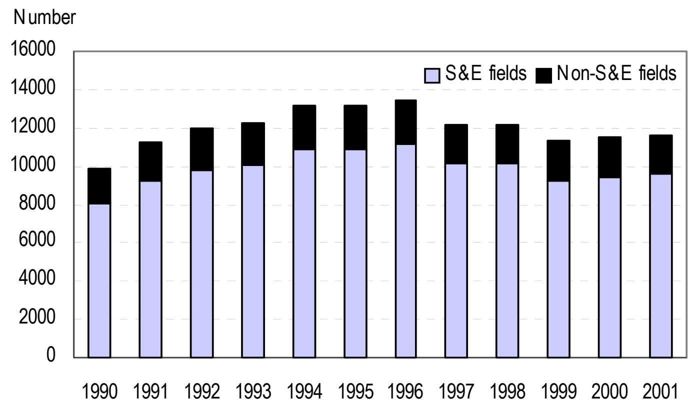
	Research assistantships		Teaching assistantships		Fellowships (1)		Traineeships (2)		Other (3)		Personal (4)		All students
U.S. citizens	4,086	25.4%	2,389	14.9%	3,776	23.5%	566	3.5%	613	3.8%	3,937	24.5%	16,069
Non-U.S. citizen	4,281	44.7%	1,629	17.0%	1,570	16.4%	49	0.5%	749	7.8%	701	7.3%	9,574
Temporary resident	3,789	46.0%	1,398	17.0%	1,312	15.9%	28	0.3%	703	8.5%	506	6.1%	8,242
Permanent resident	492	36.9%	231	17.3%	258	19.4%	21	1.6%	46	3.5%	195	14.6%	1,332

(1) Includes fellowships, scholarships and dissertation grants
(2) Includes traineeships, internships and residencies
(3) Includes employer reimbursement or assistance, foreign support and other sources
(4) Includes personal savings, other personal earnings in graduate school, other family earnings or savings, and loans.

After rising steadily until 1996, the number of **foreign students** who have completed a PhD in the United States declined in the late 1990s (Figure 35). In 2001, 11,602 doctorates were awarded to foreign students, most of which were in S&E fields (82.5%) – permanent residents accounted for 1,822 doctoral completions and temporary residents accounted for 9,780 doctoral completions. Foreign students also accounted for 28.5% of all doctoral completions and 36.3% of all S&E doctoral completions in the United States in 2001. Just over 56% of students who were awarded a U.S. S&E doctorate between 1998 and 2001 were from East and South Asian countries, in particular China, India, South Korea and Taiwan. Data on the number of U.S.

students undertaking doctorates abroad is difficult to obtain. OECD data on the net balance of international student exchange shows that total foreign students in the United States exceeded U.S. students going abroad by 544,000 in 2002 (OECD, 2004b). This data suggests that the number of foreign research students in the United States was well above the number of domestic research students undertaking a doctorate or participating in a student exchange abroad.

Figure 35: Doctoral completions by foreign students, United States 1990 to 2001



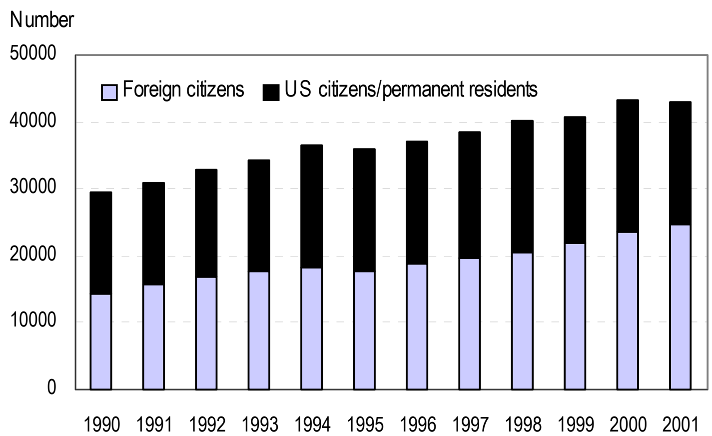
Between 1990 to 2001, the share of **foreign recipients of S&E doctorates** from U.S. universities who were planning to stay or had firm plans to stay in the United States continued to rise. For those who were awarded a doctorate between 1998 and 2001, 76.3% were planning to stay and 54.1% had firm plans to stay (Table 21). There was variation in these plans depending on the origin continent/country of recipients, with those from East/South Asia (particularly China and India) and Europe (particularly the United Kingdom) more likely to stay. The National Science Board (2004) estimated that 3,500 foreign students from each annual cohort of new S&E doctorates remain in the United States, with recipients in computer and electrical engineering, physical sciences, life sciences, and computer sciences more likely to stay.

Table 21: Plans of foreign recipients of U.S. S&E doctorates to stay in the United States, 1990 to 2001

	Plans to stay			Firm plans to stay		
	1990-1993	1994-1997	1998-2001	1990-1993	1994-1997	1998-2001
East/South Asia	68.6%	75.4%	83.2%	44.1%	46.2%	58.5%
China	93.5%	96.6%	96.2%	58.0%	57.3%	67.5%
India	85.6%	90.1%	94.0%	62.6%	61.8%	73.2%
West Asia	59.5%	60.4%	67.2%	32.7%	34.4%	46.1%
Pacifica/Australasia	49.2%	50.6%	59.7%	33.1%	28.7%	43.1%
Africa	48.2%	55.1%	70.3%	24.5%	25.8%	40.7%
Europe	61.2%	67.2%	76.2%	44.5%	47.9%	57.5%
United Kingdom	76.2%	77.5%	80.8%	57.7%	59.5%	62.4%
North/South America	49.9%	51.6%	56.9%	36.0%	36.1%	42.4%
All non-U.S. citizens	**63.4%**	**69.3%**	**76.3%**	**40.9%**	**43.3%**	**54.1%**

Increasing stay rates have contributed to the steady rise in the number of foreign citizens working as **S&E postdoctoral researchers** in U.S. universities (Figure 36). In 2001, 24,601 foreign citizens were in S&E postdoctoral positions, which represented 57.2% of all postdoctoral positions. The U.S. Bureau of Census estimated that foreign born people (permanent residents and temporary residents) with doctorates accounted for 37.6% of all people employed in S&E occupations in the United States in 2000. The National Science Board (2004) estimated that there were around 192,000 foreign born U.S. residents with S&E doctorates in 1999.

Figure 36: S&E postdocs at universities in the United States 1990 to 2001



The number of **permanent visas** issued to immigrants in S&E occupations between 1990 and 2001 ranged from 7,000 in 1999 to 33,900 in 2001 (Figure 37). Most of the visas issued in 2001 were to engineers (47.5%) and mathematical/computer scientists (37.5%). More recent data shows that the number of permanent visas issued in 2003/2004 was 5% lower than the previous year (Brown & Syverson, 2004). Data on the number of **non-immigrant (or temporary) visas** issued to students (F-1), exchange visitors (J-1) and temporary skilled workers (H1-B) shows steady increases until 2002 (Figure 38). Falls in permanent and temporary visas are expected to contribute to a decline in the number of S&E postdoctoral researchers employed by U.S. universities from 2002.

Figure 37: Permanent visas to immigrants in S&E occupations, 1990 to 2001

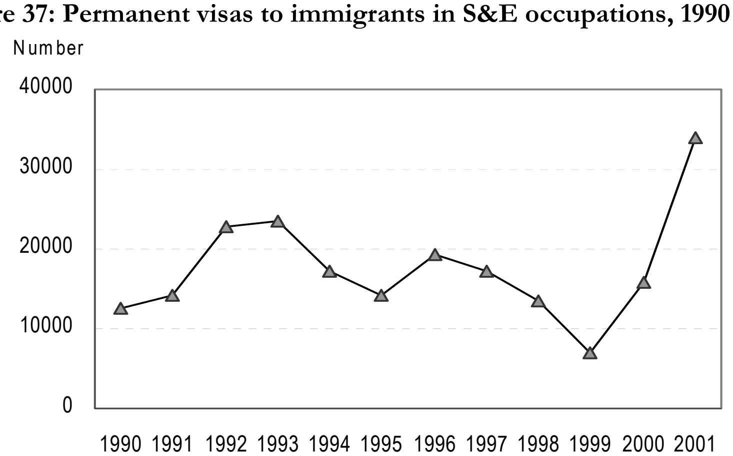
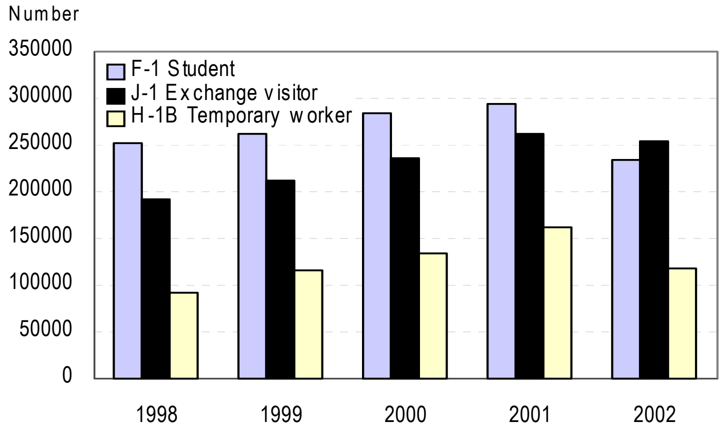


Figure 38: Non-immigrant (temporary) F-1, J-1 and H-1 visas, United States 1998 to 2002



Source: National Science Board (2004), Figures 35 to 38 and Tables 20 and 21

The National Science Board (2004) attributed the slowdown in inward mobility to fewer applications and a higher rejection rate caused not only by events on September 11 but also to increased competition elsewhere in the world for S&E students and talent. The National Science Board (2004) believed that the United States is becoming "less dominant as a destination for migrating scientists and engineers" (p. 3-32). The President of the Council of Graduate Schools, Debra W. Stewart confirmed further falls in graduate school enrolments of 28% in 2004 and 5% in 2005. She stated if this downward trend continues "… the lack of foreign graduate students could seriously affect the continued quality research. Such a trend may also signal a change in the nation's status as the destination of choice for international students" (p. 1). Stewart (2005) argued that the United States must *redouble* its efforts to develop the domestic talent pool given that the European Union is now producing more PhDs in science and technology than the United States and harmonising its systems of education, and the Governments of China, India and Korea are investing heavily in graduate education.

In the summer of 2004, Heather Brown and Peter Syverson from the Council of Graduate Schools surveyed U.S. Graduate Schools on international student admissions trends. They also attributed the decline in foreign students to global competition in graduate education, changing visa processes, and the diminished perception of the U.S. as a destination for advanced graduate study. Brown and Syverson (2004) found that many institutions are developing specific practices to improve the administration process for international graduate students. Examples included earlier application deadlines (giving students more time to deal with visa processes), early notification, increased guidance on the admissions and visa process, and other changes such as electronic applications and streamlining the admissions process.

Richard Freeman (2004) from the National Bureau of Economic Research believes that U.S. science and engineering would have been in crisis without the influx of foreigner students and workers. At the same time he argues that this influx (until recently) has been both a blessing and a problem:

> It is a blessing because it brings the best and brightest from around the world to our universities and labs and strengthens our comparative advantage in science and high-tech fields. Given the nature of the American position in the global economy, this is not a luxury; it is necessary for long-term U.S. economic well-being. It is a problem because, at the same time, the huge influx of foreign students and workers keep wages and employment opportunities below what they would otherwise be. This discourages U.S. citizens from investing in science and engineering careers, and thereby increases our dependence on the foreign born.

5.7 Research careers

As pointed out in the introduction of this chapter, the potential gain or loss of research graduates to a national innovation system through international mobility has a lot to do with the nature and extent of research opportunities in the host country. It should be noted, however, that a lot of the issues raised in this section (such as uncompetitive salaries and access to permanent positions) are occurring in other countries with a strong R&D system. For example, the final report of the United Kingdom's Roberts' Review (2002), *SET for success: The supply of people with science, technology, engineering and mathematics skills*, found PhD study was financially unattractive and did not prepare people adequately for careers in business or academia. In France, the lack of research careers in the private sector forced many graduates to accept temporary positions, such as postdoctoral positions in other countries, until they secured an academic position back in France (Gaughan & Robin, 2004).

5.7.1 Australia

The perceived lack of a career structure for young researchers was one of the findings of the review of higher education research policy by Robert Smith in 1988. In the ministerial statement, *Research for Australia: Higher Education's Contribution,* Dawkins (1989) stated that opportunities for research graduates in the academic labour market were limited. Research graduates were no longer destined for university teaching and research positions. Research training should prepare students for a research career in industry, government and higher education, and for a career outside of research (Higher Education Council, 1992). The Higher Education Council of the National Board of Employment, Education and Training (1990) called for a concerted effort "to attract the best people into research since the rewards for the extra endeavour, both immediate and long-term, are usually meagre" (p. 41). The Australian Research Council evaluated the National Research Fellowship Scheme in 1990, leading to an increase in the value and number of grants. The scheme aimed to provide young researchers with an opportunity to progress through postdoctoral, research fellow and senior research fellow positions, subject to competitive processes. Five types of fellowships were offered from 1991 and most of these still exist today in a revised form: Australian Postdoctoral Fellowships, Australian Research Fellowships, Queen Elizabeth II Fellowships, Senior Research Fellowships, and Australian Research Fellowships (Industry).

In the late 1990s, a number of major reports found that career opportunities for scientists were still limited. Stocker (1997) cited the reasons of poor linkages between academic research and industry; science and engineering being considered unattractive choices for students; a mismatch between research training and subsequent career opportunities; and an inadequate number of, and intensive competition for scholarships at PhD and postdoctoral level. Stocker (1997) believed these factors were contributing to young scientists leaving Australia or pursing other careers, which represented a loss of investment in their training and opportunity for Australia.

The final report of the Health and Medical Research Strategic Review, *The Virtuous Cycle, Working together for health and medical research*, released by the Peter Wills on behalf of the National Health and Medical Research Council in May 1999 stated that Australia's lack of opportunities for scientists was exacerbated by uncompetitive remuneration scales compared to those in the United States (Table 22). Wills (1999) recommended that career development for scientists be improved through greater opportunities at Research Assistant and Research Officer levels, and by enhancing the attractiveness of postdoctoral research by developing exchange fellowships and assisting the targeting of skills development. These opportunities needed to be backed up by "realistic grant opportunities, a strong on-going system of mentoring, and reasonable access to early career rewards" (Wills, 1999, p. 4).

Table 22: Researcher pay scales, Australia (NHMRC) and United States (NIH) 1998 ($AUD)

	Australia	USA
Research Assistant/Postdoc	$38,000-$51,000	$30,000-$73,000
Senior Research Assistant/Senior Research Officer	$43,000-$75,000	$67,000-$145,000
Senior Research Fellow/Principal	$53,000-$96,000	$124,000-$169,000

Source: Wills (1999) p. 4

The Chief Scientist Robin Batterham stated in his report, *The Chance to Change,* released in November 2000 that attracting and retraining the best researchers was difficult due to the limited number of postdoctoral fellowships and the high rejection rate. This situation has led many researchers to pursue careers outside Australia that provide more attractive research environments, such as the United States. Batterham (2000) called for an increase in Australian postdoctoral fellowships from 55 to 110. To regain and attract brilliant researchers, he recommended the establishment of 50 Federation Industry Chairs (at $300,000 per annum) in universities or a research entity affiliated with a university "as a vehicle to provide career paths, stimulate link formation between universities and industry, and to increase the potential for universities to develop commercially relevant research" (p. 55). Both of these recommendations were included in *Backing Australia's Ability* to "excite and retain Australian researchers" (Howard, 2001, p. 20) – although the number and value of Federation Fellowships were lower at 25 new Federation Fellowships valued at $225,000 a year for five years.

In his discussion on postdoctoral fellowship schemes available in Australia, Nelson (2003a) stated that "early career support, as part of an overall focus on career pathways, is a significant issue in maintaining an adequate supply of researchers" (p. 213). The Group of Eight universities identified a number of issues about research careers in Australian universities, including a lack of a well-defined career path, reduced employment opportunities, contract and short term nature of postdoctoral employment, and uncompetitive salaries (Nelson, 2003a). As a result, many postdoctoral fellows are more attracted to industry and other research agencies than universities, and there is an increasing tendency for the best doctoral graduates to go overseas.

Table A19 in the appendix contains the current Australian postdoctoral fellowship and award schemes that are funded by the **Australian Research Council**. The total number of fellowships funded by the Australian Research Council rose from 144 in 2001 to 232 in 2002 (Table 23) due to extra funding provided in *Backing Australia's Ability*. Consequently, the success rate for fellowships improved, particularly for Australian Postdoctoral Fellowships which rose from 14% in 2001 to 24.5% in 2002. The Australian Research Council continues to allocate funding to early career researchers in the form of 112 Australian Postdoctoral Fellowships and 138 Discovery projects[26] in 2004, with success rates of 22.9% and 20.8% respectively. A lower number of fellowships were available for more experienced researchers (i.e. ARF, QEII, APF and FF), and success rates of between 14.6% and 17.5% in 2004 indicate that these fellowships are even more competitive.

Table 23: Fellowships and early career researcher projects, Australia 2000 to 2004

Fellowships	2000	2001	2002	2003	2004
Discovery Australian Postdoctoral Fellowships	55	55	110	110	112
Success rate	14.5%	14.0%	24.5%	19.0%	22.9%
Discovery Australian Research Fellowships (ARF)/ Queen Elizabeth II Fellowships (QEII)	30	30	30	31	33
Success rate	n.a.	n.a.	13.9%	12.2%	14.6%
Discovery Australian Professorial Fellowships (APF)	15	15	23	25	24
Success rate	n/a	n/a	13.9%	14.5%	15.4%
Total Discovery project fellowships	**100**	**100**	**163**	**166**	**169**
Success rate (%)	**14.6%**	**14.3%**	**19.6%**	**16.5%**	**19.4%**
Federation Fellowships (FF)	n.a.	n.a.	25	22	25
Success rate (%)	n.a.	n.a.	9.3%	24.7%	17.5%
Linkage Australian Postdoctoral Fellowships CSIRO	n.a.	n.a.	n.a.	10	n.a.
Success rate (%)	n.a.	n.a.	n.a.	14.3%	n.a.
Linkage Projects Australian Postdoctoral Fellowships Industry	17	27	32	32	46
Success rate (%)	37.0%	45.8%	55.2%	43.8%	56.1%
Linkage International Fellowships (1)	19	17	12	16	11
Success rate (%)	n.a.	n.a.	54.5%	72.7%	48.0%
Total number of fellowships funded	**136**	**144**	**232**	**246**	**251**
Discovery projects, early career researchers	64	54	161	162	138
Success rate (%)	15.0%	20.6%	25.0%	18.8%	20.8%
Linkage International Awards (1)	89	86	54	24	39
Success rate (%)	n.a.	n.a.	n.a.	53.3%	47.6%

(1) Fellowships and awards were granted under the International Researcher Exchange Scheme (IREX) until 2002.
Source: Australian Research Council (2001), (2003) and (2005a)

[26] **Discovery Projects, early career researchers** support applications for early career researchers under the Discovery Projects element of the National Competitive Grants Program. In the 2003 application round, approximately 15% of the Discovery Projects budget was set aside for this purpose. This initiative commenced in the 2001 application year in response to concerns that young researchers had become discouraged from applying for Discovery grants (ARC, 2005a).

Other agencies in Australia also fund postdoctoral positions. In 2005, the **National Health and Medical Research Council** funded 67 new Research Fellowships (full-time, usually for five years, and at varying doctoral levels), seven Practitioner Fellowships, 42 Career Development Awards, 90 Training Fellowships for recent PhD graduates (undertaken in Australia or overseas), and one Burnett award (to attract back medical researchers of a high calibre who have spent at least seven years overseas and who have not returned because of the lack of suitable opportunities). Eight industry fellowships that fund researchers to spend two years in industry and two years in a research institution were awarded in 2004. **The Commonwealth Science and Industrial Research Agency (CSIRO)** appointed 22 new postdoctoral fellows across 16 divisions under the CSIRO Postdoctoral Fellowship Program in 2003/2004. The number of postdoctoral fellows employed by the CSIRO rose from 194 in 2002/2003 to 259 in 2003/2004. Ten fellowships were awarded under the Linkage Australian Postdoctoral Fellowships CSIRO program in 2003. **Cooperative Research Centres** also offer employment to non-tenured scientists and postdoctoral scientists until they find more permanent employment (Howard Partners, 2003). Many universities also fund their own postdoctoral fellowship schemes.

Australia employs more people as researchers (as a proportion of total employment) than the OECD. Following strong growth in the first half of the 1990s, growth in the employment of researchers in all sectors has slowed (Figure 39). Growth in research degree completions in the mid 1990s was significantly above growth in the **research workforce**. The number of researchers based in higher education has almost doubled over the decade from 20,667 in 1990 to 39,507 in 2000. Therefore, the higher education sector continues to account for the largest proportion of researchers, rising from 47.9% in 1990 to 59.8% in 2000 (Figure 40). Despite the rise in business researchers in Australia from 12,604 in 1990 to 16,214 in 2000, the proportion of total researchers in business enterprises fell from 29.2% to 24.4% over this period. The fall in researchers employed in Government (from 9,281 in 1990 to 8,972 in 2000) and the increase in researchers employed in higher education led to a fall in the Government share of researchers from 21.5% to 13.6%.

Figure 39: Growth in research degree enrolments and research workforce, Australia 1990 to 2000

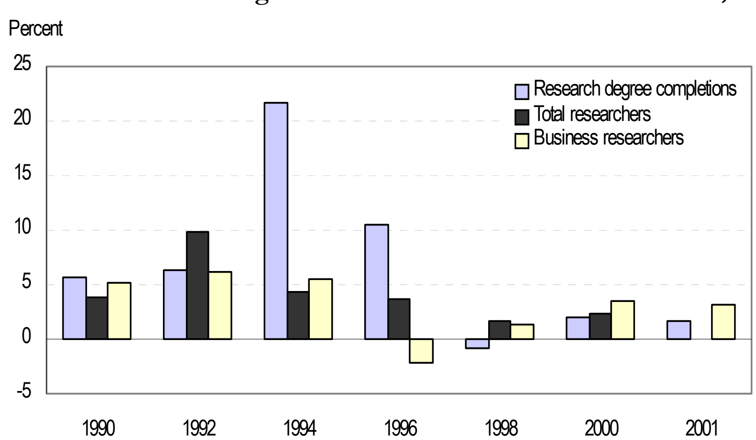
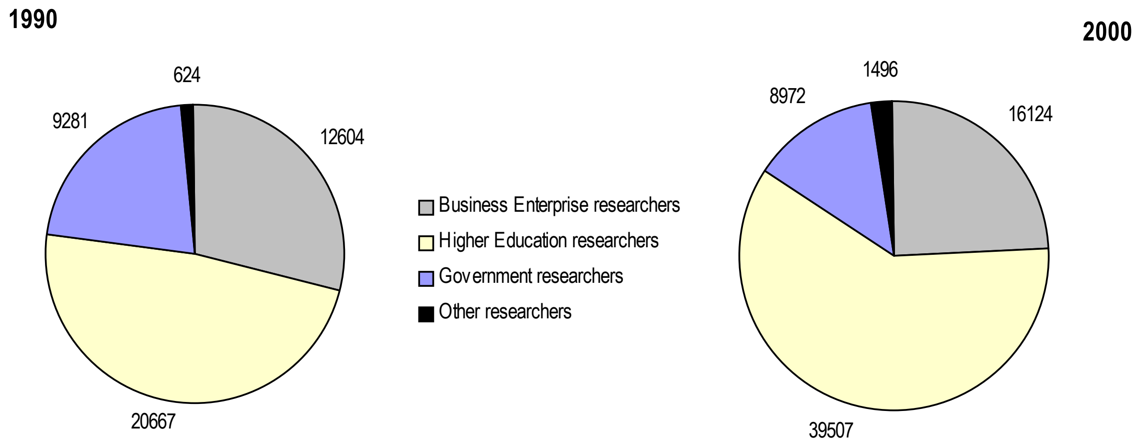


Figure 40: Researchers by sector, Australia 1990 and 2000



Source: OECD (2005a), Figures 39 and 40

Data is not yet available to show the full impact of initiatives announced in *Backing Australia's Ability* on the size of the research workforce. It can be assumed from the sheer volume of research completions (over 60,000 completions between 1990 and 2003, with overseas students accounting for over 10,000 of these completions) that many research graduates are not pursuing research careers in Australia or are not working as researchers. The Australian Bureau of Statistics (ABS) estimated that around 19,000 of the 68,000 people with a doctoral degree in Australia were not working in an S&T occupation in 2001. Research graduates with a doctoral degree accounted for only 4% of the HRST Core and 2.8% of all people with S&T qualifications in 2001.

Uncompetitive salaries have been regarded as a key impediment to research careers in Australia, particularly for younger people who may not pursue a research career in Australia or at all because of the relatively low starting salaries. There are two sources of information that support these concerns: Changes in salary rates of the Australian Research Council (ARC) and the 2003 report by Horsley and Woodburne that examined trends in academic salaries. Improving the competitiveness of researcher salaries in national competitive grants was an initiative included in the extra $736 million provided to Australian Research Council in *Backing Australia's Ability*. Table 24 shows significant increases in ARC salary rates in 2002, and further (smaller) increases in the three years that followed. Growth of 2.1% in all fellowship salaries in 2005 was below the CPI (2.4%) and growth in average weekly earnings (4.5%).

Table 24: Australian Research Council fellowship salary rates, 2001 to 2005

Fellowship	2001	2002	2003	2004	2005
Australian Postdoctoral Fellowship (APD)(1)	$42,225	$49,621	$52,240	$53,567	$54,692
Australian Research Fellowship (ARF) Queen Elizabeth II Fellowship (QEII)	Step 1: $50,337 Step 2: $52,063	Step 1: $62,755 Step 2: $74,483	Step 1: $65,210 Step 2: $77,497	Step 1: $66,867 Step 2: $79,465	Step 1: $68,271 Step 2: $81,134
Australian Senior Research Fellow	$66,994 (average)				
Australian Professorial Fellowship (APF)	Step 1: $66,994 Step 2: $87,442	Step 1: $82,152 Step 2: $100,078	Step 1: $89,516 Step 2: $105,125	Step 1: $91,790 Step 2: $107,795	Step 1: $93,718 Step 2: $110,059
Federation Fellowship (FF)	n.a.	$225,000	$235,201	$241,224	$246,290
Growth in salaries	**2001**	**2002**	**2003**	**2004**	**2005**
Australian Postdoctoral Fellowship	n.a.	17.5%	5.3%	2.5%	2.1%
ARF/QEII Step 1 ARF/QEII Step 2	n.a.	24.6% 43.1%	3.9% 4.0%	2.5% 2.5%	2.1% 2.1%
APF Step 1 APF Step 2	n.a.	22.6% 14.5%	9.0% 5.0%	2.5% 2.5%	2.1% 2.1%
Federation Fellowship	n.a.		4.5%	2.6%	2.1%
Consumer Price Index (2)	n.a.	2.9%	3.4%	2.0%	2.4%
Average Weekly Earnings (3)	n.a.	4.1%	4.3%	5.1%	4.5%

(1) From 2002, includes Australian Postdoctoral Fellowship Industry (APDI), Linkage-Australian Postdoctoral Fellowship CSIRO (APDC) and Research Cadetship-Aboriginal and Torres Strait Islander (RC-ATSI)
(2) Annual change for quarter ending March
(3) Annual change for quarter ending February

Sources: ARC (2005a), ABS Catalogues Consumer Price Index (6401.0) and Average Weekly Earnings (6302.0)

Horsley and Woodburne (2003) found that academic salaries in Australia have declined relative to average earnings and the CPI between 1977 and 2002. This decline varied across academic levels with senior levels (i.e. professors) experiencing greater declines than lower entry-level grades. They found that the decline started in 1977 but slowed in the early 1990s. As shown in Table 25, a professor's salary was 3.17 times greater than average weekly earnings in 1977 compared to 2.39 times greater in 2002. Many early career researchers are employed at the associate lecturer salary level i.e. academic level A. In 1977, an associate lecturer's starting salary was 1.03 greater than average weekly earnings; by 2002 it was below average weekly earnings. Only the associate lecturer's salary kept pace with the CPI during 1977 and 2002 (both experiencing real growth of 3.84%), with salaries at other levels growing at a rate below inflation i.e. professor level (3.39%), senior lecturer (3.4%) and lecturer (3.82%). These increases were also below the rate of growth for average weekly earnings of 4.51% during this period.

Table 25: Australian academic salaries as a ratio of average weekly earnings, 1977 to 2002

Year	Associate lecturer (Level A bottom of scale)	Lecturer (Level B bottom of scale)	Senior Lecturer (Level C top of scale)	Professor (Level E top of scale)
1977	1.03	1.48	2.35	3.17
1978	1.03	1.45	2.27	3.04
1980	0.99	1.39	2.17	2.91
1982	0.92	1.29	2.02	2.70
1984	0.86	1.21	1.90	2.54
1986	0.88	1.24	1.94	2.59
1988	0.84	1.16	1.80	2.40
1990	0.82	1.13	1.74	2.32
1992	0.94	1.34	1.89	2.54
1994	0.90	1.29	1.82	2.45
1996	0.87	1.25	1.76	2.37
1998	0.90	1.28	1.81	2.44
2000	0.90	1.28	1.81	2.44
2002	0.88	1.26	1.77	2.39

Source: Horsley and Woodburne (2003), Table 1, p. 8

5.7.2 Finland

The **Academy of Finland** is the key public body that supports research careers in basic science. As well as funding research training places through projects and programs, it also has schemes to support postdoctoral researchers, research fellows and professors (Table 26).

Table 26: Research posts funded by the Academy of Finland

The Academy's **Postdoctoral Research System** is designed to advance the competence and independence of young researchers who have recently earned their doctorate. As well as doing their own research as set out in their research plans, postdoctoral researchers supervise undergraduates and doctoral students preparing their thesis, and teach at university. Appropriations are granted for hiring postdoctoral researchers for a period of two years. Applications may be submitted by an individual researcher, a research team, a graduate school or a public sector organisation, a business corporation or other business organisation together with a university. Researchers who have completed their doctorate may also apply to the Academy for grants to work abroad or to support their further training.

Academy of Finland **Research Fellowships** are among the hotly contested positions in Finland. The posts are intended for researchers working independently on a project in accordance with a set research plan. Academy Research Fellows are also expected to do some teaching and to supervise undergraduate and doctoral students researching their theses. Successful candidates shall have published and done other scientific work after taking the doctorate. Research Fellowships are awarded for periods of no more than five years at a time. Academy Research Fellows work with their host organisation, but their salary is paid by the Academy of Finland.

The post of **Academy Professor** is the highest research post funded by the Academy of Finland. Persons appointed to the post shall be eminent researchers who are well placed to promote research within their discipline, as well as enjoy international recognition. Apart from working on their own research, Academy Professors are responsible for running their research teams, supervising junior researchers and often teaching at university. Researchers are appointed to the post of Academy Professor for a fixed term, usually for five years at a time.

Source: Academy of Finland (2002b)

As at 1 August 2002, the Academy was funding 360 postdoctoral researchers, 230 research fellows and 38 professors. In 2004, the Academy allocated funding of 22.9 million euros to research posts which represented 11% of its funding decisions (which totalled 208 million euros). The Academy also supports research careers by funding research projects, research programs and centre of excellence programs. In the case of research grants, competition has intensified with only 19% of applications granted in 2004 compared to 31% of applications granted in 2000 (Table 27). Lower success rates, combined with a decline in the number of applications (from 257 in 2000 to 219 in 2004), have led to a fall in the total number of general research grants awarded by the Academy in 2004 (estimated at 80 in 2000 and 42 in 2004).

Table 27: Success rate of general research grant applications to the Academy of Finland

	2000		2001		2002		2003		2004	
Research Council	No.	%	No.	%	No.	%	No.	%	No.	%
Biosciences & Environment	64	30%	46	20%	40	21%	40	19%	37	16%
Culture & Society	45	26%	42	24%	46	22%	60	27%	46	17%
Natural Sciences & Engineering	100	35%	105	31%	104	30%	116	27%	88	20%
Health	48	33%	62	34%	52	37%	64	37%	48	27%
Total	**257**	**31%**	**255**	**28%**	**242**	**28%**	**280**	**27%**	**219**	**19%**

Source: Academy of Finland (2004) p. 11

As the largest R&D funding body in Finland, **Tekes** also supports research careers through the funding it provides to the business sector and higher education sector. In 2004, Tekes funded 1,464 corporate R&D projects at a cost of 165 million euros and 778 public research projects in universities, research institutes and polytechnics at a cost of 172 million euros (Table 28). Although the number of public research projects in 2004 is about 20% smaller than the number funded in 2000, funding for these projects has steadily increased. Key outcomes from projects completed in 2004 that relate to research careers include 999 academic theses and 2,451 scientific publications.

Table 28: R&D projects funded by Tekes, 2000 to 2004

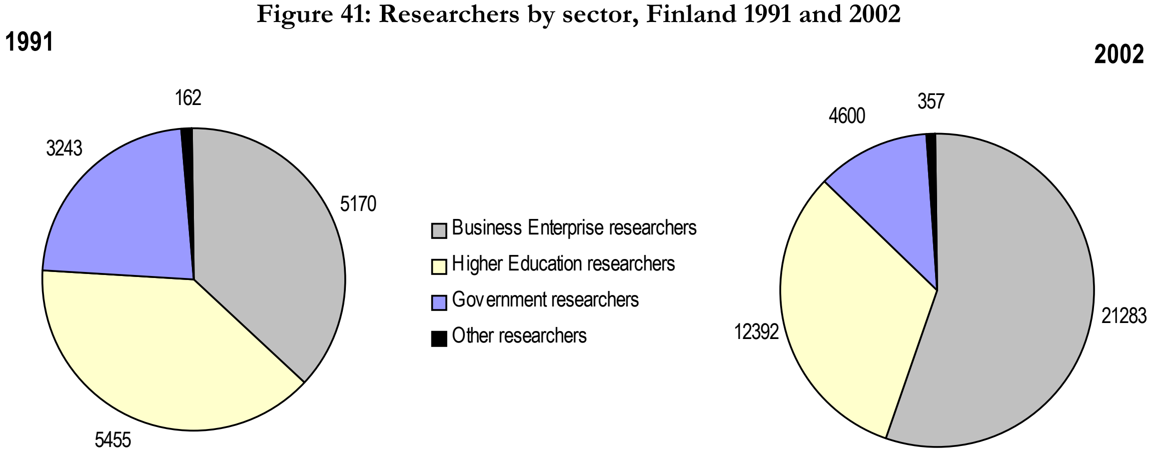
	2000		2001		2002		2003		2004	
	No.	Million euros	No.	Million euros	No.	Million euros	No.	Million euros	No.	Million euros
Corporate R&D projects	1,302	154	1,339	160	1,219	157	1,395	156	1,464	165
Public research projects	995	140	922	146	798	144	801	162	778	172

Source: Tekes (2004) p. 10

Tekes also stated in its 2004 annual review that Finnish researchers continue to be active participants in the **Sixth EU Framework Programme** (estimated at 750 participations, 73 project coordination roles and total funding of over 190 million euros in 2004), EUREKA[27] (27 projects), COST[28] (26 projects) and ERA-Nets (with Tekes involved in 14 projects aimed at enhancing national and regional research and technology programs).

Data in section 4.5.1 shows that Finland continues to employ significantly more people as researchers (as a proportion of total employment) than the OECD – 16.4 people out of every 1000 people compared to 6.5 people out of every 1000 people. Finland's **research workforce** has grown from 14,030 in 1991 to 38,632 researchers, with all sectors employing more researchers (Figure 41). The business sector recorded the highest growth in the employment of researchers between 1991 and 2002, and it now accounts for the largest share of researchers – rising from 36.8% in 1991 to 55.1% in 2002. Growth in doctoral degree completions and the research workforce has slowed in recent years following a decade of relatively high and consistent growth (Figure 42). Growth in business researchers in 2002 was the lowest recorded in almost 10 years. HRST data from Eurostat presented in section 7.5.2 shows HRST stocks, HRST core, and the number of scientists and engineers in Finland have fallen after peaking in 2001.

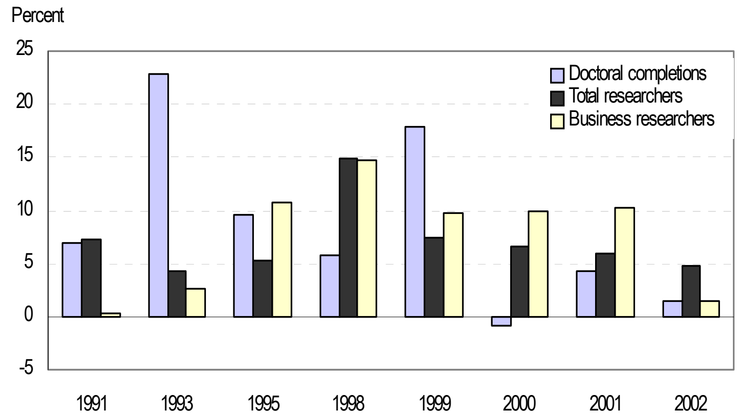
Figure 41: Researchers by sector, Finland 1991 and 2002



27 EUREKA is a pan-European network for market-oriented and industry-related R&D. It provides support for the competitiveness of European companies through international collaboration and by creating links and networks of innovation. Tekes is the coordinator of EUREKA's activities in Finland.

28 COST is an intergovernmental framework for European cooperation in the fields of scientific and technical research. COST's activities are conducted by Tekes in Finland. COST enables the coordination of nationally funded projects with the intention of reaching a wider European perspective. Basic and pre-competitive research activities beneficial to the public sector are the main focus for activities.

Figure 42: Growth in doctoral completions and research workforce, Finland 1991 to 2002



Source: OECD (2005a), Figures 41 and 42

In the report, *PhDs in Finland: Employment, Placement and Demand 2003,* the Academy of Finland (2003a) estimated that almost 12,000 new PhDs will graduate in the first decade of the 21st century. The report included factors indicating that **demand for people with a PhD** in the labour market should continue: Changing industrial structure, the growing investment in the private sector in research and development, the increasing competency requirements or different job tasks, and the departure of the baby boom generation (p. 40). Uncertainty about public research funding means that employment prospects within universities are likely to become more dependent on funding from external sources. The Academy identified the need for attractive career options in both the private and public sectors, and for researcher training to provide the competencies for careers outside of basic research: "It is necessary to look into how the contents of different options within PhD programs could be developed and how a multidisciplinary approach could be more broadly and firmly integrated into PhD programs" (p. 44). The Academy also highlighted the importance of competitive, high quality education and research environments that can act in an internationally networked environment and retain and attract top researchers and research teams. In another report, *Scientific Research in Finland, A Review of Its Quality and Impact in the Early 2000s*, the Academy of Finland (2003b) called for a new strategy for research careers that considers the needs of individual researchers and different fields of research, sets out clear targets for research careers, removes obstacles to research careers, and maintains and strengthens the competitiveness of the researcher's profession (p. 7).

An article called, *The Reforms in Finland: A Student's Perspective,* by Minna Varis (a PhD student from the University of Helsinki) highlighted some of the **obstacles to research careers** in Finland. She believes it is difficult to secure a permanent job in a research group or a suitable company after completing a PhD as most postdoctoral positions in research groups are "fixed-term appointments, with no dependable future". Many postdoctoral researchers are paid through tax-free scholarships and are not entitled to certain social benefits. Despite the upcoming changes to legislation that would entitle scholarship holders to a pension and workers' compensation, they would still not be eligible for medical care, access to unemployment benefits and maternity allowance. Varis (2004) also believes that pressure by the Ministry of Finance to replace temporary posts with permanent posts in universities (where similar work in carried out on a regular basis) will be secured by experienced researchers with established teaching skills. Even if young research graduates were to secure a post as a university lecturer, she argues that these posts are not ideal positions for scientists who are beginning their independent research career. Although the University of Helsinki does have posts for new research graduates not all departments have funding to offer such posts. After finishing a M.Sc. degree, Varis was unable to find work in biotechnology companies as many companies were on a recruitment break due to lower funding. She doesn't believe that the situation will improve when she completes her PhD arguing that "often times a scientist with a M.Sc. can do the same job as a PhD at a lower cost. Currently only about 3% of the industrial R&D workforce has PhDs".

5.7.3 United States

It is well known that many research students and graduates from around the world are attracted to research careers in the United States. They are *pulled* by the availability of opportunities within a large research workforce and well equipped and funded facilities made possible through massive investments by Government, foundations and industry since World War II. Despite a slowdown in R&D investment over the past decade, the United States still dominates global research and development, accounting for 43.7% of all investment in R&D by OECD countries in 2003 and 38.2% of all researchers employed by OECD countries in 1999.

The United States also employs more researchers than the OECD – 8.6 researchers out of every 1000 people employed compared to 6.5 researchers. In the mid to late 1990s, growth in the **research workforce** exceeded growth in doctoral completions (Figure 43). The number of researchers in the United States increased from 981,659 in 1991 to 1,261,227 in 1999, with an additional 239,300 researchers employed in the business sector and an additional 47,768 researchers employed in the higher education sector. In 1999, the business sector employed 80.5% of researchers (Figure 44) compared to 63.8% for the OECD. People with a doctorate accounted for only 13.7% of people in the HRST core in 1999, which totalled 3.54 million. Most people working in S&E occupations have a Bachelor's degree (56.3%) or a Masters degree (29.1%).

Figure 43: Growth in doctoral completions and research workforce, United States 1991 to 1999

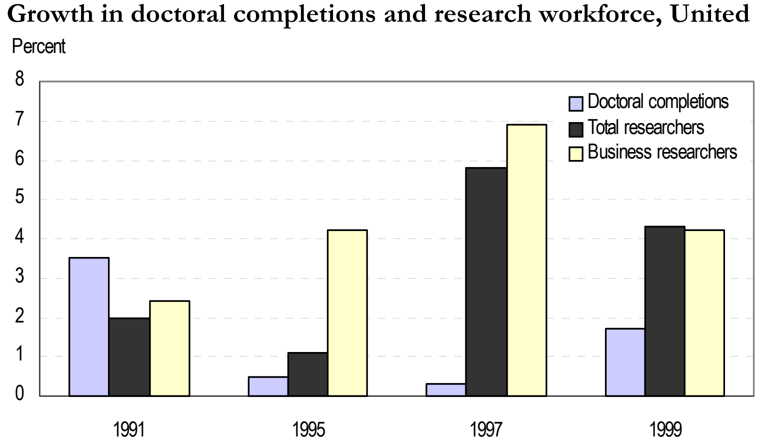
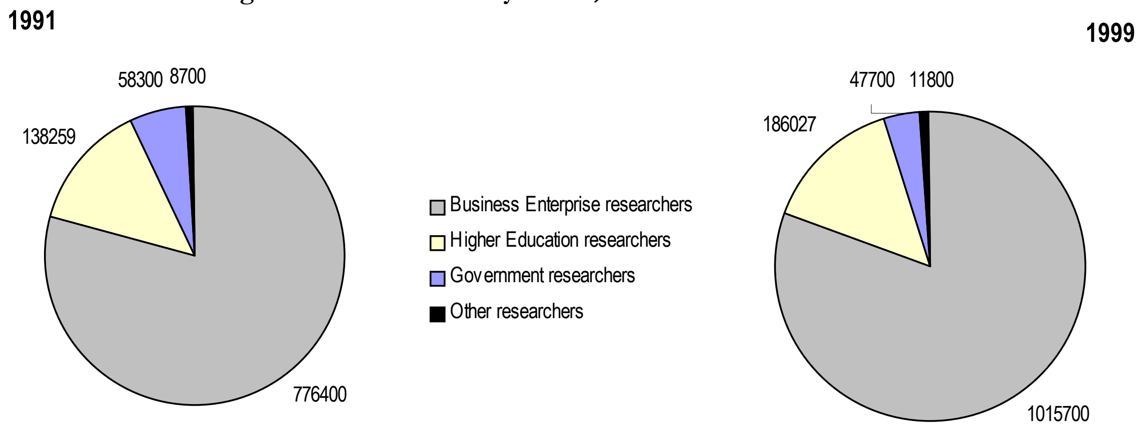


Figure 44: Researchers by sector, United States 1991 and 1999



Source: OECD (2005a), Figures 43 and 44

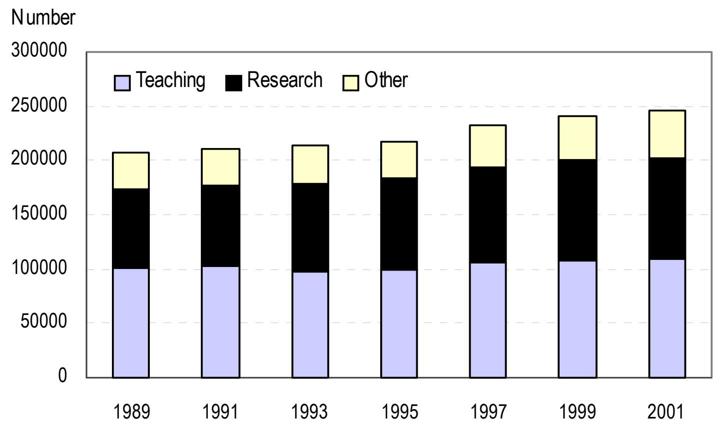
Data from the National Science Board (2004) indicated that in 1999 there were 484,100 people with doctoral degrees working in S&E occupations in the United States (399,900 as scientists and 84,200 as engineers), with 50.5% of these people working in education, 40.3% in business/industry, and 9.3% in government. A greater share of doctorate qualified engineers work in business/industry (60.6%) whereas more scientists work in education (54.6%). With over half of all doctorate holders in S&E occupations working in education (particularly in academia), this career path remains an important option for many research students and graduates. Those working in **academia** are employed through the faculty tenure track system[29] or work in other positions that are not considered for tenure. Faculty titles in order of academic rank include *professor*, *associate professor*, *assistant professor* and *lecturer/instructor*. It normally takes an assistant professor between five and seven years to gain tenure, which is recommended by a committee of faculty members. Many faculty members earn outside income as consultants to business, industry and government, and some hold joint appointments with part-time teaching responsibilities and part-time administrative responsibilities (Education USA, 2005).

The number of S&E doctorate holders working in universities and colleges in the United States rose from 206,600 in 1989 to 245,500 in 2001 (Figure 45). The proportion of those working primarily as researchers has also increased from 34.9% in 1989 to 38.2% in 2001. Many doctoral students in the United States are financed through research assistantships which have grown from 79,100 in 1989 to 99,700 in 2001. The number of postdoctoral researchers at U.S. universities has also increased significantly from 27,932 in 1989 to 42,289 in 2001. Many postdoctoral researchers work in biological sciences (39.4%), medical and other life sciences (30.1%), physical sciences (14.5%), and engineering (7.3%). The median age of S&E doctorate holders employed in academia is rising. In 2001, the median age of full-time faculty was 48.3 years (compared to 46 years in 1989), the median age of postdoctoral researchers was 33 years (compared to 32.6 years in 1989) and the median age of S&E doctorate holders in other positions was 45.6 years

[29] Tenure is a guarantee that a faculty member will remain employed by the university until retirement except in the case of very unusual circumstances such as the elimination of an entire department or extreme misconduct on the part of the tenure holder. The purpose of the tenure system is to preserve academic freedom, to prevent an institution from firing a professor for making unpopular or radical statements or for advocating unorthodox ideas (Education USA, 2005, pp. 116-117).

(compared to 42.2 years in 1989). Given that the average age that students complete their doctoral degree in the United States is 29 years, the relatively high median age of postdoctoral researchers indicates that research graduates are staying in lower paid postdoctoral positions for longer periods of time.

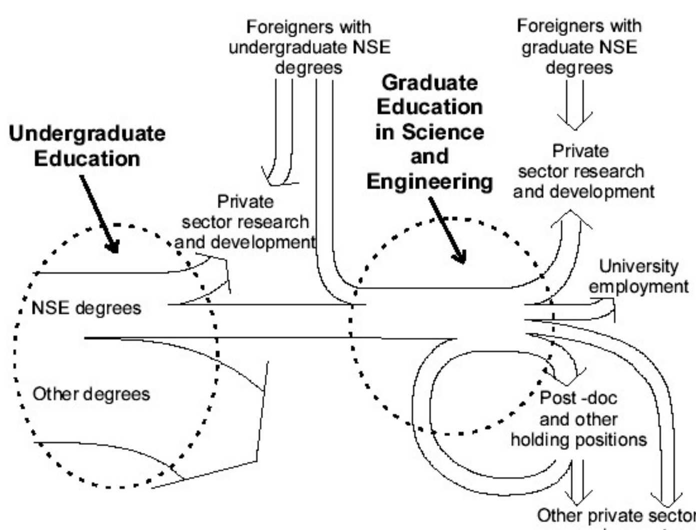
Figure 45: S&E doctorate holders employed in U.S. universities & colleges by activity, 1989 to 2001



Source: National Science Board (2004)

Romer (2000) included the possible career directions for PhD graduates in science and engineering fields in his diagram that depicted the two stages in the production process of scientists and engineers (Figure 46). He was concerned that much of the flow of S&E (PhD) graduates has been directed at university employment and postdoctoral and other holding positions. Growth in academic research appointments has been outstripped by growth in the number of doctorate recipients seeking to work in academia, leading to many of these people working in non-faculty appointments. Romer (2000) argued that the challenge is not to increase the total number of doctorate recipients but to increase the number of them working in private sector research and development. He called for new funding from the Federal Government to encourage universities to introduce innovative PhD programs that would train people primarily for work in the private sector without affecting existing programs.

Figure 46: Production process of scientists and engineers in the United States



Source: Romer (2000) p. 25

Romer (2000) referred to the National Research Council (1998) report, *Trends in the Early Careers of Life Scientists,* which found that young people are finding careers in life science research to be less attractive. A key **disincentive** is the difficulty that doctorate recipients have in securing a permanent position in academia, industry and government. For example, the number of doctorate recipients without permanent full-time jobs five or six years after graduating had increased from 11% in 1975 to 39% in 1995. Many graduates join the ever-growing pool of postdoctoral fellows who stay longer in these positions. For example, the number of people in postdoctoral positions three or four years after graduating had increased from 6% to 29% between 1973 and 1995. At the same time, the supply of life science PhD graduates was rising, particularly between 1987 and 1996 when many doctorates were awarded to foreign students. The Council (1998) argued that these factors have led frustrated young scientists to be caught in a holding pattern:

> These people, most of whom are 34-40 years old, typically receive low salaries and have little job security or status within the university. Moreover, they are competing with a rapidly growing pool of highly talented young scientists – including many highly qualified foreign postdoctoral fellows – for a limited number of jobs in which they can independently use their research training. (p. 3)

The National Research Council (1998) made the following recommendations to address the excess supply of PhD graduates working outside faculty in postdoctoral and other academic positions:

- Restrain the rate of growth of the number of graduate students in life sciences.
- Disseminate accurate information on the career prospects of young life scientists.
- Improve the education experience of graduate students by encouraging Federal agencies to invest in training grants and individual graduate fellowships rather than in research grants to support PhD education.
- Enhance opportunities for the independence of postdoctoral fellows such as career-transition grants for senior postdoctoral fellows.
- Provide alternative paths to careers in life sciences whilst retaining the PhD as a research-intensive degree aimed at training future independent researchers.

Issues raised by the National Research Council about research careers in life sciences can probably be applied to most S&E fields. Consequently, Freeman (2004) found that people are choosing to work in other occupations rather than spending years in low-paid postdoctoral positions before finding real jobs in academia, industry or government. He stated: "Do you want to be a 35-year-old postdoc earning $40,000 in someone else's lab, or an MBA earning $150,000 working in a major business directing others?" (p. 1). He argued that more effort and funding are needed to create attractive research careers. This would involve improved pay and career opportunities for younger scientists and engineers (perhaps at the expense of principal investigators) and addressing the lower research costs brought about by the flow of foreign born researchers. Freeman (2004) called for big agencies like the National Science Foundation and

National Institutes of Health to devote more of their R&D budget to larger and more attractive fellowships and stipends for younger scientists and engineers; a major revamp of the career structure and timing of rewards to ensure that pay and career opportunities are frontloaded rather than backloaded; and an athlete type relationship between principle investigators and young researchers where principle investigators are coaches rather than employers. Apart from improving the job market for scientists and engineers, Freeman (2004) believes another major challenge is ensuring the right balance in the S&E workforce between domestic and foreign supplies.

5.8 Case study results

Case studies of 30 research students in the fields of geospatial science, wireless communication, biosciences, and materials science and engineering from three universities[30] were undertaken as part of this study. Some of the questions that the research students and their supervisors were asked related to the students' mobility experiences and possible career intentions after they graduate:

- Have you undertaken any of your research in other universities or industry at home or overseas? (research students)
- Have you received any training during your doctoral studies related to your research or research management? (research students)
- What are your career options after you finish? (research students)
- Has the student undertaken any of his or her research in other universities or industry at home or overseas? If yes, how was that arranged? Where there any particular benefits or issues? (supervisors)
- Has the student attended training during his or her doctoral studies related to their research or research management? (supervisors)
- What do you think the student could do when he or she finishes? (supervisors)

The international mobility experiences of these students during their studies and possible mobility after they graduate as part of their career intentions are relevant to this discussion on each country's performance in encouraging the mobility of research students and graduates. The mobility experiences of these research students during their studies were mainly short term overseas visits in the form of specialist training, conference attendance and study tours, and in a few cases, longer visits to other universities.

5.8.1 Australia

Table 29 shows that only three of the 10 RMIT research students from the two participating departments were internationally mobile during their PhD studies. These three students presented a paper at an international conference. Lack of funding was the main reason given by those students who were unable to attend international conferences held outside of Australia – although most of the students had

[30] RMIT University in Melbourne (Australia), University of Oulu (Finland) and University of Urbana at Urbana-Champaign (USA).

presented papers at relevant conferences in Australia. One student who had an abstract for a poster presentation accepted at an international conference in Freiburg (Germany) stated that "my supervisor presented by poster and results on my behalf". The same student had established a network (through electronic communication) with researchers at the University of Pennsylvania who were undertaking similar work. The industry supervisor of a student stated "we are expecting her to go overseas soon to feed back into our offices in Paris and in the U.S., in Saratoga". One student acknowledged the benefits of international mobility when he stated that "undertaking research somewhere else is good for the experience, good for your knowledge and gives you an idea of what sort of techniques other people use, and bring that knowledge back to RMIT and Australia. But in my case, I didn't need to as I had the resources I needed". This was the case for most of the other students who didn't see a need for international mobility during their studies, except in the case of attending international conferences. Most of the students were satisfied with the facilities that they had at RMIT University, and some students used the facilities of other local universities.

Table 29: International mobility of RMIT University research students

	Yes	No
International mobility during PhD studies		
Department of Biotechnology and Environmental Biology		
Student 1		✓
Student 2		✓
Student 3	✓ Conference in Spain	
Student 4		✓
Student 5		✓
Department of Geospatial Science		
Student 6	✓ Conference in South Africa and expecting to visit overseas offices of the industry partner	
Student 7		✓
Student 8		✓
Student 9	✓ Conference in United States	
Student 10		✓
International mobility after graduation		
Department of Biotechnology and Environmental Biology		
Student 1	✓ Seeking postdoc position in Australia or Europe	
Student 2	✓ Overseas student, postdoc position at RMIT University	
Student 3	✓ Postdoc position in New Zealand	
Student 4		✓ Postdoc position at RMIT University
Student 5	✓ International student, postdoc position in The Philippines	
Department of Geospatial Science		
Student 6	✓ Seeking consulting work with Australian branch of French based company that will involve travel	
Student 7		✓ Seeking Australian university teaching/research position
Student 8		✓ Government non-research position
Student 9	✓ Migrated to Australia and seeking postdoc position in United States	
Student 10	✓ Migrated to Australia and seeking research work in an Australian university or company	

Five of the 10 RMIT research students have graduated since participating in the study in the first half of 2003. Three of these research graduates are internationally mobile: Student 2 was an overseas student who accepted a post doc position at RMIT University; Student 3 was an Australian student who accepted a post doc position in New Zealand; and Student 5 was an overseas student who accepted a post doc position in The Philippines. The two other research graduates who were domestic students are working in Australia: Student 4 accepted a postdoc position at RMIT University and Student 8 accepted a non-research position in State Government. Of the remaining five students, four are likely to be internationally mobile: Student 1 is a domestic student seeking a postdoc position in Australia or Europe; Student 6 is a domestic student seeking consulting work with her industry partner which would involve regular overseas travel; Student 9 is a permanent resident of Australia originally from China seeking a postdoc position in the United States; and Student 10, a recent permanent resident also from China, is seeking a research position in an Australian university or company. Student 7 is a domestic student seeking a teaching and/or research position at an Australian university.

Most of the research students had a general career direction, but tended to concentrate more on their studies than plan their career. As one student said, *"I just want to take one step at a time at this stage and have just some vague ideas about the future"*; although the same student did say that "*I am pretty sure I don't want to become an academic"*. Another student identified opportunities for himself in a government department or consulting firm but also said he was "*keeping it open and sort it out as we go"*. Two other students who had completed enough work for their thesis were interested in continuing their PhD work. One of these students stated that "continuation of my research is very tempting if I am given an opportunity to stay back and really do a little more work on this. If you are doing research for the sake of getting a degree it is a different matter. It's like I could a degree for just one or two experiments, then wrap it up. Research is a continuous process and once you get so passionate it just continues and difficult to give up and probably addictive to it, constantly thinking about it". The same student was encouraged by her supervisor to "look at America and go to one of the top well funded labs … where she is surrounded by 20 people who know as much or more about what is going on in her area".

One of the Australian students indicated that she may pursue a postdoc in Europe because "other than research I'd like to be overseas to see something different because Australia is pretty isolated. You don't get to see a lot of different cultures. And it's hard to get around. If you are in Europe, it's easy to go from one country to the next, even when it comes to conferences and things like that". Her supervisor also encouraged her to undertake a post doc overseas:

> There are opportunities particularly now in the United States for instance. They have far more research money, and providing you go to an institution with good standing you are in a better position when you come back to Australia as you have those perceived international skills. For good reason or bad, you are probably perceived as better than if you have stayed in Australia.

The supervisor of the student who is an Australian permanent resident from China and seeking a post doc in the United States believed that she would undertake a post doc position overseas:

> Unlike perhaps Australian domestic students, she is far more receptive to thinking about positions overseas as she is used to travelling, she is used to getting around, she is determined and she wants to succeed in this area. I am sure if we could find a suitable positions as a post doc in North American or Europe I am sure she would do well.

Two of the students secured post doc positions in RMIT University, one in the same research group and the other in a different school. The supervisor of another student (an Australian permanent resident from China) expects him to remain in his group as a researcher:

> After the PhD it depends on the funding and also the commercial stuff. If after a year that the commercial thing can be profitable I think he will remain in the group and transfer to a researcher instead of a student. I think he will probably be transferred into a part-time student, full-time working on the commercial side and part-time on the PhD.

5.8.2 Finland

Nine of the 10 University of Oulu research students had been internationally mobile during their PhD studies (Table 30). The tenth student is planning mobility activities. Mobility activities typically included attendance at conferences, meetings, workshops, forums and courses. One of the students stated that Biocenter Oulu regularly funds students to attend relevant conferences and courses:

> Biocenter is one big organisation that funds. For example, in the course in Croatia, I went with Biocenter money. There is also the possibility to apply for grants from foundations. But many times it is very easy to apply from money from Biocenter and quite easy to get money from there.

One of the students from the Centre for Wireless Communication (CWC) described the support provided:

> "Usually when you write the conference paper you are allowed to go to that conference to present your results … It's very important for our sponsors to show our work in that forum so it does not matter even if it is outside Europe".

Apart from conferences and courses, two students participated in a study tour to San Diego and Lund in southern Sweden as part of Biocenter's Biobusiness course. Two students were based at other universities in Europe for an extended period of time. One student from the Centre for Wireless Communication (CWC) was based at the University of Aachen for about one month not only because his Finnish supervisor was working there but also because "I don't know all the other people who Petri is working with there and the resources that are there. It also benefits me to have time by myself just to work on my PhD". Another student who was based at the University of Groningen in the Netherlands for a couple of months explained that "my supervisor comes from this group of Groningen. We also had a post doc from here. The programs I've been using have been developed in Groningen so in that group there is lots of expertise".

Table 30: International mobility of University of Oulu research students

	Yes	No
International mobility during PhD studies		
Centre for Wireless Communication (CWC)		
Student 1	✓ Conference/forums/workshops in United Arab Emirates, Norway, Japan, Portugal, United States (Boston), China and Singapore	
Student 2	✓ Conference/forums/workshops in Portugal, France, Germany and The Netherlands	
Student 3	✓ Two conferences in United States (Boston)	
Student 4	✓ Conference/forums/workshops in Hawaii, United States (Boston and Baltimore), Portugal, Denmark, Greece, Italy and South Africa	
Student 5	✓ PhD placement in Aachen University (Germany) and conference in Alaska (Anchorage)	
Biocenter Oulu		
Student 6	✓ Conference in Prague	
Student 7	✓ Meetings in Germany, United Kingdom (Brighton) and Greece; course in Croatia; and study tour to United States (San Diego) and Sweden (Lund) as part of Biobusiness Course	
Student 8	✓ Course in United Kingdom (Brighton), summer school in United Kingdom (Manchester), collaborative project at University of Groningen, and study tour as part of Biobusiness Course	
Student 9	✓ Conference in Vienna	
Student 10	✓ Planning to attend conferences/meetings and undertake study tour as part of the next Biobusiness Course	
International mobility after graduation		
Centre for Wireless Communication (CWC)		
Student 1		✓ Likely to remain at CWC
Student 2	✓ Post doc position in Finland but likely to work abroad	
Student 3		✓ Likely to pursue research in Finnish industry
Student 4	✓ Migrated from Italy and likely to remain in Finland	
Student 5	✓ Migrated from the U.S, and likely to remain in Finland	
Biocenter Oulu		
Student 6	✓ Seeking postdoc position in Canada or Central Europe	
Student 7	✓ Seeking postdoc position in United States or European Union	
Student 8	✓ International student from Italy seeking postdoc position in Europe	
Student 9	✓ International student from India seeking a postdoc position in an English speaking country	
Student 10		✓ Likely to remain in Finland as a PhD student after completing Masters

Four of the 10 University of Oulu research students originated from abroad (two from Italy, one from the United States and one from India). Two of these students are likely to remain in Finland after they complete their studies. One student stated that he wanted to stay in Finland to "go on with this research because here there is a lot of interest" and also because he had settled in Oulu: "I am an Italian that comes from Oulu. This is my town". One of the international students from Biocenter Oulu intends to leave Finland to pursue a post doc position in an English speaking country "where I will have better interaction with people and could learn much more than what I have learnt here in the past two years". Both research students from the CWC who originated from abroad had participated in student exchanges at the CWC during their Masters studies.

Of the six Finnish students who were case studied, three of them had no plans on leaving, and the other three students were planning to work in Europe or North America. Two of the Finnish students intending to work abroad had undertaken student exchanges during their previous studies. As stated by one of these Finnish students, “it is usually very common that people go into some other groups to do their post doc work and that is something I’m most likely to do, whether in Finland or abroad, in the European Union or in the United States. There are lots of places for postdoc people”. Another student who has graduated and is continuing to work in the CWC intends to work abroad at some stage: “I am managing one European Union project with Markku which will start in the beginning of next year. The project will go for two years. In some future time I will try to go abroad for sometime”. The other Finnish student intending to work abroad is likely to return to Finland:

> I think I will go abroad for a couple of years and then after that back to Finland. I would like to go to Canada again to Ontario or Montreal but also Central Europe to Switzerland, Austria, Germany would be possible. Hopefully for a company not university because I have an idea I would like to work on R&D questions for a Finnish biotech company when I get back from my postdoc period. So I would like to get knowledge on working for a company abroad, kind of getting ideas for Finnish companies.

The coordinator of the Graduate School Infotech Oulu collects data related to collaboration with other universities, such as the number of visits and duration. He found that there were “much more people coming here than people going out. Most of these are graduate students. If there is deeper co-research operation, half year visits are common”. Where there are frequent visits between research centres, the research groups usually “hire a house for the whole year and all the time some people from the research group is here”. One of the functions of the Coordinator of the Graduate School for Biocenter Oulu is to manage travel grants: “Although we get funding for 30 PhD students at this moment, we have decided that all PhD students who are working here in Biocenter groups they are members of our graduate schools. So they have the same rights to get those travelling grants and participate in our education”. He also stated that the Graduate School is aiming to collaborate further with universities to encourage greater mobility and internationalisation of research students. The Director of the CWC also discussed the importance of international mobility to networking and high quality research to the centre:

> We want people to be able to go to an event, network, have an impact where they go. Deliver their message and have it well received. Build relationships to form networks. Also the work they do should be of international standard, world best, world leading type activities. We are also encouraging good students to go overseas, spend some time at another university, not any university, but universities where we have a good relationship or a good group of people. We certainly want to raise our profile and have better international relationships and connections with key research centres around the world. We have research agreements with MIT, ETH (Swiss

> Federal Institute of Technology) in Zurich, University of New South Wales in Australia, and several other places. We want to start sharing and internationalising our people a little bit more. We are placing two people at MIT, placing someone at ETH, placing some people in Canada and hopefully in Australia as well as bringing more people over here. So getting better connected with the rest of the world.

5.8.3 United States

Three research students from the University of Illinois at Urbana-Champaign (UIUC) were internationally mobile during their studies (Table 31). Two students attended international conferences outside of the United States and one student was awarded an *East Asia and Pacific Summer Institutes for U.S. Graduate Students Fellowship* from the National Science Foundation to work as a visiting researcher at the University of Western: "I'll be spending two months and will be bringing some of these samples with me. There is a professor who has a similar technique to analyse these. I want to compare what he is doing with what we are doing. Which is better. What can I learn about both techniques to build the best system". The other seven students were not internationally mobile but were mobile within the United States where they regularly attended relevant conferences, meetings, workshops and specialist training, and/or collaborated with other universities:

> I work in conjunction with researchers at other universities. The University of Wisconsin has been very good to me. So I have done a lot of work with pathologists up there who know my advisor rather well and they do a lot of conjunctive studies. So we will run material back and forth. We will visit each other a couple of times a year. Talk about projects.

The lack of international mobility by these research students may be due to the availability of relevant events and courses within the United States and the existence of high level research and infrastructure at the UIUC (which in turns attracts researchers from elsewhere to the UIUC). As stated by one department head:

> The faculty are outstanding. That is something we work on very hard when we recruit. We tend to attract, recruit and retain leaders in the field. Part of this comes because the environment that we have locally and the infrastructure that we have. We have built up tremendous infrastructure in terms of tools that we can play with to do our research. And of course since we have a good nucleus, we've got a good record with funding agencies especially for getting new equipment we can play with. Those resources in our case are open. They are not intended to be for isolated uses. Open policies where graduate students get trained then get turned lose on millions of dollars equipment.

Table 31: International mobility of University of Illinois at Urbana-Champaign research students

	Yes	No
International mobility during PhD studies		
Department of Materials Science & Engineering		
Student 1		✓
Student 2		✓
Beckman Institute of Advanced Science & Technology		
Student 3		✓
Student 4	✓ International conference in Puerto Rico	
Student 5	✓ Summer school at the University of Western Australia funded by the National Science Foundation	
Department of Crop Sciences		
Student 6	✓ International meeting in South Africa	
Student 7		✓
Student 8		✓
Student 9		✓
Student 10		✓
International mobility after graduation		
Department of Materials Science & Engineering		
Student 1		✓ Seeking a teaching position in universities or a postdoc position in a national lab
Student 2	✓ International student from India seeking a postdoc position in United States in industry or another university	
Beckman Institute of Advanced Science & Technology		
Student 3		✓ Seeking work as an educational developer
Student 4	✓ International student from China working as a postdoc at Beckman Institute, UIUC	
Student 5		✓ Seeking a postdoc position in university
Department of Crop Sciences		
Student 6		✓ Working as a postdoc in Crop Sciences, UIUC
Student 7		✓ Working as a visiting senior research specialist in Crop Sciences at UIUC
Student 8		✓ International student from Argentina who has returned home to work as a specialist in pathology and weeds
Student 9		✓ Working as an extension and research (plant pathology) specialist at the University of Nebraska
Student 10		✓ International student from Argentina intending to return home to work in a university or to set up a soil consultancy

Four of the ten students from UIUC were international students. The students from China and India were both seeking postdoc positions in the United States. One of these students wanted to remain at the Beckman Institute of Advanced Science & Technology (and since being interviewed has secured a postdoc position there) because: "Illinois is a pretty good place plus Beckman Institute is a very unique place to work. Basically here you meet every kind of person. Down the hall is Professor Schulten's simulation, and the other end of the hall is the chemistry people. The lab is there and if I need some help, there is the NCSA upstairs". Both students from Argentina intended to return home. Family and cultural ties were the reasons given by one of these students: "I think in Argentina that is where my roots are. The culture is different. They are much more socialable people than here. People here are colder and live to work". None of the six local (U.S. born) students discussed intentions to work abroad at some stage. They all planned to remain in the United States and most were seeking postdoc positions in universities. Two students have been employed by the same department at UIUC where they completed their PhD and another student is working as a postdoc in another university.

5.9 Chapter summary

This chapter started with an explanation of international mobility and migration of research students and graduates by describing common terms, its importance, drivers, obstacles and mobility indicators. International mobility and migration of highly skilled people is vital to the science and technology performance of countries by facilitating knowledge transfer, creating new fields of knowledge when researchers come together, and increasing the stock of available human capital. Australia, Finland and the United States have a range of programs in place which aim to facilitate the international mobility of research students and graduates. However, each country faces different issues in gaining full benefit from international mobility.

In Australia's case, Linkage International and the Endeavour Programme are key initiatives that encourage international mobility through postgraduate and postdoctoral awards. There is also a range of mobility initiatives that are funded by other Governments, educational institutions and private organisations in Australia and overseas. International mobility opportunities were found to be limited and highly competitive, and only three of the 10 RMIT students had between internationally mobile during their studies. In terms of international migration, the Commonwealth Government has successfully encouraged greater permanent and temporary stays of skilled people by expanding the skilled migration program, allowing graduating overseas students to apply for permanent residence without leaving Australia, and reducing restrictions on temporary work visas. Data indicates that there has been a large increase in the number of foreign research students in Australia but not as large as foreign enrolments in lower degrees. The net loss of 12,152 Australian residents in S&T occupations between 1995/1996 and 2002/2003 was offset by continuing increases in settlers and visitors in S&T occupations, leading to net gain of 38,119 people in S&T occupations. Similarly, the net loss of 700 Australian residents who attained a PhD between 1996 and 2001 was offset by a gain in migrants and the return of Australians with a PhD, resulting in an overall gain of 1,730 people who attained a PhD between 1996 and 2001. The key mobility issue for Australia is the loss or *brain drain* of Australian residents in S&T occupations who were *pulled* by their desire to see the world, higher material rewards and greater research opportunities; and *pushed* by scarce jobs in some scientific fields in Australia and the inability of Australia to acknowledge and reward high achievement.

Key providers of mobility programs in Finland are the Academy of Finland and the Centre for International Mobility (CIMO). Programs funded by Tekes, the European Union, and other Finnish and international organisations also facilitate international mobility. In addition, the Finnish Government has in place an *International Strategy for Higher Education* and a strategy for the *Internationalisation of Finnish Science and Technology.* These efforts are proving successful in encouraging greater international mobility of tertiary students to and from Finland through student exchanges. The number of research students participating in student exchanges or undertaking doctoral studies in Finland remains small. Also of concern is the downward trend in the number of Finnish teachers and researchers making overseas visits and the number of foreign researchers visiting Finland. Despite increases in the foreign born population, Finland has low migration rates and consequently the share of foreign HRST remains below other European countries. Finland is well aware of the obstacles it faces in attracting foreign research students and graduates, such as its remoteness from global market centres, language and severe climate. Those that have made it to Finland were attracted to the high level research environment and as a whole were satisfied with the quality of information and guidance provided. As a result, nearly half of those people surveyed in 2004 were intending to stay permanently in Finland. Friendships, personal contacts and recommendations are proving to be the most successful ways to attract foreign students and researchers to Finland. Although most of the Finnish research students are internationally mobile, activities are usually short term (i.e. international conferences, workshops and/or courses) and may not be sufficient to develop strong and ongoing international networks.

The United States has been very successful in attracting and retaining research students and graduates, which had led to a dependency on the supply of foreign students and researchers. The majority of foreign PhD students on temporary visas have been funded through programs that support international mobility and/or by financial assistance available from different sources. Until recently, an increasing number of foreign recipients of U.S. S&E doctorates stayed in the United States, contributing to a steady rise in the number of foreign citizens working as S&E postdoctoral researchers. Events on 11 September 2001 and increased competition elsewhere in the world for S&E students and talent have led to falls in foreign students and researchers, suggesting that the United States is no longer the primary destination for these people. OECD data on the net balance of international student exchange shows the total number of foreign students in the United States exceeded the number of U.S. students going abroad by 544,000 in 2002, indicating that local research students are less mobile during their studies. This was confirmed by case study data that showed only three of the 10 research students from UIUC had been internationally mobile during their studies and eight of the 10 students were planning to remain in the United States, or return to their home country, after graduating.

A basic analysis of research careers in Finland, Australia and United States was also presented in this chapter to determine whether talented people are encouraged to pursue research careers in the three countries. Australia, Finland and the United States employ researchers at rates that are consistently above the OECD average, and all three countries have expanded the number of research jobs (particularly in industry in Finland and the United States). Overall, people with doctoral degrees were found to account for a small proportion of those people who work as researchers, particularly in the business sector. Despite the existence of publicly funded programs that support research careers, the attractiveness of research careers remains an issue in each country for similar reasons. These reasons include the difficulty in securing permanent positions, pay rates that are below other professional occupations, and intense competition for fellowships and scholarships. Academia remains the key career choice for many research graduates mainly because this is where their interests lie; research training programs may not have prepared them to work in other sectors; and/or demand for research graduates in industry is not sufficient. In light of the issues highlighted in this chapter, Australia, Finland and the United States should reassess how they approach international mobility and research careers in order to attract and retain talent.

Chapter 6: Knowledge production and distribution by research students (30 case studies)

6.1 Introduction

The second element of the conceptual framework explores the contribution of the 30 research students (case study participants) to knowledge production and distribution within a national innovation system. There is a focus on whether the actual R&D work performed by these students is likely to contribute to an innovation (Research Question 6). Research students were asked the following questions about their **R&D work** and these questions were slightly rewritten for the supervisor interviews:

- Where did the idea for your topic come from?
- How relevant is your research to the needs of the industry/users? Who will benefit?
- What role, if any, has industry (i.e. the users of the research) played in your research?
- Have you (or are you considering) commercialising your research?
- What will happen with your research/results?
- How are you disseminating your results?
- What is innovative about your research?

Research students and supervisors were also asked a number of questions about the **research training environment**. The purpose of these questions was to assess the research training environment against the characteristics of an innovative culture i.e. an internal market for ideas, capital and talent; risks are managed; and innovation is a core competency entrenched within the culture of the organisation:

- Are you encouraged to generate new ideas by your supervisor/department? How do they respond to new ideas?
- Have there been risks or issues that have arisen or could arise with your research? How does your supervisor/department assess and manage risks related to your research?
- Are there any intellectual property issues? Are there measures in place to protect the intellectual property of your research?
- Have you received any training in innovation or commercialising research?
- What infrastructure do you use to undertake your research? How adequate are these facilities?
- How are you funded as a research student? Is this funding arrangement impacting on your ability to undertake your research?
- What does the term innovation mean to you?

Case study findings in relation to some of the above questions have been framed around a discussion in this chapter about knowledge production and distribution in a national innovation system and the preferred capabilities of researchers within knowledge-based economies. This discussion identified the following features that are likely to enhance the contribution of knowledge production and distribution by research students to a national innovation system:

- Knowledge transfer to the research students (from supervisors and other sources) and knowledge creation by the research students are based on the features of both Mode 1 and Mode 2 knowledge production (although Mode 1 by itself can lead to discovery-based knowledge production).
- Research students are trained in a way that develops their knowledge in not only the codified areas of *know-what* and *know-why* but also in the tacit areas of *know-how* and *know-who*.
- Research students are provided with opportunities to maximise existing knowledge bases and are kept up-to-date with new knowledge.
- Research students are encouraged and/or shown how to widely distribute their research findings to relevant publics.
- Research students are exposed to different fields and social networks, particularly those that are associated with university-industry relationships.
- The research training program in which the research students are enrolled aims to develop those capabilities required by employers operating in a knowledge-based economy.

The analysis of the case studies in the second half of this chapter focuses on three areas that incorporate most of the above features:

- <u>Knowledge production</u> - The new knowledge produced by the 30 research students is extended beyond Mode 1 by incorporating key features of Mode 2. Students consider the context of application i.e. their research is useful to industry, government or society; and students are encouraged to constantly interact with, and seek input from stakeholders such as potential users of their research and researchers from different fields. These practices lead to research results that are transdisciplinary. This part of the analysis also aims to address Research Question 6 which is linked to the context of application: Is the R&D work performed by research students likely to contribute to an innovation?
- <u>Knowledge dissemination</u> - Mode 2 knowledge production includes the effective dissemination of new knowledge beyond the traditional Mode 1 methods of reporting in professional journals and at conferences. Knowledge is diffused to stakeholders through the process of production, ensuring that the social return of the R&D expenditure is maximised. Research training should ensure that research students are encouraged to widely disseminate their findings and provided with incentives to do so. Intellectual property arrangements should not restrict the disclosure of new knowledge, particularly knowledge produced with public funds.

- Capability development - The contribution of research students to a national innovation system (either during their studies or after they graduate) is also expected to be enhanced if research training equips them with the four different types of economically-relevant knowledge i.e. *know-what*, *know-why*, *know-how* and *know-who*. Many of the characteristics of Mode 2 knowledge production and distribution (which overlap the four different types of economically-relevant knowledge) reflect the capabilities that employers expect of researchers. Some of these capabilities presented in this chapter include applying scientific and technological expertise in shifting problem contexts; collaborating with project teams (within and across disciplines) and external agents to create new products, processes and systems i.e. innovation potential; generic skills like project management; and adapting to a more open and heterogeneous environment.

6.2 Knowledge production and distribution in a NIS

There are three pieces of literature that are widely cited by those who write about the importance of knowledge (as a critical input in the production of goods and services) to economic growth within a national innovation system, and therefore to the competitiveness of countries. Michael Gibbons, Camille Limoges, Helga Nowotny, Simon Schwartzman, Peter Scott, and Martin Trow in their 1994 book, *The New Production of Knowledge*, argue that knowledge generation has shifted from Mode 1 to Mode 2. Learning is the most important process in economies in which knowledge is the most fundamental resource is the key message in the 1994 journal article, *The Learning Economy*, by Bengt-Åke Lundvall and Björn Johnson. Paul David and Dominique Foray focused on how to improve the production and utilisation of scientific and technological knowledge in their 1995 STI Review article, *Accessing and Expanding the Science and Technology Knowledge Base*. These articles provide important insights into knowledge production and distribution, which have been considered in this study's analysis of how the 30 research students are receiving, creating and disseminating knowledge within their national innovation system.

Before presenting the aspects of the above literature which are most relevant to this study, it is necessary to describe what is meant by a **knowledge-based economy**. McKeon and Lee (2001) defined a knowledge-based economy as "an economy in which the production, distribution, and use of knowledge is the main driver of growth, wealth creation and employment across all industries" (p. 1). Ideas and knowledge transform economic activity into innovation. Knowledge is regarded as technological, cultural, social and managerial (most of which is tacit), and organisations develop knowledge by integrating information with experience and expertise to take action. McKeon and Lee (2001) identified human capital (the competence of the firm), structural capital (the organisation's ability to learn and adapt), and external capital (the organisation's customers and other relationships) as key elements of a knowledge-based economy. These elements require a significant investment by society in human capital, the information and communications infrastructure, and science and technology.

The OECD (2004C) identified three key characteristics of a knowledge-based economy. Firstly, the increasing speed at which knowledge is created, accumulated and depreciated in terms of economic relevance and value. Secondly, a knowledge-based economy invests in human or *intangible* capital to "create new knowledge and ideas and incorporate them in equipment and people" (p. 14). Thirdly, breakthroughs occur through formal R&D (learning off-line), learning online where individuals learn by doing, modular structures of technological systems[31], and ICT based systems geared to the production and dissemination of knowledge and innovation. The following drivers were found to be increasingly important to innovation in a knowledge-based economy (OECD, 2004c): the interaction between people in communities of knowledge; the capacity of different sectors to "codify" or make explicit knowledge that can contribute to economic advance; and the relationship between the public aspects of knowledge that allow it to spread and the private features that give an incentive to private agents to produce it in the first place (pp. 9-10). Individuals within a knowledge-based economy are expected to learn how to learn and how to manage their learning (OECD, 2000), which is placing pressure on the education system to adequately prepare students for life and work in a knowledge-based economy.

One of the best known books about the changing nature of knowledge production and distribution is by Gibbons et al. (1994). They found that knowledge generation has shifted from taking place in a traditional disciplinary, primarily cognitive context (referred to as **Mode 1**) to broader, transdisciplinary social and economic contexts (referred to as **Mode 2**). Gibbons et al. (1994) identified the following differences between Mode 1 and Mode 2 knowledge production:

> In Mode 1 problems are set and solved in a context governed by the, largely academic, interests of a specific community. By contrast, Mode 2 knowledge is carried out in a context of application. Mode 1 is disciplinary while Mode 2 is transdisciplinary. Mode 1 is characterised by homogeneity, Mode 2 by heterogeneity. Organisationally, Mode 1 is hierarchical and tends to preserve its form, while Mode 2 is more heterarchical and transient. Each employs a different type of quality control. In comparison with Mode 1, Mode 2 is more socially accountable and reflexive. It includes a wider, more temporary and heterogeneous set of practitioners, collaborating on a problem defined in a specific and localised context. (p.3)

A **socially distributed knowledge production** system has emerged as a key feature of Mode 2. In such a system, knowledge is produced when it is useful to industry, government or society; involves continuous negotiation between the various actors; and is diffused throughout society. Research and problem solving is usually organised around the context of an application although it can involve genuine basic research. As Mode 2 knowledge production is undertaken by practitioners with different skills who join together in a framework of action, the result is transdisciplinary i.e. goes beyond any one single discipline. A research team consists of people with different skills and experience from a number of university and non-university sites[32] where knowledge is created. As a team is formed temporarily to solve a problem, flexibility and response time are crucial factors. Afterwards, team members will form different groups to

[31] Modularity is building a complex product or process from smaller subsystems that can be redesigned independently yet function together as a whole. The fact that different companies or different units are working independently on modules is likely to boost the rate of innovation. (OECD, 2004, p. 52)

[32] Non-university sites include institutes, research centres, government agencies, industrial laboratories, think-tanks, and consultancies (Gibbons et al., 1994, p. 6).

solve different problems. Team members are linked together through highly mobile communication networks that support electronic, organisational, social and informal interaction. Given the importance of social accountability and reflexivity, the team will represent different stakeholders (and/or build in such considerations from the start) and reflect on the purpose and outcomes of the research. Quality of the research in Mode 2 is determined by a wide set of criteria based on intellectual, social, economic and political interests compared to peer review in Mode 1. Gibbons et al. (1994) found that creativity in Mode 2 is manifested as a group phenomenon whereas in Mode 1 individual creativity occurs within disciplines and is "hidden under the consensual figure of the scientific knowledge" (p. 9). The new Mode 2 knowledge is diffused through the process of production to team members who form and maintain communication networks and then move into new problem contexts. This compares to reporting in professional journals or at conferences in Mode 1.

As the number of research graduates has exceeded that required to work in disciplinary structures, many graduates are working in other sites such as government laboratories, industry, think-tanks and consultancies. Consequently, there are more sites that are competent in carrying out research, which is undermining the monopoly that universities have on knowledge production. This was a key factor that led Gibbons et al. (1994) to urge governments to rethink how they model their scientific and technological institutions from that largely based on Mode 1 knowledge production. This includes a different approach to policy that integrates "education, science and technology and competition policy into a comprehensive innovation policy that is sensitive to the fact that knowledge production is socially distributed" (pp. 15-16).

Section 3.3.1 in Chapter 3 described how a learning economy is integral to the interactive learning approach to national innovation systems. Lundvall and Johnson (1994) identified four different types of **economically-relevant knowledge** that are combined in the innovation process in a learning economy: ***know-what*, *know-why*, *know-how*** and ***know-who***. Lundvall and Johnson (1994) argue that *know-how* is the most important type of knowledge in the economic process as this is how new methods and products come about and is much more difficult to learn than facts and science i.e. *know-what*. Much of *know-how* is tacit, embedded in human and social context, and is unable to be codified. In a more recent article, Lundvall (2000) continued to stress the importance of *know-how* by stating that it is a characteristic of successful businessmen and great scientists who have "experienced based capabilities to interpret and give meaning to emerging complex patterns and to act purposefully on the basis of this insight" (p. 2). Given that many new products are based on technologies from different scientific disciplines, Lundvall (2000) also highlighted the increasing importance of *know-who* i.e. "the social capability to co-operate and communicate with different kinds of people and experts" (p. 2). Acquiring *know-how* typically through apprenticeship relationships and *know-who* through social practise and learning in specialised education environments involve a large amount of trust[33] and social capital.

[33] Knack and Keefer (1997) found that interpersonal trust and norms of civic corporation are essential to well functioning societies and contribute to stronger economic performance and innovation. In their study on levels of trust and civic norms in 29 market economies, Finland ranked second (2nd), Australia ranked sixth (6th) and the United States ranked eighth (8th).

Given the significance of sub-national and supranational systems in shaping technological opportunities, David and Foray (1995) were cautious about discussing how science and technology knowledge is produced and utilised within a *national* system of innovation. This is because science and technology activity is increasingly organised and conducted internationally, and as such, many institutions are operating beyond their national boundaries. They also found that a significant amount of scientific and technological knowledge is not completely codified. As a result of these factors, David and Foray (1995) stated that there must be opportunities for direct personal contact among parties involved in order to assimilate and transfer such knowledge – for example, informal and formal networks which link scientists and engineers in private companies and research workers in educational and pubic research institutions.

David and Foray (1995) criticised the lack of attention given in public policies to the processes of knowledge access and distribution in innovation systems. They argued that innovations systems should not be assessed only by input measures like R&D expenditures and output measures like patents or high-tech products but also by the use of the knowledge produced[34]. They called for an **efficient system of science and technology learning** that would increase the social value of the knowledge that is produced through wider distribution and inexpensive access to new findings. Wider access to knowledge would "increase the probability of useful new products and processes arising from novel and unanticipated combinations" (p. 22). This would lead to an increase in the marginal social rate of return on R&D expenditure and an increase the social payoff from past outlays through greater commercial exploitation of new knowledge. The science and technology learning system proposed by David and Foray (1995) is characterised not only by its ability to generate new knowledge (which many countries have concentrated on doing for some time) but also by its *distribution power* i.e. its ability to "support and improve the efficient functioning of procedures for distributing and utilising knowledge" (p. 23). Improving the distribution power of a system requires countries to modify intellectual property arrangements in a way that would speed up disclosure of new knowledge, reduce the marginal costs of accessing new technological information, and promote co-operation and investment coordination. Individuals must be provided with incentives to enter into co-operations and an ability to search within the entire possible space of knowledge distribution.

6.3 Capabilities of researchers in knowledge-based economies

The changing nature of knowledge production and distribution within knowledge-based economies is significantly impacting on the capabilities expected of research students when they graduate. Many of these capabilities are being developed in environments that involve university-industry relationships or are under increasing pressure to so. This section presents findings from Alice Lam (2002), Hans Schuetze (2000) and Mary Walshok (1995) in relation to researcher capabilities that are regarded as essential for contributing to innovation in a knowledge-based economy. This literature informs the analysis of the case studies in terms of the capabilities that the 30 research students have developed as a result of their research training. In a

[34] Measures of the use of knowledge included ratios between what is produced and what is used (by recombination, diffusion, dual development, change of form, etc.), and how efficiently they allocate resources between accessing existing knowledge bases and undertaking (potentially duplicative) independent programs of discovery and invention (David & Foray, 1995, p. 61).

critique of a presentation about this study in Maastricht in 2003[35], Bengt-Åke Lundvall stated that the key function of research training in a national innovation system is to develop capabilities:

> I would say for research training that the most important link is the way the PhDs enter the labour market after they have finished their PhD. That is the most important. PhD is still training, it is not primarily there in order to produce patents, they might contribute and it is interesting to note if they do. But this is not the major aim. The major aim is to train people to come with capabilities where they can go in and work in different fields.

Alice Lam (2002) examined how the emergence of the knowledge-based economy has impacted on the organisation of R&D and the types of skills and knowledge required for productive and innovative activities. Her key findings presented in Figure 47 were based on six in-depth company case studies in the pharmaceutical, chemical and ICT sectors in the United Kingdom. Lam (2002) argued that knowledge-based economies are characterised by **third generation R&D** which she defined as follows:

> The third generation R&D requires the integration of R&D into business and organisational context. Yet in contrast to the market-driven second generation R&D, it seeks to maintain the ability to generate new knowledge beyond the existing core competencies. Innovation in third generation R&D is generated in the context of application and networks of interaction within and external to the enterprise. It is a de-centralised, network form of R&D organisation. The ability to access knowledge from a wide variety of contexts and sources is critical to sustaining its capability to generate radical innovation. (p. 8)

Figure 47: R&D models of innovation and competence building

Model of R&D	First generation	Second generation	Third generation
Innovation & knowledge strategies	Strong corporate R&D centralisation Knowledge accumulation	Divisional R&D decentralisation and externalisation Knowledge acquisition	Alliances and partnerships Decentralisation and internal/external networking Knowledge sharing and creation
Operational forms	Bureaucratic	Market-based	Network organisation
Types of knowledge workers	Mode 1 ⟶ Disciplinary experts Problem identifiers and problems solvers		Mode 2 Transdisciplinary experts Problem identifiers, problem solvers and strategic brokers
Competency building	Internal labour market (ILM) Internal core competence Careers and training	Reduced ILM Sub-contracting and externalisation	Extended internal labour market (EILM) Extension of "core" to external knowledge suppliers (e.g. universities)
University-industry relationships	Linear model ⟶ Supplier of fundamental knowledge Certified competence Pool of codified knowledge		Interactive model Partner in knowledge generation Reputation-based competence Tacit knowledge embodied in people and institutional networks

Source: Lam (2002), p. 20

[35] Economics of Technological and Institutional Change (ETIC), European Doctoral Training Programme, Maastricht, The Netherlands, 13-24 October 2003.

Lam's findings about the impact of the third generation model of R&D on knowledge workers and university-industry relationships were particularly relevant to this study. In this model, **R&D (knowledge) workers** operate in flexible and interactive environments in which their work (and therefore innovation) is increasingly organised in a multidisciplinary basis. Managers interviewed were critical of universities for putting too much emphasis on academic specialisation, which led to graduates who regarded research as a process of solving pre-defined problems. One of the managers stated that "research is about knowing what to do when nothing is written down. It is about learning to anticipate the unexpected and deal with it" (Lam, 2002, p. 11).

Lam (2002) identified several Mode 2 attributes that company managers sought in R&D workers and that universities must incorporate into their curriculum:

- Broad understanding of the context and strategic vision beyond traditional disciplinary expertise
- General capabilities, including project management skills
- Innovative potential
- Operating in interdisciplinary and transdisciplinary project teams
- Applying scientific and technological expertise in shifting problem contexts
- Collaborating and negotiating with external agents
- Exploiting external knowledge
- Engaging with business functions and other corporate functions
- Adapting to a more open and heterogeneous environment given the increasing volatility and diversity of R&D careers and roles.

Lam (2002) found that **university-industry relationships** had moved away from first and second generation R&D models where knowledge flows were linear from academia to industry. The university was the primary source of fundamental knowledge and supplier of certified competencies in these earlier models. Relationships are closer and interactive in the third generation R&D model in which academia and industry are co-producers of knowledge and human resources, thus facilitating the transfer of codified and tacit knowledge. This two way flow of knowledge and mobility of people requires the construction of social networks. These social networks enable a range of linking mechanisms (such as collaboration in research, industrial inputs to curriculum development, student placements, and exchange of staff) and forge long-term, multi-dimensional and trusting relationships i.e. strategic partnerships. Companies are able to access the best talent, influence the education of students and graduates, and gain access to research results before they are published. These findings led Lam (2002) to extend the concept of extended internal labour markets (EILMs) to university-industry relationships which she defined as the "active role of firms in developing social networks of knowledge and skills resourcing" (p. 16). Lam (2002) referred to Cyert and Goodman (1997) who proposed evaluating the effectiveness of university-industry relationships by whether learning is created at the organisational level for both the university and the firm rather than the level of funding, technology transfers and papers.

Hans Schetze (2000) wrote a chapter on how industrial innovation and knowledge creation and dissemination is impacting on university-industry relationships as part of the OECD publication, *Knowledge Management in the Learning Society*. He recognised the enormous increase in the commercialisation of research and university-research linkages over the last decade and the ongoing challenge that universities face in making their research more relevant and accessible to industry. However, Schetze (2000) was critical of universities for not engaging more in learning activities made possible through these linkages[36]. He argued that technology transfer "is often seen as unrelated to other university activities, especially teaching and learning" (p. 168). Schetze (2000) identified several ways that **teaching and learning functions** of universities could be organised to contribute to industrial innovation. Given the massive increase and rapid turnover of knowledge, he recommended that universities look at new forms of extension and dissemination beyond the traditional channels of teaching and scholarly publications. As shown in Table 32, Schetze (2000) matched university-based knowledge resources against the three types of knowledge flows identified by Walshok (1995): education and training to provide professional/work-related updates as part of lifelong learning; the synthesis of knowledge from different disciplinary fields; and knowledge, diffusion, transfer and exchange.

Table 32: Knowledge needs and university-based knowledge resources

Knowledge needs	Knowledge resources
Professional/work-related updates	➢ Professional continuing education ➢ Developmental continuing education in new knowledge areas or interdisciplinary fields. ➢ Skill training in new technical fields in response to, changing or emerging job requirements, such as laser technology in manufacturing, new diagnosis/technologies in medicine, new paradigms in fields such as biotechnology. ➢ Training for crossover skills, such as management skills for engineers.
Knowledge brokering across fields and industries	➢ Provision of interdisciplinary knowledge and skills to practitioners and problem solvers in technical, social, economic and community contexts. ➢ Provision of assistance on complex interdisciplinary problems such as regional economic development or technology assessment. ➢ Interactions between researchers and practitioners in areas of research-affected practice undergoing rapid changes.
Knowledge updates through knowledge diffusion, transfer and exchange	Provision of science based information and knowledge to: ➢ consumers and users of basic research interested in the application of research findings for new services, processes, or products ➢ constituencies interested in new business formation, such as venture capitalists, bankers, new entrepreneurs ➢ professionals and lay people whose work requires technological literacy, such as journalists, managers, environmental experts, etc.

Source: Schuetze (2000) p. 170

[36] University-industry linkages or forms of collaboration include corporate affiliation programs, consortia for pre-competitive R&D (including centres of excellence), contract R&D, modelling and testing, use of university researchers as consultants, purchases of patents and copyrights, hiring of university graduates, internships, co-operative education placements, and participation in continuing professional education and other learning activities (Schetze, 2000, Table 1, p. 165).

Schetze (2000) used the example of engineers to discuss the particular challenges they face and how university-based knowledge resources could be used to address these challenges. His findings are also applicable to research training. For example, universities could provide continuing education and skills training that enable research students and graduates to keep up-to-date with new scientific and technological knowledge that is being generated rapidly. Universities could broker knowledge across fields through the provision of interdisciplinary knowledge and skills and assistance with interdisciplinary problems. Universities could provide more science-based information and knowledge to consumers, users, constituencies, professionals and lay people – thus increasing knowledge diffusion, transfer and exchange. Such a role would involve more active outreach and liaison activities, particularly with enterprises, and incentives to encourage academic staff to do so.

Schuetze (2000) based a significant amount of his discussion about knowledge needs and university-based knowledge resources on the 1995 book by Dr. Mary Walshok, *Knowledge Without Boundaries: What America's Research Universities Can Do For the Economy, the Workplace, and the Community*. With greater demand by industry, organisations and groups for access to university knowledge resources together with the pressure on universities to be more accountable for the benefits of their new knowledge, she called for universities to have "better institutional mechanisms for connecting the new knowledge they develop to increasingly larger and diverse publics who can use and contribute to that knowledge" (p. 2). Walshok (1995) argued that this would require the creation of a **new cadre of university students and staff** who are characterised by:

- an interest in and knowledge of real problems and their societal, economic and political context
- an ability to function effectively as members of a team creating new products, processes and systems
- an ability to operate effectively beyond the confines of a single discipline
- an integration of a deep understanding of science and technology with practical knowledge, a hands-on orientation, and experimental skills and insight.

6.4 Case study results for Australia

6.4.1 Introduction

Ten (10) research students enrolled in a Doctorate by Research from the Department of Biotechnology and Environmental Biology and Department of Geospatial Science at RMIT University were case studied in the first half of 2003. Table 33 contains the research topics and funding sources for these students. Table A20 in the appendix describes their R&D work in more detail. This section starts with an overview of RMIT University and the two departments before analysing the case study findings within the three areas informed by element 2 of the conceptual framework: Knowledge production, knowledge dissemination and capability development.

Established as the Working Men's College in La Trobe Street in 1887, RMIT University is a dual sector university offering over 200 higher education and TAFE programs to around 57,000 students. It employs around 3,500 staff across three main campuses in Melbourne (City, Bundoora and Brunswick), two regional sites (Hamilton and East Gippsland) and an international campus in Vietnam. RMIT University attracts students in the many fields, in particular Management and Commerce and Engineering and Related Technologies, and is also known for its large overseas student population (which accounted for 25% of all enrolments in 2003). There were 1,691 research students enrolled at RMIT University in 2003, and 60% of these research students were enrolled part-time.

Table 33: RMIT University case studies

	Research Topic	Funding source
Department of Biotechnology and Environmental Biology		
Student 1	Development of a vaccine for the prevention of necrotic enteritis in poultry	CRC for MicroTechnology
Student 2	Examining the major causes of mastitis in dairy cows to develop a rapid diagnostic test	APAI/Linkage grant
Student 3	Bacterial germ, *Campylobacter*, in the paralytic disease Guillian Barré syndrome	International Postgraduate Research Scholarship (IPRS)
Student 4	Genes in grasspea controlling resistance to fungal disease, *ascochyta blight*	APAI/Linkage grant
Student 5	Examining the whole genome response in plants to auxinic herbicides	Internal RMIT scholarship
Department of Geospatial Science		
Student 6	Representation models for the delivery of useful, interactive geospatial information services via the mobile Internet	APAI/Linkage grant
Student 7	Data integration – an application in rural property valuation	Internal RMIT scholarship
Student 8	Creation of a predictive model for salinity risk in the Murray Valley Irrigation Region of New South Wales	APAI/Linkage grant
Student 9	Creating sustainable cities – the role of green systems an biodiversity in urban environments	Internal RMIT scholarship
Student 10	Development of a miniaturised real time kinematic GPS system with high accuracy, velocity and acceleration	CRC for MicroTechnology

The *Department of Biotechnology and Environmental Biology* is a large, multidisciplinary department with around 50 academic and support staff and over 60 research students. It offers postgraduate research degree programs in plant pathology and biotechnology, gene technology, bioprocessing technology, microbiology, and environmental biology and ecotoxicology. Research students are based in the purpose-built Biosciences Building at Bundoora which houses high tech labs and other facilities to support research in several life science and biotechnology fields. The building includes collaborative, multidisciplinary research areas and conversation areas for students and staff. The *Department of Geospatial Science* has a long history, going back as far as the early 1930s when RMIT University first delivered lectures to cadet surveyors. Today it has over 60 academic and support staff, with an increasing number of research students. It offers PhD programs within its core research areas of sustainable development, multimedia and geographical visualisation sciences, geographic information systems (GIS) technologies and applications, remote sensing technologies and applications, and measurement sciences such as global positioning systems (GPS).

Both Departments have a track record of attracting external funding through national competitive grants and industry sources. As a result, many research students are recruited to work in projects with an industry partner, some of these supported by Australian Research Council Linkage Grants and CRC fellowships. Other students are funded by Commonwealth Government Australian Postgraduate Awards or International Postgraduate Research Scholarships, or were awarded an RMIT Internal Scholarship with a HECS (fee-free) place.

To be eligible to enrol in a PhD by Research degree at RMIT University, students must have a Masters degree from RMIT University or have qualifications or experience that are deemed equivalent. Masters by Research students may also transfer or upgrade to a PhD. The duration of the candidature for a full-time PhD research student is a minimum of two years to a maximum of four years (with a normal duration of three years). For full-time Masters by Research students, the duration is one year to two years (with a normal duration of 1.5 years). All research students are required to pass a research methods course, normally in the first semester of enrolment. They also must gain approval for their research proposal at a first review of candidature (which usually involves a verbal presentation and submitting a proposal of between 3,000 and 5,000 words) within the first six months for full-time students. Research that involves humans or experimentation on animals must conform to ethics requirements. During their candidature, research students are required to make a presentation based on their work (referred to as the *second review*) which is usually organised by the academic unit in which the student is enrolled. They must also complete progress reports at least every six months. Students are encouraged to publish their work in journals and conference proceedings. The upper limit for thesis sizes is 55,000 words for a Masters by Research and 90,000 words for a Doctor of Philosophy. The thesis is examined by at least two external examiners who are given around eight weeks to complete the examination.

6.4.2 Knowledge production

6.4.2.1 Context of application

Department of Biotechnology and Environmental Biology: Three students were investigating animal related diseases (necrotic enteritis, mastitis, and Guillain-Barré syndrome) with the intention that their research would lead to the development of a vaccine or test. In the case of Student 2, the development of a rapid and cheap diagnostic test for the detection of mastitis that would be used at some later point by veterinary laboratories was an expected outcome of her research. Similarly, Student 1 was developing a vaccine to combat necrotic enteritis to proof of concept stage as part of her research. Student 3 expected his findings to lead to applications in the longer term but not as part of his research: "The findings will allow researchers to devise treatments and curative strategies like drugs and vaccines." Student 4 was continuing research that had started 10 years ago and her findings would contribute to further research aimed at developing a more resistance field pea crop. Research by Student 5 on the genome responses in plants to auxinic herbicides was likely to be the start of a long program of research that in time would contribute to the development of novel herbicides.

Department of Geospatial Science: Three research students were aiming to develop an actual application and/or innovation. Student 10 was developing a compact GPS speedometer and accelerometer with state-of-the-art accuracy and performance at low cost. At the time, this student and his supervisors were applying for a provisional patent. The industry partner of Student 6 was planning to use her findings to improve the representivity and interactivity of their geospatial information services. Developers and service providers were likely to use her findings at some later stage. The predictive risk model for salinity risk developed by Student 8 was expected to be used widely by practitioners in the agricultural sector. Research by Student 7 (rural property valuations) and Student 9 (creating sustainable cities) provided findings that were useful to a range of stakeholders and, with further research, could lead to applications in the future.

6.4.2.2 Interaction with stakeholders

Before discussing the extent to which these students interacted with stakeholders, it is worth noting the funding sources of these students. Funding sources indicate the involvement of stakeholders prior to the students commencing their research degree. Four of the 10 students were funded through Australian Postgraduate Awards Industry (APAI) as part of ARC Linkage grants between RMIT University and industry partners. Two students received PhD scholarships from the Cooperative Research Centre (CRC) for MicroTechnology to undertake projects supported by industry. Three students were funded by internal RMIT University scholarships and one student was funded by the Commonwealth Government's International Postgraduate Research Scheme (IPRS). The extent to which the students interacted with relevant stakeholders varied significantly from having no contact to close contact. The Commonwealth Government assumes that ARC Linkage grants facilitate the exchange of postgraduate students between sectors and encourage greater dialogue between universities and industry. This occurred for two of the four research students who were funded through an ARC Linkage grant. The degree of interaction seemed to depend more on the extent to which the supervisor supported this interaction combined with the motivation of the student and the nature of the topic.

<u>Department of Biotechnology and Environmental Biology</u>: Student 1 (CRC scholarship) had not interacted very much with key stakeholders (i.e. the poultry industry) because her "research is still in the process of getting developed." She believed that there would be greater interaction when "you have something to show them." Her contact with the stakeholders was more indirect given comments from her supervisor: 'She gives reports to the CRC and what she had done has been reported in the context of the report back to the Rural Industries Research & Development Corporation". Student 2 (APAI/Linkage grant) visited a commercial VET lab and a milk factory, and surveyed 17 labs in Australia and New Zealand. Student 3 (IPRS) had not interacted with potential users, although he had created national and international links with scientists who were interested in his research. Student 4 (APAI/Linkage grant) had minimal involvement with her industry partner, which her supervisor explained was due to the retirement of the direct link from the Victorian Government department two years earlier. Student 5 (internal RMIT scholarship) met regularly with representatives from the chemical company: "Off and on we meet and have meetings to show them the progress of my work". The industry partner explained that she has met with a range of people at the company:

> She interacts not so much with me at the technical level but the development team – Australian R&D manager, formulation people, a couple of chemists. She would come out here once every six months and a little more frequently at the beginning because we were in the process of selling the project internally and letting people know what they got themselves in for. It is an issue of communicating what R&D is doing as it is a cost not a benefit. That is how a lot of people see it and if there is a benefit, it is long term. And it's risky. Sometimes projects fail for a whole host of reasons. And other people in sales, production and marketing actually pay for it. So you need to have them on side. You are an unnecessary evil to some of them.

Department of Geospatial Science: Student 6 (APAI/Linkage grant) is based in the industry partner's office two to three days a week where they "introduced me to a lot of people that can help me. One human factors expert, some of the companies they are working with to get ideas. They are there for support when I am developing". Although research being undertaken by Student 7 (internal RMIT scholarship) was supported by a Victorian Government department, their involvement was limited at that time to "bits I fill in, valuation specific information that she might not have a good knowledge of. Otherwise there isn't much. I usually come in when she has finished something and will go over it". The supervisor of Student 10 (CRC scholarship) has taken a lead role in interacting with the industry partner while the student is more responsible for data collection: "We had quite a number of experiments and field trials in Canberra and those guys do the work. So those guys implement the idea. I will design the big frame. When required, they attend meetings, do the data processing, field work and those kinds of things". Student 8 (APAI/Linkage grant) interacted regularly with the industry partner to gather data, provide results and obtain feedback. The industry partner explained that the interaction was more frequent at the start of the project:

> He gives us regular update reports where it is up to. It could be an informal email, and is normally six monthly. In the initial phases it was quite regular. As time went on he was focused on his own field activities. The number of meetings and reporting in the initial phase of the project was quite frequent until we were quite certain we were going on the right path. It takes time for any research student to set up the model. From the industry perspective and from a supervisory perspective, David's role is to ensure he is going on the right path and right direction so we can meet our final goal and final objective.

According to her supervisor, Student 9 (internal RMIT scholarship) has interacted as much as possible with stakeholders:

> She has been doing her best and been supported to interact with the key players located in the fields, so academics elsewhere in Australia including the University of Melbourne, Melbourne City Council, Darebin, Kingston and other councils in metropolitan Melbourne. She has brought with her that legacy of working in a civil environment in Brisbane and Greater Brisbane … So she has been interacting with people on Council, senior members of those councils in terms of policy making and bureaucrats, and people involved in the day-to-day operating management of areas.

Some students mentioned that they had used lab and library facilities at other universities, sought specialist advice from people outside of their department, and were liaising with other scientists. In all cases, their research occurred within their own disciplines.

6.4.3 Knowledge dissemination

6.4.3.1 Dissemination of findings

The Mode 1 methods of journals and conference papers were the main methods that the students were using or planning to use to disseminate findings to their relevant scientific community (Table 34). Some students were presenting results at meetings and/or in reports to stakeholders (such as industry partners), and planning to conduct workshops. The Department of Biotechnology and Environmental Biology coordinates a seminar series where experts and research students who are nearing the completion of their studies present topics to staff and students. Some of the research students had already given a presentation at the Department's seminar series. Student 2 produced and disseminated a report on survey findings to VET labs that participated in her survey. The supervisor of Student 9 stated that she may distribute summaries of key results to stakeholders. Overall, students did not have a strategy in place to widely disseminate their results to stakeholders as the results were produced.

Table 34: Methods of disseminating research results, RMIT University

	Mode 1 methods	Other methods
Department of Biotechnology and Environmental Biology		
Student 1	Conference presentations and journal articles (planned)	CRC activities Reports to CRC
Student 2	2 journal papers (1 planned), 3 Australian conference/meeting poster presentations	Report of research findings to participating VET labs
Student 3	3 journal papers (2 planned), 2 conference presentations (Australia and international). International presentation made by supervisor on behalf of student.	3 presentations to science community, including department seminar series
Student 4	4 journal articles (3 planned, Australia and international), 1 conference paper	1 presentation to science community at department seminar series
Student 5	1 conference presentation and journal articles (planned)	3 presentations to science community, including department seminar series Meetings/reports to industry partner
Department of Geospatial Science		
Student 6	2 journal articles (Australian and international, planned), 3 conference papers (one international)	Guidelines for optimal representation, presentation and interaction techniques for industry use Meetings/interviews with stakeholders, with international meetings planned Workshop for industry (planned)
Student 7	1 journal article, 2 conference presentations (one poster)	Occasional meetings with Government department Presentation by Government representative (planned)
Student 8	2 articles, 4 conferences presentations	Face-to-face and written reports to industry partner Community workshop (planned)
Student 9	2 conference presentations (one international)	Group and individual meetings with meetings Summaries of key findings to stakeholders (planned)
Student 10	At least two publications (planned)	Meetings with stakeholders CRC activities Provisional patent

6.4.3.2 Incentives

As stated in section 4.2.1, research publications account for 10% of the funding formulae for the Research Training Scheme (RTS) and Institutional Grants Scheme (IGS). Universities receive funding from the Commonwealth Government when their research students produce refereed publications. For those research students wanting to pursue an academic career, a publications record is essential. As such, these students have an incentive to publish. For some students, the possibility of attending an international conference may be another incentive to publish. Only three of the 10 research students had attended an international conference during their studies, due mainly to funding limitations.

RMIT University Guidelines to Examiners of Theses (2002) explain that one of the purposes of a research degree is to provide research students with skills to identify, solve and present problems. Therefore, to some extent the examination process is context-oriented. However, significant weight is given to whether the thesis can lead to publications: "The originality and significance of the contribution to the field, and the rigour of the independent, critical thought should be high enough to suggest that the candidate can initiate and conduct independent research leading to publication in a scholarly journal or equivalent" (p. 3). There are no requirements in these guidelines for students to effectively disseminate their results to all relevant publics.

According to RMIT University's Intellectual Property Policy of August 2004, R&D intellectual property created *solely* by a research student is owned by the student *except* when they are employed by the university or when they are involved in a project or specific commission "in which the University or any party to an agreement with the University has provided funds, equipment, facilitates or supervision" (p. 4). In these circumstances, research students may be required to enter into an intellectual property and/or confidentiality agreement before commencement, which may impede their ability to disseminate their findings. Six of the 10 research students were required to sign an intellectual property statement when they enrolled because they were funded through an ARC Linkage grant or CRC scholarship. Some of these students were concerned that they did not fully understand what they were signing. For example:

> I don't know the measures in place, maybe I should. Because of the CRC, I have part rights of what happens but CRC has main intellectual rights and RMIT gets a percentage – they can split, but I'm not sure of the split. When I started I wasn't sure where I was going to get up to and if there was going to be any intellectual property or commercialisation as the end result. I didn't know much about IP at the start so hard for me. You sign at RMIT to get the scholarship, to get the scholarship you need to sign forms, you sign with the CRC to get the scholarship, because as a student you need some form of income or are you meant to work for three years unpaid. At the point, I was thinking about doing this but I'd like to get paid for it. I didn't think of IP until my second year where I started to learn these things. So I said to myself, am I still OK? Have I done anything wrong? Have I signed the wrong forms? They tell you to sign before you learn about it and then you learn about it and you have already signed and can't change it.

The policy also states that the university may restrict public access to a thesis for a specified period in order for those concerned to benefit commercially from the research results. This was expected to happen to one student who at the time was involved in a provisional patent application. One of his supervisors stated: "We will seek restricted access for some time. Sensitive material which normally goes into the library is held off for three to five years. Examiners will have to sign a confidentiality agreement". The intellectual property agreement signed by the student at the commencement of the project meant that he would get less than 10% of any commercial income which his supervisor believes is not a big enough incentive for researchers:

> Currently the final percentage is not decided. Normally a split procedure is CRC 50% and RMIT 50%. Because we are an employee or student of RMIT, what we get is just from RMIT, and RMIT normally keeps 50% and the other 50% is given back to the research group. In that research group we have quite a number of people and have to split it somehow. To Jason, something like less than 10% of the whole thing. Because it is not an incentive to researchers, CRC is changing its rules. RMIT will still get 50%, whatever according to RMIT policy you can split. CRC policy is you can also split, maybe 40% to researchers, 60% remains, so if the new policy is in place we will get double.

In another case, the industry partner negotiated a formal IP agreement with RMIT University at the start of the project. According to her supervisor, this agreement "really tied down rigorously to who owns what … It was agreed that the student owned the results of the research and they owned the proprietary software". Conversely, another industry partner (a State Government department) believed that the results should be shared with other areas facing similar problems:

> "If the approach is found or we validate the approach here, and found it quite beneficial, why do we want to keep it to ourselves? Other areas confronted with similar situations should be able to use it and that is the case in other irrigation parts of NSW or for that matter in Victoria".

6.4.4 Capability development

Research students had a high level of knowledge about their topic i.e. *know-what* and the reason for undertaking it i.e. *know-why*. Most supervisors talked about specific skills that the student had developed i.e. *know-how*. For example: "He is far more of an expert in a particular area of technology. He has researched very thoroughly. Programming and technical skills"; and "In her PhD, she has learnt how to cross plants, interpret genes, create linkage maps, fish genes out of plants, make a cDNA library, and most importantly, how to put everything together at the end of this writing stage". One supervisor referred to the importance of developing generic and transferable skills:

> Some people stay within the particular topic they did their PhD in but her generic skills are such she could apply what she has learnt in clostridia in most other infectious disease, cancer research, all that sort of research I call molecular microbiology. In some ways you don't want to only be in one particular narrow niche but use your skills for what is available in the scientific job market.

Another supervisor described his research student as "one out of the box" and "a standout" with four key qualities: "Common sense, initiative, willingness to go and read something through and think about it, and hard work". The same supervisor was concerned about the quality of some of the PhD graduates:

> In our cohort in the Department there are clearly students who are clever and students who are less clever. There are students who are less clever and still get over the line. But the standout ones in terms of being productive, being innovative, making the next step. I worry we are producing PhD graduates who really aren't going to end up initiating, supervising and running actual projects.

Comments about the ability of students to co-operate and communicate with different kinds of people and experts i.e. *know-who* were limited. One supervisor commented that "she developed the ability to work with industry contacts and drag together those contacts in meetings and so on". Another supervisor described the increased confidence of his student, leading to improved communication skills;

> He has developed a tremendous amount of skills in different areas. Basic techniques developed over the past 3.5 years are only part of it. Confidence in his own research has grown into something very outstanding and he is very good at giving presentations. That's really what I have tried to teach all students. It's a lot more than being good at techniques and being an expert in the field, but also the qualities of being a good scientist and presenting your data. There are many scientists that can't communicate with anybody and it's such a pity they don't have these skills.

All research students at RMIT University have an opportunity to participate in online generic capabilities modules offered by the Australian Technology Network (ATN) Leap Project. Modules include Project Management, Entrepreneurship, Leadership and Communication, Research Commercialisation, and Public Policy. None of the 10 research students mentioned that they had participated in these modules, but one student did enter and win (with his supervisor) the major prize in the 2002 RMIT Business Plan Competition.

6.4.5 Key findings for Australia

As indicated in the descriptions of their R&D work in Table A20 in the appendix, all 10 research students from RMIT University had an excellent understanding of the reasons for undertaking their research and the benefits that were likely to arise (who would benefit and how). The head of one of the departments stated that "our work here is what I class as applied advanced scientific. Most of our projects are looking at potential applications rather than just doing science. Other universities are at the basic science level and we are at the applied level". The research undertaken by the research students was context-oriented, aiming to explore and solve real problems. Most of the students believed that their research could lead to an application/innovation, and this was happening during the PhD candidature in some cases. In other cases, further research beyond the PhD study would be required. As stated by one supervisor in this situation: "In the context of her PhD, she would get it to proof of concept. There is possibility of funding for a post doc position for the translation of proof of concept to prototype. If I can get money and have had some discussions already, she is an appropriate person to appoint".

The research students were aware of the stakeholders who could benefit from their research. The level of interaction that students had with stakeholders and activities they undertake to disseminate research results to stakeholders varied significantly. Some students were researching only from a mode 1 perspective i.e. conducting the majority of research within their own group and disseminating results to their scientific community through journal papers and local conference presentations. Other students liaised regularly with key stakeholders, providing research results throughout the production process. There were not enough incentives to encourage research students to develop a strategic approach to effectively disseminate their research results to all relevant stakeholders. Thesis examination requirements and intellectual property arrangements at RMIT University may restrict the ability of research students to widely disseminate their results. In terms of capability development, research training was providing students with the ability to generate knowledge in terms of *know-what*, *know-why* and *know-how*. Most students did not have the opportunity to attend international conferences held outside of Australia due to funding restrictions – thereby limiting their exposure to international networks. More effort is needed to ensure that students are exposed to different fields and social networks within Australia and overseas to develop their knowledge in terms of *know-who*.

6.5 Case study results for Finland

6.5.1 Introduction

Ten (10) research students from the Centre for Wireless Communication and Biocenter Oulu at the University of Oulu were case studied in the second half of 2003. Table 35 contains the topics and funding sources for these students.

Table 35: University of Oulu case studies

Research Topic		Funding source
Centre for Wireless Communication		
Student 1	Physical layer issues of ultra wideband systems	Part of Future Ultra Wideband Radio Systems (FUBS) project funded by Nokia, the Finnish Defence Forces Technical Research Centre, Elektrobit and Tekes
Student 2	Equalization in WCDMA terminals	Advanced Baseband Receiver Algorithms for Wideband CDMA Systems (ABRAS) project funded by Nokia and Texas Instruments
Student 3	Performance study on ad hoc networks and MAC-layer techniques	Part of Future Radio Access (FUTURA) project funded by Nokia, Elektrobit, the Finnish Air Forces, Instrumentointi Oy, and Tekes
Student 4	Physical layer evaluation and analysis of Ultra Wideband Communication Systems	Part of FUBS project funded by Nokia, the Finnish Defence Forces Technical Research Centre, Elektrobit and Tekes
Student 5	Alternatives to routing for wireless embedded networks with mobility	Part of TRILLIAN project funded by Nokia
Biocenter Oulu		
Student 6	Phosphatidylethanol (PEth) as a marker molecule and a cellular factor	Supported by grants from the Finnish Foundation for Alcohol Studies and the Yrjö Foundation
Student 7	Type I, II and III prolyl-4-hydroxylase knock-out mice, and properties of modified recombinant fibrillar collagens and their fragments	Graduate research position funded by the Ministry of Education and funding from FibroGen Inc
Student 8	Protein-ligand interaction: affinity calculations	Graduate research position funded by the Ministry of Education
Student 9	Theoretical studies on prostate specific proteins	Graduate research position funded by the Ministry of Education
Student 10	Interactions of SCP-2L and TPR-domain of PEX5 at the molecular level	Seeking funding from European Commission to continue Masters research at PhD level

The University of Oulu was formally established in 1985 and is currently structured around four focus areas: Information Technology, Biotechnology, Northern Issues, and the Environment. As at 2003, there were 15,829 students of which 1,347 were doctoral students and 3,096 staff. Over 80% of students were from the northern regions of Finland i.e. Province of Oulu and Province of Lapland. The university coordinated seven graduate schools in the autumn of 2003, with the graduate schools of Biotechnology and Information Technology accounting for the majority of doctoral degrees awarded.

The University of Oulu and local industry established the **Centre for Wireless Communication (CWC)** in 1995 with a mission to "conduct scientific research supporting users and developers of wireless communication systems in their research, development and application projects, as well as to enhance the exchange of know-how between the University and society in an academic environment" (CWC, 2003, p. 5). The CWC is an independent research institute with an annual budget of around 5 million euros. It is entirely funded by projects financed by outside sources such as the Tekes, European Union, Nokia, Finnish Defence Forces, Elektrobit, Texas Instruments, Saab and other international companies. It has strong international connections and partnerships in the United States, Europe and Japan. The focus of research at the CWC is future broadband air-interface and wireless networking technologies. Research for the Finnish Defence Forces has concentrated on radio communication systems. Currently, the major research application areas are ultra wideband systems (UWB) and fourth generation (4G) mobile systems.

In 2003, the CWC employed around 90 research staff which included professors, postdoctoral researchers, postgraduate students preparing their licentiate and doctoral thesis, and graduate students preparing their diploma or master's theses. The CWC is part of Infotech Oulu, an umbrella organisation for information technology research at the University of Oulu. The CWC has several doctoral students from the Infotech Oulu Graduate School as well as doctoral students from the Graduate School in Electronics, Telecommunication and Automation (a collaboration of four Finnish universities). To complete the licentiate or PhD requirements, research students are required to complete 160 units of courses offered by the CWC or graduate schools, three or four referred publications and a thesis. Once the thesis has been accepted by the external examiners for publication, students publicly defend their research topic.

Biocenter Oulu was established by a small number of research groups in 1986 "to provide the University's most talented researchers with a sustainable research environment that is internationally competitive. From the very beginning there has been emphasis on excellence in research and education, regular international peer evaluation, and collaboration extending across disciplinary and faculty boundaries" (Biocenter Oulu, 2003, p. 6). Biocenter Oulu is made of up 20 research groups and around 300 staff (including over 150 PhD students) within 11 departments of the Faculties of Science, Technology and Medicine and at the University Hospital. The total funding of the Biocenter and its research groups was 11 million euros in 2002, with 53% from the University of Oulu and 46% from outside sources such as the Academy of Finland, industry, foundations, European Union, University Hospital and Tekes. Most biomedical research groups, administration, the graduate school and some of the core facilities were relocated to a new building at the Medical Campus in 2004.

The **Biocenter Oulu Graduate School** was established in 1995 and is the largest graduate school in the fields of bioscience and biomedicine in Finland. All research students are employees of Biocenter Oulu and are members of the graduate school. There are 30 four-year PhD positions funded by the Ministry of Education. Other positions are funded by the Academy of Finland, foundations or other external sources secured by research groups. The key function of the graduate school is to provide postgraduate education in the areas of cell and molecular biology, developmental biology, molecular medicine, structural biology, biobusiness and bioethics. These topics are delivered in English through seminars, advanced courses, short summer courses and workshops. Students are required to complete 40 units of credits, publish three or four articles in leading international journals, and prepare and defend a thesis. The graduate school coordinates thesis committees where PhD students report on the progress of their research, and gives grants to PhD students to visit laboratories and participate in courses in Finland and abroad. The graduate school invites international experts to deliver topics related to cutting-edge research and to meet with research groups and interested students.

6.5.2 Knowledge production

6.5.2.1 Context of application

Centre for Wireless Communication (CWC): The five research students from the CWC are employees who undertake their PhD research as part of, or related to industry funded projects. This is explained further by the Director of the CWC:

> They are all employees. Some people are employed on a part-time basis. The five students are full-time employees. We both have a university requirement regarding thesis progress and the projects requirement. We live and die with projects; if we don't have projects we don't have people. Some projects are closely aligned with research topics than others. Ideally, we get projects and research topics that are perfectly aligned. That tends to be the case in the FUTURA project, fairly academic project with competence building. Whereas the military projects allow for very little academic progress, staff are still required to make academic progress irrespective.

The PhD and licentiate research by these students is cutting-edge, context-oriented research that is based on the needs and/or interests of the potential users who are also funding the research. As stated by one of the students, "the idea of research projects is that they benefit the sponsors. Otherwise, why would they fund these projects? Supporters are willing to fund this research, so obviously they have some clear ideas how to benefit from this". Student 1 who is researching interference issues with ultra wide band explained further:

> The main reason why the sponsors came and funded us is that they like to have information about what is technology, what they can do, and is it worth anything … it is to give this theoretical background to the industry and then they can use this information we provide and start doing something which might be in the interest of their applications.

Student 2 expects that findings from his research will be considered for "real applications and real implementations". Student 3 believes the sponsors are interested in his research "because ad hoc networking and generally wireless networking is going to be a hot thing in the future and is already". Student 4 who works closely with Student 1 (who are both funded through the Future Ultra Wideband Radio Systems project) believes that his "research is good because when someone starts to think about building the system and starts to think about all the possible systems you can create using this technology, he can restrict the choices based on the results we have produced". Student 5 stated that the key reason why industry funded his research was "to make money. That is a reality in my research field. This kind of technology goes to companies who want to produce money, profit. It is going to benefit them". He believes "companies who for instance make sports products or make products who need to embed things more" will benefit significantly from his research.

Despite the students' research being clearly context-oriented, both the Director of the CWC and Coordinator of Infotech Graduate School were concerned about the length of time it took for people to complete their PhD whilst undertaking their normal project work. The Director of the CWC is aiming to reduce the completion time to "five years as a maximum". The Coordinator of Infotech stated that the CWC has "good postgraduate courses and their research is unquestionably top quality". However, he went on to explain that "to finish their PhDs is the problem in our point of view. This is a problem everywhere in our research groups, but especially there. People are working in industrial projects and PhDs are not top priority".

Biocenter Oulu: The five students who participated in the case studies were from three research groups within Biocenter Oulu. In four of these cases, research results were expected to contribute to a broad base of knowledge aimed at solving a particular problem or opening up other possibilities. The supervisor of Student 7 stated that her student's research into recombinant collagens "could lead to some applications in medicine" such as "sponges to stop bleeding" and "skin in burn injuries". The research being undertaken by Student 8, Student 9 and Student 10 from the Biocomputing Group is likely to "springboard" further studies by the scientific community. As stated by the supervisor of these three students, "most of the work is directed towards better computational models, which are faster and give good and accurate results". In the longer term, drug designers in the pharmaceutical industry are expected to benefit from the availability of such tools:

> Computational tools for drug design are being explored a lot because you have so many possibilities when you design a drug and so many possible effects. If you can save 1% of your time because you have a good computational tool so you are doing analysis rather than buying enzymes and working in the lab that is a lot of time and money that you can save.

The other student from Biocenter Oulu (Student 6) was developing a simple, sensitive and rapid immunoassay method for testing the blood samples of patients to detect the level of alcohol consumption. If the detection method proves to be successful, the student believes he will provide the health care system with a tool to identify those people who are at the high risk of getting alcohol-related liver disease or Pancreatitis. At the time of interview, the student and his supervisor were patenting his research.

6.5.2.2 Interaction with stakeholders

Centre for Wireless Communication: The five research students from the CWC were encouraged to interact with experts and peers through conference and workshop attendance. As part of reporting arrangements for industry projects, the research students regularly met face-to-face with the sponsors of their research. For example: "We meet usually bimonthly. This goes within project procedures. We produced also plenty of written documents within the project. So cooperation was good and they provide technical steering". Similarly, another student stated that "I think it's scheduled every four months. There is a steering group meeting where the funding for projects is discussed in one part and there is a technical part where you just show some of the results". In some of these meetings, the presentation of results is more structured: "Sometimes researchers also do briefings and presentations in FUTURA [Future Radio Access] and direct comments from sponsors are received". Apart from meetings, one research student stated he "is frequently communicating with the sponsors" and another research student stated "I work with some of the companies quite closely. I have a pretty good idea where they see their business case".

Two of the students commented that the information they provide about their PhD in meetings with their sponsors is part of overall project reporting and is tailored to meet the interests of the sponsors. The following comments from two students explain this approach further:

> The FUBS project is funded by industry and Tekes. The industry partners may not know that I am doing a PhD. They are not interested in our academic degrees but are interested in what we can give.
>
> Usually we don't anyway present too many results as most of the people participating are mainly related to economical issues. What we try to do is put some good stuff to say we are dong well. You don't tell them everything. Even if you tell them everything they get bored because most of them are not technical people.

Biocenter Oulu: Research being undertaken by two of the five students from Biocenter Oulu was supported by project funding from two foundations (Student 6) and a U.S. company (Student 7). At the time, these students had not interacted with their sponsors. Similarly, none of the students from the Biocomputing Group has interacted with potential (industry) users of their research results. All the students to varying degrees had interacted with their relevant scientific communities through attendance at conferences, workshops and courses.

6.5.3 Knowledge dissemination

6.5.3.1 Dissemination of findings

Centre for Wireless Communication: All five research students regularly disseminated their research results as part of the project reporting arrangements to their sponsors (Table 36). Relevant results were usually embedded in reports and presentations to sponsors made about the larger project. The CWC also hosts seminars where staff and students present their work. The research students are expected to present their work at relevant conferences and workshops, and to prepare papers for publication in high quality journals. Some students had produced more conference and journal papers than other students due mainly to the fact that some students were nearing the completion of their studies and others had just started. One student described the publication guidelines at CWC:

> We have some publication policy rules in CWC. The major dissemination media are journals and international and national conferences in the field of telecommunication. Usually when you write the conference paper you are allowed to go to that conference to present your results.

The Director of the CWC explained the type of dissemination activities that students are involved in:

> We are trying to get people to go to conferences with good quality papers. Good quality conferences, not techno-tourism conferences. We have some rules in place. The first conference must be here in Finland, then Europe, then the rest of the world. Maximum twice a year and they should try and get that maximised. There are also a lot of workshops related to projects that happen within Europe, EU programs. Also ad hoc groups, things called COST, interest groups with a semi-formal nature.

Table 36: Methods of disseminating research results, University of Oulu

	Mode 1 methods	Other methods
Centre for Wireless Communication		
Student 1	2 journal papers, 8 international conference/workshop papers, and 5 local (Finland) conference/workshop papers	All students (as employees) present research results as part of reports to and meetings with project funding bodies. They also make presentations to CWC staff. Three students were involved in patent applications as part of their overall research project.
Student 2	2 journal papers, 1 book chapter, 10 international conference/workshop papers, and 1 local conference/ workshop paper	
Student 3	1 journal paper (submitted), 1 poster presentation, and 1 international conference/workshop paper	
Student 4	1 journal paper, 7 international conference/workshop paper and 4 local conference/workshop papers	
Student 5	1 journal paper and 1 international conference paper	
Biocenter Oulu		Biocenter Seminar Series
Student 6	4 journal papers (2 planned)	1 international meeting, 1 university presentation, 1 patent application
Student 7	1 journal paper	3 international meetings, 1 patent application by industry partner
Student 8	1 journal paper, 2 international conference poster presentations and 2 local conference poster presentations	1 collaborative project
Student 9	2 journal paper, 1 international conference paper	Invited speaker at local workshop
Student 10	1 journal paper	

<u>Biocenter Oulu:</u> Research students from Biocenter Oulu are also encouraged to present their research results at conferences and in journals. Two of the students had attended international meetings of their scientific community, one student used and extended her results in a collaborative project with another university, and another student was invited to present his results at a scientific meeting in Finland. One student stated that "when you go around and talk to people you realise there are many more applications that you can actually do, so it helps with future planning". Results from one student have been patented by the industry partner in the United States. The student who is developing the alcohol detection

method/tool had to delay some of his publications because of his patent application. The supervisor of this student also mentioned that he was likely at some stage to make a presentation at Biobreakfast which is a meeting between companies and scientists held in Oulu once a month. One supervisor discussed the process that her students take to prepare for presentations:

> I think it is easier for the students to give an English presentation first in our sort of small group that you are familiar with everyone before going into some international big meeting. Then the next step is to give seminars in our Biocenter seminar series. Biocenter currently has 12 biosciences groups so you have a broader audience and then the next step is these international meetings. So our idea is that every student should attend an international meeting every year.

6.5.3.2 Incentives

Research students in both the CWC and Biocenter Oulu are required as part of their PhD requirements to publish three or four referred publications in leading international journals before submitting their thesis. As stated by one supervisor, "without papers people cannot get their PhD. This is a demanding requirement here in Oulu. It has one disadvantage as it doesn't always promote risk-based research". If students believe that their research has commercialisation possibilities, they are able to gain assistance from Research and Innovation Services at the University of Oulu. However, current Intellectual Property Rights (IPR) Policy at the University of Oulu (Table 37) states that research students who are funded by the European Union, Tekes or the Academy of Finland do not hold intellectual property rights. In those circumstances where students own the IPR and transfer it to the university, they are entitled to 60% of profits generated from the invention.

Table 37: Intellectual Property Rights (IPR) Policy at University of Oulu

Financially Profitable New Knowledge
Resulting knowledge may be born in EU R&D projects and in some TEKES technology programs, in which case the University has the exploitation obligation as the holder of the intellectual property rights.
New knowledge may also be developed in cooperative projects and with the support of foundations, or in research realised with the University's basic funding. In such cases the IPR belong to the researcher. The IPR to the knowledge resulting from work by researchers of Academy of Finland belong to the Academy of Finland.
Principles for the Distribution of Benefits in the University of Oulu
When the intellectual property rights concerning the invention have been transferred to the University, the following principles are followed. A transfer of rights agreement is made between the University and scientist(s) on a project-by-project basis.
Exploitation and protection of an invention always causes costs. If business activity is successful, there may also be profits after the costs have been covered.
The profit is divided in a following way:
• 60% to the inventor(s), unless otherwise agreed upon
• 20% to the University to be used for innovation activity
• 20% to the Department (clinic, laboratory etc.)

Source: University of Oulu (2005)

<u>Centre for Wireless Communication:</u> When the case studies were undertaken in the second half of 2003, any intellectual property that was created by the research students belonged to the industry sponsors. As stated by one of the students "*the copyrights of our research belong to the sponsors so that's the price you pay for making research work funded by third parties*". As a result, the students must obtain permission from the industry sponsors to release findings in publications: "*First the results are delivered or shown to sponsors so they can take a*

look if there is some let's say invention". According to one student, this hasn't been an issue in his case with most results being published:

> Most of the results will be published to be available for everyone. Some research activities were more oriented to a specific project concerning a specific problem, and they might be confidential information and therefore some results will only be available for the sponsors.

Another student who believes that some of his research is not publishable encourages the industry sponsor to distribute his findings as open source:

> The research I do is not very publishable; a lot of it is too practical. I try to publish where I can … The other thing we do to promote this study; my idea for this is to give it a way. We are into this open source thing. Most of the tools we use are open source. I have an open source mentality. As soon as I can get the sponsors to give it away, we give it away.

The three research students involved in patent applications were aware that there was little benefit to them as researchers: "We produced some invention reports and they have been evaluated if it is reasonable or not to patent. But no patent applications have been driven". If the student had come up with a patent "I would have got the same type of compensation as a normal research engineer in their company". One student was part of a patent application that was rejected "because the company in the States that started to work on the topic first made a wide patent application first". Although the intellectual property belonged to the sponsor, one student believed he did benefit from the knowledge gained:

> We had one patent already that we submitted. Nokia owns it. Of course, sponsors own the patents. For myself more of the knowledge that I know how to do that and that I am an expert in the field. That is how it is nowadays with IPR, it doesn't go to researchers.

One of the supervisors believes that selling all the rights to the industry sponsors is not an issue given the financial returns from the research:

> It is not a big issue because what we get in returns is we get much better financial compensation for our research than we would if we would own the results ourselves. As I said most of the direct commercialisation requires so much muscle that I don't see that any small company could benefit out of those.

Yet another supervisor believes that the environment where his student is undertaking the research doesn't adequately support commercialisation opportunities:

> There is a lot of commercialisation possibilities. I know if his environment was let us say, Stanford University or Silicon Valley, there would be already a start up. No doubt about that. I would tend to say that if there is no start up or commercialisation product from his research then it is not because of the results but because of the environment where it is. Definitely there is a commercial aspect coming out. I know already that some of the funding companies have been starting to take pieces of the research and drop that to their development phase.

Biocenter Oulu: The research student from Biocenter Oulu who was patenting his alcohol detection method/tool indicated that he was motivated to do so "because it is always good for a science group to think in the real usage of inventions, what kind of possibility one has for them if there is a real need for that research and industrial field". Apart from having to delay some of his publications, he also discussed some of the legal and financial difficulties:

> Legally it is very difficult and very expensive to work on because always doing the agreements with industrial partners is very difficult if you cannot define it very carefully. Using money for the attorneys is tough for science people as we do not have much money in our field. We have possibility in Finland to use public funding for the initial steps. When going further the money is not that easy to get. To become a rich man you should have business skills, being a scientist is not being a business man.

Research results that another student had presented in a journal paper were patented by her research group's industry partner that is located in the United States. Her supervisor described the background to, and the nature of the agreement reached between the University of Oulu and Fibrogen:

> In Finland the patenting is underdeveloped if you think about patenting scientific innovations. You don't really have the expertise here. It is evolving. For example, the universities in the beginning of the 1990s did not have any patenting personnel. There was no know-how to make international patenting applications. The biggest issue in that is there is no money to patent because it is terribly expensive. Our deal with Fibrogen takes care of the patenting. Basically they own the rights for our work but in exchange we have obtained first of all research funding for more than 10 years now, and secondly, there is this agreement between this university and Fibrogen that if there ever is a product and profit that also the university benefits from that. I would say without Fibrogen none of our inventions would have been patented. We as a group would not have the money to do that.

As already stated, research students are required to have internationally refereed publications to obtain a PhD qualification. The above supervisor also discussed the difficulty in patenting at the expense of publishing and the arrangements that have been made with the industry partner:

> The issue that before you have a patent you cannot really publicly tell about your work and in science the public knowledge of your work is everything that there is. In our case it has been arranged that there is a written agreement that every time we are ready and we are starting to write a manuscript of our work, in a very early phase we send the manuscript to Fibrogen. Their patent lawyers and patent personnel look through the manuscript and see whether there is anything of patentable interest. If there is they have one month to file the patent application. That really does not delay us because we send it in a very early phase and usually in such a phase that we still have some experiments to repeat before we write up the final manuscript. During that month we can finish and they can file the patent application if they want to. It has been smooth because sometimes you hear these not so nice stories.

6.5.4 Capability development

Interviews with, and observations of the research students from the CWC and Biocenter Oulu indicated a high level of knowledge about their topic i.e. *know-what* and the purpose of undertaking their research i.e. *know-why*. To determine the extent to which students had developed the ability of *know-how* and *know-who*, supervisors were asked what skills they believed their student had developed as a result of their research training.

Centre for Wireless Communication: Some supervisors from the CWC talked about specific skills i.e. *know-how* that the students had developed. For example:

> He will get deep knowledge about let's say issues that are related to this thesis which is interference issues to and from UWB systems.
>
> He has been more involved in the simulator development so he has a very good background and knowledge on that. He has focussed more on some specific topic which are these performance issues. Then he should have these capabilities of analysing the performance issues of the UWB systems.
>
> What I can say about him is he has been very deeply oriented and got familiar with the simulator involved with the issue and his research in these networking issues. So he has a very deep background and knowledge and ability and to use that in his research.

Another supervisor believes that the purpose of PhD research is not just to develop the skills of *know-how* but to train a person to become an independent researcher who understands and learns from issues:

> As a PhD definitely you develop a lot of skills like analytical skills to perform mathematical derivations, also computer simulations. This is hugely developed because the studies we provide in the Master programme only provide the basic information and basic tools. It is needed to understand these issues but really to learn to use them and do something useful that is done always after you start working whether you go to industry or whether you come to university to do a PhD. He is definitely much more mature to do personal decisions. After research training, you are ready to start independent research, maybe you are not fully ready for that but you should be soon ready for doing it. I would say it has been very well completed in his case. But basically becoming a doctor, more or less you are entitled to be kind of an independent researcher.

Similarly, another supervisor stated that his student "has learned how to handle projects and manage them at the certain level", and is also "a very international person and he is well competent at the international level. I feel comfortable to send him to international conferences". This supervisor believes that the main purpose of research training is to develop the ability of students to learn quickly and deal with different problems:

> The consensus in my college was to say that the PhD is really a journey, so you can list this number of skills that people get but you never really know if these skills were coming from the PhD studies themselves or they would have been coming naturally for the talented person. So in a sense it is a journey. I would say that we [universities] are good on giving some of the modern skills, lets say solving partial differential equations to students. However, the most valuable skills coming out are the capability to learn quickly and to work with diverse problems.

The Director of the CWC discussed the importance of "building relationships to form networks" i.e. *know-who*. He was concerned that some Finns who attend international events "don't talk, stand in the corner by themselves. If they meet a colleague from Nokia or someone like that they will talk together. They don't really mix, mingle or have any impact". At the time, the CWC was introducing a strategy of *internal networking* to maximise the benefits of research staff attending such events in order to build up their international exposure and to raise further the profile of the CWC. This would involve "more senior people who should have these skills introducing younger researchers to a larger network, doing some coaching, training, and mentoring on an occasion by occasion basis". The Director of the CWC believed that such a process would "assist, direct, network, push, force, bring people to the understanding that you have to operate in the larger community and hopefully this will happen".

<u>Biocenter Oulu:</u> The supervisor from the Biocomputing Group discussed the journey that two of his research students have experienced:

> People when they start to do this kind of work they have to climb this mountain. There is a lot of unknown territory that they have to understand and that takes times. Many people who come here don't have the right background. They are not so familiar with these computational facets and have to go thorough this fairly steep learning curve.

The same supervisor also referred to specific skills i.e. *know-how* that his students had developed:

> I think she has gained quite a lot of understanding of the concepts and issues such as protein dynamics, free energy, carrying out simulations, programming skills, there are many things there.
>
> I think he learned quite a bit about protein modelling and also computer simulations during the last six months.
>
> In the beginning he was able to get quick results which were somehow unexpected. It went quite fluently. The next thing he really wants to do now is to do these quantum simulations - detailed type of analysis that can be used to understand reactions in great detail. If he manages that part as well, he would have a fairly complete understanding of the various computational models that are out there.

Another supervisor believes that his student has greater confidence to generate ideas:

> Usually what you see in students when they proceed in their PhD project is their way of thinking. Their way of thinking becomes more critical, they can evaluate their results better, and also they sort of gather confidence in themselves along the way so they are brave enough to bring up their own ideas.

This view is similar to comments from a supervisor who stated that a PhD is more than developing specific skills:

> In general when you do a thesis you learn a lot more things which are very helpful in future careers. You learn many methods how to develop or set up methods, that is one thing. You now have to evaluate the results. Also, how to be critical, argue for your results and against others. Great critical thinking is the main point you learn by doing it. He is more confident because he has been doing many things that have succeeded very well.

Research students from Biocenter Oulu have an opportunity to participate in the Biobusiness programme that is conducted every two years. The programme was initiated by Biocenter Oulu, and is currently funded by the European Union and the City of Oulu. The programme aims to bridge the gap between scientists, venture capitalists and business. Students learn about product development, business culture, entrepreneurship, international marketing, finance, networking and presentation skills. They also spend three weeks in San Diego visiting biotech companies and participating in activities delivered by San Diego Connect at the University of Southern California. In the last programme, students also visited the Medical Valley region in Lund, Sweden. Two of the research students had participated in the programme and another student was planning to participate in the next programme.

6.5.5 Key findings for Finland

The unique model of research training embedded in industry funded projects at the CWC means that doctoral research is context-oriented, based on the needs/interests of the sponsors and is expected to contribute to applications/innovations. As employees who report on the progress of the projects to sponsors, research students have an opportunity to gain feedback about their own research. The degree to which these students can get direct feedback from sponsors about their research varies, with one student stating that the sponsors may not even be aware that they are undertaking academic research. Another issue was the length of time taken to complete a PhD qualification whilst working on these projects.

Research results of the students in the Biocomputing Group were expected to contribute to improved computational tools that can be used by drug designers in the future. In the case of the other two students from Biocenter Oulu, the patented results indicate a real application from their research. Only one of the five students from Biocenter Oulu had direct contact with potential users of his research results as part of the patenting process. The networks that have been established by the CWC and the structure of

Biocenter Oulu indicate support for transdisciplinary research. However, there was little evidence that the students were conducting their research beyond their own discipline and scientific community.

The current requirement that students must publish three or four internationally referred journal articles as part of their PhD requirements (a requirement that is based on Mode 1 knowledge production) may be a disincentive for students to diffuse their results to all relevant stakeholders during the process of production. IPR arrangements at the CWC (where it is given to industry sponsors) and at the University of Oulu (where students funded by particular organisations do not own the IPR) may also impact on the ability of students to widely disseminate their results.

In terms of capability development, the students are gaining economically-relevant knowledge in the areas of *know-what*, *know-why* and *know-how*. Some supervisors referred to the development of other relevant skills such the ability to learn, network, think critically and generate ideas. Support to attend conferences, workshops and meetings in Finland and abroad was the key way that the CWC and Biocenter Oulu assisted students to develop *know-who* in their relevant fields. The Director of the CWC stated that despite these opportunities, more needed to be done to help younger researchers to learn how to network and build relationships.

6.6 Case study results for the United States

6.6.1 Introduction

Ten (10) research students undertaking a PhD by Research in the Department of Materials Science & Engineering, Beckman Institute of Advanced Science & Technology, and the Department of Crop Sciences from the University of Illinois at Urbana-Champaign participated in case studies in the first half of 2004. Table 38 contains the research topics and funding sources for these students.

The University of Illinois at Urbana-Champaign (UIUC) opened in 1868 and is one of the original 37 public land-grant institutions created as a result of the signing of the *Morrill Act* by Abraham Lincoln in 1862. In 2004, the university had 7,900 staff and 40,360 students, with 11,066 of these students enrolled in graduate and professional programs. It has also employed 11 Nobel laureates and 18 Pulitzer Prize winners. Students come from across the United States and around 100 countries. At this time, the university offered were over 100 academic programs, including combined interdisciplinary degree programs together with over 80 centres, laboratories and institutes which perform research for government, agencies and campus units. UIUC is ranked among the top five universities in the United States in terms of the number of doctorates awarded. In 2002, it was ranked 19th of all U.S. universities for spending on R&D in science and technology. In 2004, 71% of graduate students received fellowships, research or teaching assistantships or tuition aid. PhD fellowships recognise superior achievement and potential, and most are awarded after a student has been accepted for, and begun a graduate program. Assistantships include an annual stipend and usually carry a waiver of all tuition fees.

Table 38: University of Illinois at Urbana-Champaign case studies

Research Topic		Funding source
Department of Materials Science & Engineering		
Student 1	Fundamental studies of dislocation-particle interactions at elevated temperature in aluminium alloys	Department of Energy and Alcoa
Student 2	Fluctuation electron microscopy investigation of photo induced changes in the medium-ranged order of a-Si:H	National Science Foundation
Beckman Institute of Advanced Science & Technology		
Student 3	Quantifying and directing molecular diffusion on surfaces and through grafted polymer layers	Beckman Foundation's Young Investigator award, the Nanoscale Interdisciplinary Research Teams (NIRT) initiative of the National Science Foundation, and the U.S. Department of Energy's Division of Materials Science
Student 4	Atomistic and continuum simulations of electroosmotic transport in nanometer channels	Department of Defense's Defense Advanced Research Projects Agency (DARPA) and the National Science Foundation
Student 5	Optical Image Enhancement for the Diagnosis of Breast Cancer	Whitaker Foundation and National Science Foundation
Department of Crop Sciences		
Student 6	Herbicide resistance in tall waterhemp	Illinois Soybean Program Operating Board
Student 7	Investigation into the genetic basis of resistance to brown stem rot in soybean	Illinois Soybean Program Operating Board and the Pioneer Seed Company
Student 8	Gene flow among weedy Amaranthus species	United States Department of Agriculture
Student 9	Effects of soybean cyst nematode population densities on Fusarium solani f. sp. glycines colonization of soybean roots in the field and a potential application of Q-PCR for quantification of fungal colonization in roots	Illinois Soybean Program Operating Board
Student 10	Improving the fertiliser value of swine manure	United States Department of Agriculture

The *Department of Materials Science and Engineering* was established in 1987 with the merger of the Department of Ceramic Engineering and Department of Metallurgy & Mining Engineering. The Department is one of the largest in the country, with 30 full-time faculty members and over 300 undergraduate and graduate students. Students specialise in various aspects of materials science and engineering, including ceramics, metals, polymers, electronic materials, biomaterials and composites. As the Department emphasises interdisciplinary research, students work with faculty in Chemistry, Civil Engineering, Mechanical Engineering, Electrical and Computer Engineering, Nuclear Engineering and Physics. Students can also access an outstanding array of facilities such as the Materials Research Laboratory (MRL), the Beckman Institute of Advanced Science and Technology, and the Micro and Nanotechnology Laboratory.

The Department's graduate (PhD) program aims to provide the fundamental knowledge, practical skills, and professional experience necessary to enter a successful career involving advanced materials. It has continually been ranked by U.S. News as one of the best graduate programs in its field in the country. There are three stages in the PhD program. The first stage involves coursework. A PhD student entering with a Bachelor of Science degree must complete 24 units of graduate work and a student entering with a Master of Science degree must complete 16 units of graduate work. Students also complete three department courses (or the equivalent): *Statistical Thermodynamics of Materials*, *Kinetic Processes in Materials* and *Fundamentals of Laboratory Safety*. To be admitted to the second stage of the PhD program, a student must have a grade point average (GPA) of at least 3.00 in their coursework, a grade of at least B in *Statistical*

Thermodynamics of Materials (or the equivalent), and pass both topics in the oral qualifying examinations. During the second stage, students must prepare a written research proposal and pass a preliminary (oral) examination covering their proposed thesis research. The final stage involves the student presenting a final unbound copy of the thesis to a committee and successfully completing an oral examination before receiving the PhD degree.

Beckman Institute for Advanced Science and Technology is an interdisciplinary and multidisciplinary research institute devoted to basic research in the physical sciences, computation, engineering, biology, behaviour and cognition. It was founded with a purpose of reducing the barriers between traditional scientific and technological disciplines to achieve research advances. The Institute was opened in 1989 through a $40 million gift from alumnus and founder of Beckman Instruments Inc., Arnold O. Beckman, and his wife Mabel M. Beckman, together with a supplement of $10 million from the State of Illinois. Its daily operating expenses are funded by the State while its research programs are supported mainly by external funding from the Federal Government (such as the Department of Defense, National Institutes of Health, and National Science Foundation), corporations and foundations. Over 600 researchers including 400 graduate students from nearly 30 University of Illinois departments comprise 15 Beckman Institute groups that are focused around three interrelated main themes: Biological intelligence, human-computer intelligent interaction, and molecular and electronic nanostructures. The Institute has one of the world's most advanced Scanning Tunneling Microscopy (STM) laboratories and an extensive and powerful computer network. The Beckman Foundation also supports the Beckman Graduate Fellows Program that encourages interdisciplinary research at the graduate student level. Preference is given to those proposals that involve the active participation of two faculty members from two different Beckman Institute groups. Three of the research students from the Institute who participated in the case studies had been awarded a Beckman Institute Graduate Fellowship.

The *Department of Crop Sciences* was formed in 1995 by merging faculty from the Department of Plant Pathology, crop scientists from the Department of Agronomy, and entomologists interested in integrated pest management from the Office of Agricultural Entomology. In 2004, there were 66 faculty members and over 100 graduate students in the Department. Some faculty are extension specialists who are responsible for communicating the results of research and educational programs to Illinois citizens, and extending the application of scientifically sound principles to new needs of agricultural enterprises. PhD students can undertake programs in the fields of biometry, crop production, environmental sciences, plant pathology, integrated pest management, weed science, plant molecular biology and physiology, and plant breeding, genetics and cytogenetics. Although there is no set time requirement, students with a Masters of Science degree take on average three years to complete a PhD program. Students are required to complete 24 units of coursework and pass a preliminary oral examination that tests their knowledge in the major fields of study. Written preliminary examinations also may be required. A faculty committee appointed by the UIUC's Graduate College must approve the final dissertation and thesis defence. PhD students can access state-of-the-art facilities within the Department as well as facilities in collaborating departments and the central Biotechnology Centre. Field studies are conducted at the Crop Sciences Research and Education Centre, five outlying research centres, and farms owned by Illinois producers. The Department houses the U.S. Department of Agriculture's Soybean Germplasm Collection (the world's largest collection of wild relatives of soybeans) and the Maize Genetics Cooperation-Stock Centre (the world's largest collection of maize mutants and chromosomal aberrations). The Department supports the Crop Sciences Graduate Organization (CSGO) which is a university-recognised organisation chartered to promote social and educational interactions among its graduate students.

6.6.2 Knowledge production

6.6.2.1 Context of application

Department of Materials Science and Engineering: Student 1 described how she was providing new knowledge to the aluminium industry and scientific community about "creep" in the hot rolling process:

> Basically how materials deform if they are at a certain static stress and at high temperatures … People want to understand because not only is it interesting from a fundamental perspective but it plays a role in the lifetime of the material and how good that material is, when you need to replace it, if a material is going to be applicable in a certain regime or if it's not a good material choice.

Her supervisor stated that Alcoa has already benefited from her research "because we have suggested to them what is causing the problem that they find and they are now using that information to try and find an engineering solution that will stop it".

The scientific community and in the longer term, the solar cell industry, are expected to benefit from research on amorphous silicon based solar cells that was being conducted by Student 2:

> The science is still being established. I think that in a few years this research will develop some facts, which the industry can try to make use of. The solar cell industry for example can use it for tailoring their material so that it absorbs more sunlight and gives more electricity. Amorphous silicon based solar cells are very economical compared to solar cells made with other materials which are costly but more efficient.

Beckman Institute for Advanced Science and Technology: The three research students from the Beckman Institute were enrolled in PhD programs in the Department of Materials Science and Engineering (Student 3), Department of Mechanical and Industrial Engineering (Student 4) and Department of Electrical and Computer Engineering (Student 5). The supervisor of Student 3 doesn't expect an immediate application for a specific industry from her nanotechnology research on self assembly monolayers. However, her research is likely to contribute in the longer term to "a variety of applications including new sensor designs, maybe as important as biological studies … The things she is exploring could impact everywhere from the semiconductor industry through to some of the biological needs".

Similarly, the supervisor of Student 4 believes a range of fields can benefit from his interdisciplinary research on the transport of fluids and ions through nanochannels:

> People in mechanical engineering who are trying to design nanofluidics channels will benefit from it. People in electrical engineering who are trying to design interconnects of cooling and things are going to benefit from it. This is a topic in chemical engineering. They deal with these issues all the time. This is also of interest to bioengineering.

Student 5 is combining a computational (engineering) technique with an imaging (medical) technique to form a technique for the early and non-invasive detection of breast cancer.

Department of Crop Sciences: Research undertaken by three students from the Department of Crop Sciences was funded by the Illinois Soybean Program Operating Board. The Board is funded by Soybean growers who also sit on the board and have direct input into the funding of research proposals. One supervisor stated that farmers and herbicide dealers are making recommendations based on his student's research into herbicide resistance (Student 6). If Student 7 finds a new gene as part of her research on the genetic basis of resistance to brown stem rot in soybean she believes that "we will immediately start breeding that into our breeding materials to be put into new cultivars for the farmers". The supervisor of Student 9 stated the her student's research findings on soybean cyst nematode and sudden death syndrome "will be widely used both for recommendations and for planning by other scientists doing research on this disease and extension people who are developing management recommendations for the disease". Student 8 believes that in the longer term his research on gene flow and gene transfer in the weed species *Amaranthus* could "potentially help us to design better ways of interbreeding species and improving crops or just knowing how different traits may be acquired in nature and model the likelihood of development or adaptations of, let's say herbicide resistance". The supervisor of student 10 described how his student's research would improve the fertiliser value of swine manure:

> Will not solve the odour problem but I do think we can solve some of the manure problems. We can figure out ways that producers can manage their animals, manage their manure, to get better use out of the nutrients. And therefore less risk to the environment.

6.6.2.2 Interaction with stakeholders

Department of Materials Science and Engineering: Student 1 had presented two project reviews to the industry partner, Alcoa. These reviews were conducted in Pittsburg and Davenport where she was also shown the technical centres and facilities. Her supervisor stated that she was invited to the plant to present her work mainly because "out of all the projects they have funded there have only been two or three, and her project has been one of them, that has made it to the plant". Although Student 2 has been mainly exposed to specialists and scientists in his field of research, he had made some contact with industry as "industry sometimes wants to test their existing material. I have looked at industry material. In fact I am looking at industry material right now".

Beckman Institute for Advanced Science and Technology: The three students regularly interacted with scientists and research students in different fields that are based in research groups in the Beckman Institute. The supervisor of Student 3 said that "there is certainly the aspect of being at the Beckman just around other groups, around people in John Rogers' group, around some chemists. There is feedback back and forth there". Student 4 described how he has "access to people of various disciplines and we have very good facilities. We can collaborate with many other researchers in the same building and this really makes life a lot easier in some cases". Similarly, Student 5 stated that "it is pretty interdisciplinary so I do interact on a daily basis with biologists, physicists, engineers and medical doctors". Student 5 was planning to become heavily involved with hospital staff in order to collect human tissue samples and tumours. He was also about to commence an NSF sponsored fellowship that would fund him to work with scientists at the University of Western Australia for two months.

Department of Crop Sciences: The five research students from this department regularly interacted with industry people (including farmers) and scientists through their involvement in industry and scientific meetings and participation in the annual Agronomy Day. At the Agronomy Day held in August "we go to the cell farms, the experimental fields, south of the campus and we give presentations to farmers. So they come on that day and they do a little tour and they listen to the presentations". Student 6 stated that in his case "we are in contact with industry a lot either at meetings, go in there at least once a year, say Monsanto and we talk to them directly and they are really interested in what we are doing". Because the disease that Student 7 was researching was "more of a northern pathogen I constantly have contact with people of the north, other universities, or companies". She worked closely with pathologists from the University of Wisconsin at Madison, "run[ning] material back and forth. We will visit each other a couple of times a year. Talk about projects". Student 8, 9 and 10 interacted with their relevant scientific community through meetings, conferences, and university networks. Student 9 described her close relationship with another university:

> We also collaborate with people from Southern Illinois University. That institution has done a lot of sudden death syndrome research in the past. So they have a lot of experience and they also have a lot of field locations down in Southern Illinois. During certain times of the year when things are at critical stages we go down there and take samples at planting and we might spend the night. It is only 3 to 3.5 hours to get down there. I am always lucky enough to have anyone at my disposal to go with me and help me take my samples and do whatever needs to be done. Also we collaborate with people down at the SIU so they would help us maintain the plots, watch them, make sure everything is going OK as they are right there in the middle of their plots. These two locations were part of farmer fields. They contract out farmer fields for use for some of their research. That is pretty common practice in agriculture. They use some of those fields for screening varieties, variety testing, for resistance to certain death syndrome.

6.6.3 Knowledge dissemination

6.6.3.1 Dissemination of findings

Department of Materials Science and Engineering: In addition to conference papers and journal articles, two students had presented their work at the department's weekly colloquium and seminar series held by their particular research concentrations (Table 39). For example, Student 1 was involved with the Materials Interest Group:

> Essentially it a conglomeration of professors who either do modelling or experimental behaviour of materials and they want to learn from each other, so they and their respective research groups get together on Friday afternoons and they rotate who presents. Every semester our group presents. I have presented at that twice so that would be I suppose presenting to the university.

Student 1 described how her main funding body, the Department of Energy, "required that all the projects that they had funded in the aluminium industry had to present at this conference". The supervisor of Student 2 expects his student to publish in high quality international journals and present results at two or three major conferences.

Table 39: Methods of disseminating research results, UIUC

	Mode 1 methods	Other methods
Department of Materials Science & Engineering		
Student 1	3 journal papers (2 planned), 1 local (United States) conference	Department seminar series, talks to visitors
Student 2	1 journal paper, 2 local conference papers	Department seminar series
Beckman Institute of Advanced Science & Technology		
Student 3	4 journal papers (planned), 2 local conference poster presentations, 1 local conference paper	Presentation at Beckman seminar series and research society meetings
Student 4	8 journal papers, 5 local conference/workshop papers and 1 international conference paper	Presentation at Beckman seminar series
Student 5	1 journal paper, 9 local conference papers	1 patent, presentation at group meetings
Department of Crop Sciences		
Student 6	4 journal papers	All students provide results to extension officers, attend and present at industry meetings, and interact with farmers at events such as Agronomy Day.
Student 7	2 journal papers, 1 local workshop presentations	
Student 8	3 journal papers (2 planned), 6 abstracts	
Student 9	6 journal papers	
Student 10	2 journal papers, 1 book (co-author)	

Beckman Institute for Advanced Science and Technology: The Beckman Institute sponsors an active program of visiting speakers and a seminar series that provides an opportunity for researchers and students to learn more about each other's work. Student 3 stated that "we have internal talks we do every year. I have done that since my second year". Student 4 presented his findings at "the NSF-ITR seminar and Nano-Hour seminar. These seminars are mostly interdisciplinary in nature and many of them are related to nanotechnology". Students had also presented findings in their own research group meetings which provided them with an opportunity to practice their conference presentations. They had also presented papers and/or posters at conferences and meetings at different locations in the United States. Although there is no department requirement about the number of publications, the supervisor of Student 3 expects that she "would probably write two or three papers and another few papers perhaps as second or third author during her time here". In addition, her supervisor had "called up the editor like of Chemical and Engineering News or the editor of the MRS Boa and just self promote paper" and updated his group's website on a yearly basis. As well as presenting papers at a number of conferences and workshops, Student 4 is regarded by his supervisor as very active in terms of journal publications: "He published several. Last count eight or nine. That is really good. He has been one of my most productive students. He has published in very good journals". Student 5 has used his results to successfully apply for two external grants, one for equipment and the other to undertake a student exchange. His supervisor described how a conference presentation usually leads to a paper for publication and possibly a patent application:

> I have all my students with new results submit their results to a conference first and be able to go to present those results. Pretty much at the same time also submit a paper for publication and then if the technology is novel enough we will submit a patent disclosure as well. So they do get that experience of not all peer reviewed manuscripts but also patent applications.

Department of Crop Sciences: Conference/poster presentations mostly in the United States and journal papers were the most common methods of knowledge dissemination for the five students from the Department. Student 9 stated that her supervisor expects her "to go to one meeting and present either a paper or a poster annually". In addition, students had also distributed their results to extension specialists within the Department who then disseminates the results to farmers: "He goes to extension meetings and so he talks a lot about the stuff we are doing, directly to the farmers". The supervisor of Student 6 discussed how his student's results would be presented as a fact sheet for distribution by extension weed scientists:

> There will be an actual process of turning some of his research into a fact sheet which would be distributed to farmers and other people from the agricultural community. I am working with some of the other extension weed scientists to do that. So we are putting together a one or two page fact sheet on herbicide resistance in water hemp which farmers can get a quick rundown on what are the types of herbicide resistance. Most of what is going to be on that sheet will come out of William's research.

Most of the students also regularly presented their results at industry and scientific meetings. As stated by one student: "I present my research to the public, other researchers and people in industry people. There are a lot of industry people at these meetings". Student 7 explained the types and frequency of her attendance at these meetings: "I have been the National Agronomy meeting three times, it is a yearly thing. I have been twice to soybean bi-annual conference which is a conference just for soyabean breeders. So I have been to those twice". She also described her experience at smaller meetings:

> You get more into the heart of the problem. I liked going to, it was the BSR – Whitemold (another soybean disease) meeting that I got to go to Wisconsin. I was really happy to go to that. I got to meet people who are working with this pathogen at seven other universities. We got a chance to talk.

Students also presented research results in their research group meetings, the department's seminar series and other activities organised by the university like Agronomy Day. For example, Student 8 "did one presentation for a symposium that was organised by students in evolutionary biology and ecology within the university". The department hosted the 2004 Illinois Soybean Research Forum where three of the students funded by the Illinois Soybean Program Operating Board presented posters to stakeholders.

6.6.3.2 Incentives

As already discussed, the research students were expected to disseminate their results through the mode 1 methods of conference and journal papers. For those students seeking an academic career including tenure, they will need to work as an assistant professor for five to seven years and be recommended by a committee of peers for tenure. A key consideration is their research and publication record. All 10 students were also encouraged to attend relevant meetings across the United States. Crop science students also regularly attended regional meetings. Only one student discussed an arrangement that was made with her industry partner in relation to the dissemination of results:

> Certainly through other people, mostly through the interaction with Alcoa, they had to open up some proprietary information to us to allow us to actually communicate well with them. In doing so we were able to offer them some ideas about what really is happening when they have failures … I guess they do have the authority if they don't want that released yet.

Awareness of intellectual property rights was somewhat limited for a couple of students as indicated by comments such as "I think I know that (IP rights) loosely" and "I really think there are policies in the universities but I am not really sure what they are". Some students believed that their research is unlikely to have any commercial potential. In one student's case all research results had been given to farmers as "usually the money comes from farmers". Overall, students were more motivated to disseminate their results than pursue commercial opportunities:

> We are not worried that someone will take something from us. We are not afraid that someone comes and asks how we did things. What we are actually trying to do now is trying to get our results noticed. It is a new field so it needs some attention.

From another student: "We work very openly and since we are a public institution we share all of our data side by side. That is the goal, that we share our information". These comments were strongly supported by one supervisor:

> The other aspect of Illinois in general we are much more of a basic science university and I won't say that IP is frowned upon in a big way but if it gets in the way of the basic science most of us would rather publish and move onto the next project rather than get involved with the legal teams and patent issues.

One student believed there could be commercialisation possibilities from her research "if we find a gene responsible for resistance". Another student who had already been involved in a patenting application stated that there may be some potential for an application for his current research:

> It is possible down the road. The way intellectual property works in the university is if you have something that you think is patentable you submit the idea to an office here in the university and they evaluate it and decide whether it is something useful as they have a limited amount of funding to patent. They will look at it and evaluate it for what they see as the potential for commercialisation and things like that. We didn't end up with a patent for the idea but there are others in a group that are going down there and may have patents. Obviously there is some application commercially for these things. Some of the techniques we work with have previously been patented by other people and used in industry, or in the medical industry at least. There is some potential.

The Office of Technology Management (OTM) at the UIUC assists researchers and students by evaluating, protecting, marketing and licensing intellectual property. The university is required "under state and federal statutes, industrial research agreements, and other research relations to manage the IP that results from the University's research programs" (OTM, 2005). OTM policy guidelines on intellectual property rights state that copyright ownership depends on the specific circumstances that led to the creation of work. In the case of work prepared as part of a thesis or dissertation, the student "owns the thesis, the University retains rights to publish and distribute the thesis as well as ownership rights to the underlying laboratory notebooks and original records of the research" (p. 2). When work is commercialised, creators are entitled to 40% of the share of revenues generated, with the creator's department receiving 20% and the Office of the Vice Chancellor for Research receiving 40% after out of pocket expenses. Where there is more than one creator or department involved, the revenues are shared according to how they determined the split.

6.6.4 Capability development

Department of Materials Science and Engineering: The supervisor of Student 1 stated that his student was building collaborations and networks by showing visitors how to use equipment, explaining her work to them and generally supporting them. He also described her development in terms of what she has learnt and how her communication skills have significantly improved:

> She has changed a lot because she has gone from someone who was pure materials science to having to learn to work with people who do modelling and simulation. So she has had to learn those aspects. She's had to learn how to communicate between a basic experimentalist and someone who is more into the simulation. While we sort of maybe use the same words how we interpret and think about them are not necessarily the same. She has had to learn how she can communicate the key features of her work to them so it can be incorporated into the models. But at the same she has to been able to understand what the limitations of the models are. So she has broadened incredibly. She gave a talk recently at Lawrence Livermore National lab to both the engineering division and people in chemistry and materials science. Both divisions wanted to hire her at the end of the talk.

> The simple reason for the engineering group was this is an experimentalist we can talk to and she understands what we are saying. Most don't come out with that skill. It is a skills set that needs to be developed so we can start bridging gaps between basic science and something more heading towards an application point. So she's grown tremendously in that and the ability to stand up and present her work with confidence is quite a skill compared to where she started.

The supervisor of Student 2 talked about his student's improvement in terms of *know-how*: "He had no background in the transmission electron microscope. So he has gone from zero background to someone using a very sophisticated technique with an accompanying statistical analysis and thinking about what it all means". In addition to these technical skills, the supervisor stated his student has developed the ability of *aha* that is the "separating out of the forest of experimental or other details the significant part [through] constant re-evaluation, always thinking about what you are doing".

The Head of the Department discussed the need to ensure that research students are developing the necessary skills for future employment, which could be in research, management and/or director positions:

> Are we providing the right opportunities so that when they do hit the workforce they are probably prepared? From a research standpoint their education here is excellent. The question is should we be providing other opportunities that will allow them to not just to hit their job running and again we provide them more than other schools are. I don't think it is a real weakness in our program but it is more a question of, with the way the marketplace is changing, have we really thought enough about our graduate program. In essence it really hasn't changed in many ways over the years.

<u>Beckman Institute for Advanced Science and Technology</u>: The supervisor of Student 3 described not only to her ability to undertake particular techniques and operate equipment but also to her ability in "being able to take a general idea, look at her results, iterate how she does the experiment, design new experiments". The supervisor believes she is moving towards achieving the main goal of a PhD: "You can go out and be an independent science and engineer at a pretty high level". The supervisor of Student 4 partly attributes the shift in his student from a good student to a very good researcher to "being in a great department, being in Beckman, a fantastic interdisciplinary institute". He also stated that his student has "learnt so many things. He learnt several new methods. Physics of nanofludics. He understands at an atomic scale. He knows how to design these things now. He knows how to look for new phenomena. Explain new phenomena". The supervisor of Student 5 described his student's improved ability in terms of *know-how*:

> I think he has really developed skills in experimental optics lab where he can set up the equipment, align systems, lasers, optics. He has continually worked on developing software skills, programming skills. He has been exposed to a lot of biological aspects.

Department of Crop Sciences: The supervisor of Student 6 stated that his student has improved his writing skills and "learnt a lot of scientific skills in terms of DNA manipulation, doing PCR, that sort of thing. He learnt a lot about statistics, how to analyse data. He has developed techniques in terms of just simply growing plants". This supervisor believed that the difference between a good student and bad student is whether they can "grow plants in the greenhouse. That seems really simple but some do it better than others. If you don't have good material to start with you don't get good data out of it". This supervisor also supervised Student 8 and described this student's improvement in *know-how*:

> He had some basic skills in DNA, DNA manipulation, the general molecular biology. He has gained more skills in that. His project deals with a set of genetic aspects so they are completely new skills. I also think a lot of things he has never thought about in terms of genome and chromosome pairing and that sort of thing he is taking classes on and gaining knowledge in that area.

The supervisor of Student 7 discussed his student's development also in terms of know-how:

> She's developed laboratory skills in the area of doing genetic marker analyses. She's developed green field experimentation skills, working on the program. Taking classes she has obviously broadened her view of science and agricultural experimentation data analysis, breeding genetics, lots of areas … She is broadening or developing writing skills by working on papers.

The supervisor of Student 9 discussed not only her student's improved skills in the areas of statistics, mathematics and "molecular part of her understanding", but also her increased confidence: "She is much more confident I think. She is much less tentative about anything. We decide together for her to pursue something and she jumps in with both feet. She is not hesitant at all". The supervisor of Student 10 discussed how his student had more responsibility because she was managing a million dollar research project that involves other staff. As a result, "she has had to take on more and be more of a leader".

6.6.5 Key findings for the United States

The 10 research students from the UIUC were undertaking cutting-edge basic research that is expected to contribute to applications and innovations in the longer term. Their research has been supported by funding from major Federal Government departments, industry and foundations. All the students interacted regularly within relevant scientific communities. In the case of the three students from the Beckman Institute, their research can be regarded as transdisciplinary as they worked in research groups made up of researchers from different disciplines and were regularly exposed to other research groups. One student from the Department of Materials Science was interacting with the industry funding body through industry visits and presentations. Students from the Department of Crop Sciences benefited from close links and networks that had been developed with the Illinois agricultural industry over a long period of time. These links enabled students to meet with stakeholders at regional and State meetings and at events organised by the university.

The research students were undertaking their research in a university that has a strong reputation for basic research and widely disseminating research results. Students were not required to produce a set number of publications as part of their PhD requirements, but are expected to disseminate their results at conferences and in high quality journals. All students were funded to present their results at relevant conferences and meetings held in the United States. Only two students had attended conferences outside the United States. As stated above, students from the Department of Crop Sciences were also presenting their results at industry meetings and events. IPR arrangements at UIUC indicated that students own their results unless specific arrangements had been made. Only one student discussed specific arrangements where she was required to present her results to the industry partner before publishing them. Two other students believed that their results may have commercial potential.

Most of the supervisors discussed the improved ability of their students in terms of *know-how*. Students were supported to build their own networks i.e. *know-who,* through the presentation of their results at different forums across the United States. Other capabilities mentioned by supervisors included the ability to communicate research results, think critically, design new experiments, and project manage. One department head discussed his intention to evaluate the research training program to ensure it is aligned with the different occupations that graduates may pursue.

6.7 Chapter summary

The purpose of this chapter was to determine the extent to which the 30 research students from RMIT University (Australia), University of Oulu (Finland), and University of Illinois at Urbana-Champaign (United States) were contributing to their national innovation systems in terms of knowledge production, knowledge dissemination and capability development. Element 2 of the conceptual framework for this study assumes that their contribution is enhanced when their:

- research is characterised by a combination of Mode 1 and Mode 2 knowledge production i.e. it considered the context of application, involved stakeholders and led to transdisciplinary results
- research results were effectively disseminated to all stakeholders through the process of production, thereby going beyond the traditional Mode 1 methods of journal and conference papers
- research training program equipped them with the four different types of economically-relevant knowledge and the capabilities needed by employers in knowledge-based economies.

All 30 research students were undertaking research that to varying degrees was context-related i.e. the research was or would be useful to industry, government or society. The usefulness of their research was indicated in many cases by funding support by potential benefactors. The three universities expected the students to disseminate their results through the traditional Mode 1 methods of reporting in journals and at conferences. Students were required to produce three to four referred articles in international journals at the University of Oulu. Some students were more active than others in disseminating their results through other methods due to their own initiative and/or the existence of networks and activities established by their supervisor, department and university. Most students interacted with, and disseminated their results to their scientific community. Students from the Department of Crop Sciences at UIUC regularly met with industry and were able to disseminate their results through extension specialists. Students (as employees) of the Centre of Wireless Communication also regularly reported relevant findings to industry sponsors. There was no case where a student actually organised their research around the context of application by interacting with, and disseminating results to all stakeholders. The three students from the Beckman Institute were the only students who appeared to be directly involved in transdisciplinary research. In many cases, students were interacted with people from other disciplines through seminar series and the sharing of facilities.

Most of the 30 students were developing the economically-relevant knowledge of *know-what*, *know-why* and *know-how* in their research area. Only a small number of supervisors spoke specifically about helping their students to develop *know-who* i.e. the ability to co-operate and communicate with different kinds of people and experts. One reason for this could be that supervisors assume that students will develop their own networks and build relationships over the duration of their studies, and through attendance and presentation at conferences and other events. Most of the students from the University of Oulu and UIUC were funded to attend relevant conferences and events. As most of the relevant international conferences for the UIUC students were held in the United States, students were able to easily access these international networks. Students from the University of Oulu had attended international conferences and meetings held in Europe with some students (particularly those from the CWC) having travelled beyond Europe. Most of the Australian students had not attended international conferences due to funding difficulties. Only three of the 30 students had undertaken actual placements at universities located outside their own country. The centre head of CWC spoke of his intention to introduce a system of "internal networking" to assist young researchers to learn how to network and build relationships.

In terms of capability development that met the needs of employers in knowledge-based economies, some supervisors spoke about the role of research training in developing generic skills; helping students to become independent researchers; and improving their ability to learn, solve diverse problems and generate ideas. The online generic modules at RMIT University and the Biobusiness Course at Biocenter Oulu are examples of programs designed to provide research students with more general skills required by employers. A department head at the UIUC discussed the need to ensure that the research training program is providing students with the necessary skills to work as researchers, managers and/or directors.

Overall, the models of research training presented in this chapter are providing students with the key skills to work as independent researchers and the opportunity to create valuable new knowledge within a national innovation system. Some models were actively encouraging the internationalisation of their students (such as those in Finland), transdisciplinary research results (such as the Beckman Institute), and exposure to different stakeholders (such as the Department of Crop Sciences at UIUC). However, there is room in these models and/or adjustments that could be made to these models that would greatly enhance the way students produce and disseminate new knowledge, thereby contributing to the development of those capabilities expected of graduates working in a national innovation system. The concluding chapter of this thesis includes recommendations that aim to assist Governments and universities to perhaps rethink aspects of research training models to encourage knowledge production, knowledge dissemination and capability development in ways that have been described in this chapter – thereby improving the contribution of research students to their national innovation system during and after their research training.

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Chapter 7: Research training, human capital and economic growth

7.1 Introduction

The third element of the conceptual framework examined the relationship between **research training, human capital and economic growth** in an attempt to determine whether research training as human capital formation contributes to economic growth in Australia, Finland and the United States (Research Question 7). Addressing this research question first involved describing what is meant by human capital, how it is formed and measured. This has been followed by a discussion about the economic and non-economic impacts of human capital including endogenous growth models in which human capital is given a central role in explaining changes to growth rates. However, many studies on the impact of human capital formation through education on economic growth have acknowledged inconclusive results and problems with causality. In addition, there is limited literature on returns from research degrees and the relationship between human capital formation at the graduate or research training level and economic growth. Therefore, a basic approach has been taken in this chapter to assess the relationship between research training, human capital and economic growth. Relevant literature has informed the analysis of statistical (mainly proxy) data for each country and led to the following key assumptions for this element:

- Research training can be considered as human capital formation at an advanced level, providing students with the knowledge, skills, competencies and attributes to work as professionals.
- Returns from research training are high except when the time taken to complete an advanced research degree is extended, students commence full-time studies later on in life, and students bear education costs. The first two factors increase the amount of income foregone (lowering private returns) and reduce the amount of income tax paid by individuals (lowering social returns). When research students are liable for education costs like tuition, private returns will decrease and social returns will increase.
- Research training represents a significant investment in R&D activities by a country and helps to build a highly skilled workforce that directly contributes to technological advance and innovation. Therefore, it is likely that research training has a positive impact on economic growth and contributes to social benefits that result from human capital investment in education.

7.2 What is "human capital"?

The OECD (2001b) defined **human capital** as "the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of a personal, social and economic well-being" (p. 18). **Human capital formation** is "a process of further developing the productive capacity of human resources through investment" (Wykstra, 1971, p. xv) in life-wide settings such as formal education, work environments and enterprise-based training, and informally through interest networks, communities and families. The degree to which these settings create and use human capital will depend on how education and training is organised and the demand for skills in each country, the mobility of workers between and within firms, and flows of innovative personnel from international migration (OECD, 1998a).

Costs associated with rearing and survival (i.e. health and nutrition) and education are well known examples of human capital investments. Investment in human capital through education assumes that human beings will become more productive later if they forgo certain earnings and consumption activities in order to develop skills and cognitive capabilities necessary to gain employment in these experiences (Oxford Encyclopaedia of Economic History, 2003). Studies tend to be concerned with the value of human capital investment for production purposes rather than for consumption purposes. For example, the OECD (1998a) referred to attributes possessed by an individual as a combination of his or her level of education and the degree to which this individual *productively* uses his or her wide range of skills.

7.3 Measuring human capital

The main issue in measuring human capital is the difficulty in quantifying the knowledge, skills, competencies and attributes embodied in human beings. Measures of human capital stocks, investments and returns are necessary to evaluate the different models and systems of educational provision and to identify organisational and economic conditions that encourage (and discourage) human capital formation. The OECD (1998a) identified three approaches to measuring **human capital stocks**: Educational attainment (the highest level of education completed by an adult), direct tests on adults (e.g. literacy) to determine whether they have certain attributes relevant to economic activity, and differences in adult earnings associated with particular individual characteristics. The stock of highly skilled R&D workers relative to the workforce indicates the level of investment in knowledge development. Data on human capital and HRST stocks that are relevant to, and/or incorporate research training is shown in Table 40.

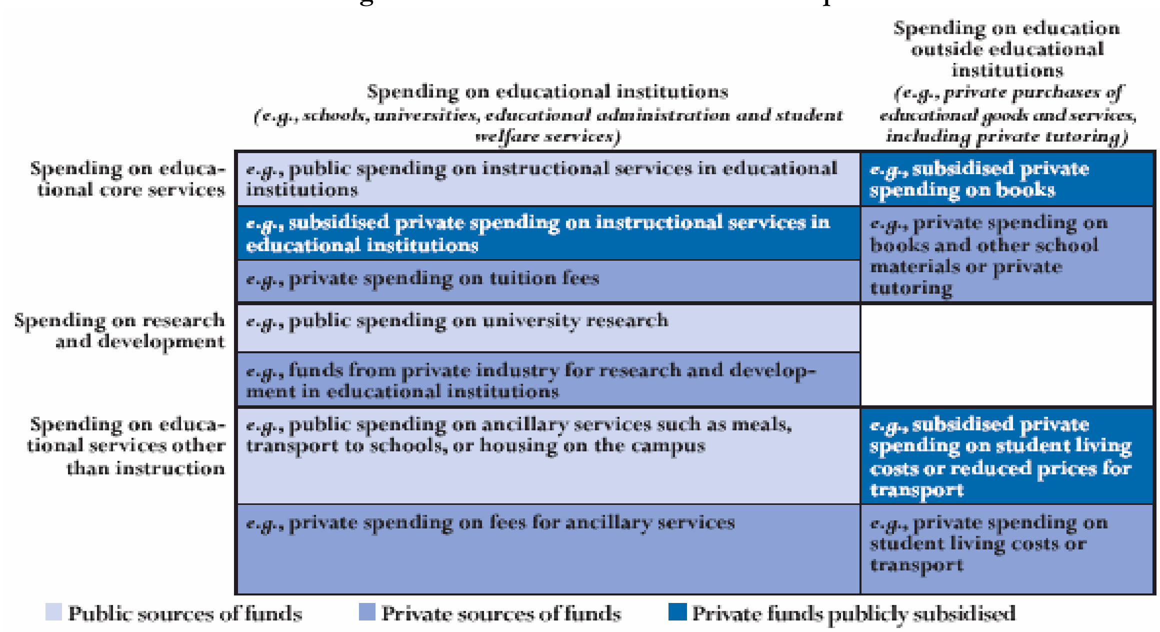
Table 40: Indicators of human capital (tertiary education) and HRST stocks

	Australia	Finland	USA	OECD
Share of population aged 25-64 with tertiary level A and advanced research programs, 2002	20%	16%	29%	15%
Number of students enrolled in advanced research programs	47,309 (2004)	22,105 (2004)	1,904,000 (total graduate enrolments 2003/04)	n.a.
Number of graduates of advanced research programs	6,321 (2003)	1,957 (2004)	44,200 (2003/2004)	n.a.
Graduation rates at PhD level (proportion of population with a PhD)	1.3% (2002)	1.9% (2001)	1.3% (2002)	1.2% (2002)
Proportion of doctorates/research degrees in S&E fields	36% (2004)	37.8% (2001 to 2003)	24% (2003/04)	n.a.
Percentage of university graduates in S&E fields, 2001	19.4%	28%	15.8%	21.8%
Researchers per 1,000 total employment	7.2 (2000)	16.4 (2002)	8.6 (1999)	6.5 (2000)
Business researchers as a percentage of total researchers	24.4% (2000)	55.1% (2002)	80.5% (1999)	63.8% (2000)
Average annual growth rate of HRST	3.07% (1996-2001)	2.32% (1997-2001)	2% (1995-2002)	2.98%
HRST occupations as a percentage of total employment	35.6% (2001)	32.5% (2002)	32.7% (2002)	28%

Source: OECD (2003), (2004a), (2004b) and (2004d)

Expenditure on education and training (by individuals, companies and governments) and time spent by individuals in education and training (income foregone) are key measures that indicate how different countries **invest** in human capital. Although some countries may have low levels of human capital stocks as indicated by educational attainment, they may have larger investments in each student and high participation rates (OECD, 1998a). The OECD (2004b) identified three dimensions to educational expenditure in Figure 48: The location where spending occurs such as schools, universities and private tutoring; the types of goods and services that are purchased such as private spending on tuition fees and ancillary services, and public spending on university research; and the sources of the expenditure i.e. private, public and publicly subsided private funds.

Figure 48: Classification of educational expenditure



Source: OECD (2004b) p. 197

Proxy indicators of **investment in research training** by Australia, Finland and the United States shown in Table 41 are total, public and private expenditure on tertiary type A and advanced research programs; expenditure on R&D at tertiary education institutions, which to some extent indicates a commitment to a research culture; and average duration of time taken to complete university studies and typical graduation age of people in advanced research programs as indicators of income foregone by research students.

Similar to all levels of education, research students are encouraged to develop their knowledge, skills, competencies and attributes in return for enhanced earnings from the labour market. OECD data combining **returns from research training** in the category of tertiary type A and advanced research programs shows that people who complete a university degree earn significantly more and are less likely to be unemployed than those people with an educational attainment of upper secondary education and post-secondary non-tertiary education.

Table 41: Proxy indicators of investment in research training

	Australia	Finland	USA	OECD
Expenditure on tertiary educational institutions as a percentage of GDP, 2001 Public sources Private sources	1.5% 0.8% 0.7%	1.7% 1.7%	2.7% 0.9% 1.8%	1.3% 1.0% 0.3%
Expenditure on tertiary type A and advanced research programs per student (USD), 2001	$13,654	$11,143	$22,234 (all tertiary education)	$10,052 (all tertiary education)
Relative proportions of public and private expenditure on tertiary educational institutions, 2001	Public: 51.3% Private: 48.7%	Public: 96.5% Private: 3.5%	Public: 34% Private: 66%	Public: 78.2% Private: 21.8%
Cumulative expenditure on tertiary education per student (USD), 2001	$32,101	$49,972	n.a.	$42,906
Expenditure on R&D at tertiary education institutions as a percentage of GDP, 2001	0.42%	0.62%	0.26%	0.35%
Expenditure on R&D at tertiary institutions per student (USD), 2001	$3,488	$3,921	$2,136	$2,716
Average duration of studies of tertiary type A and advanced research programs, 2001	2.6 years	4.5 years	n.a.	n.a.
Typical graduation ages in advanced research programs	25-29 years	29 years	28 years	n.a.

Source: OECD (2004b)

Returns to investment in human capital through education are also measured by **private internal rates of return** and **social internal rates of return**. Becker (1964) is known for devising the approach for using the costs of education and the economic returns on educational investment to determine the rates of return for school and college attendance in the United States. He found that returns vary by level of education. Blöndall et al. (2002) defined the *internal* rate of return as the "discount rate that equalises the future flows of real benefits and real costs associated with investment in upper secondary or tertiary education" (p. 59). Private returns are calculated by comparing the costs of education incurred by the individual (such as fees, books and travel costs) and the indirect costs of income forgone against the extra income that is expected to be earned during his or her lifetime (Sheehan, 1973). Social returns are calculated to determine the net benefit to society from investment in education. Private and social returns vary according to the age at which an individual commences a tertiary or advanced research degree (i.e. the older an individual the greater the income foregone especially when enrolled full-time) and the extent to which an individual bears the costs of the degree. In most countries there are gaps in returns for males and females due in part to the "different choices of career and occupation, differences in the amount of time that males and females spend in the labour force, and the relatively high incidence of part-time work for females" (OECD, 2004b, p. 168).

As with earnings and unemployment data, the OECD does not separate private returns and social returns for research degrees from other types of university degrees. Therefore, data on returns from human capital investment in tertiary education in Table 42 are proxy indicators of returns for research degrees.

Table 42: Proxy indicators of returns from research degrees

	Australia	Finland	USA	OECD
Relative earnings of the population with tertiary type A and advanced research degrees (upper secondary = 100)	Males: 160 Females: 159 Total: 148 (2001)	Males: 190 Females: 172 Total: 181 (2001)	Males: 202 Females: 185 Total: 195 (2002)	n.a.
Unemployment rates for individuals with tertiary type A and advanced research degrees, 2002	2.6% (males) 2.0% (females)	3.1% (males) 3.1% (females)	2.8% (males) 2.1% (females)	2.9% (males) 3.3% (females)
Unemployment rates all levels of education, 2002	4.5% (males) 3.1% (females)	6.5% (males) 6.2% (females)	4.7% (males) 3.3% (females)	4.6% (males) 4.1% (females)
Private internal rates of return for a tertiary degree or an advanced research degree, 2001:				
When an individual immediately acquires the next level of education	6.6% (males) 6.5% (females)	14.2% (males) 15.2% (females)	11.0% (males) 7.9% (females)	n.a.
When an individual at the age of 40 begins the next higher level of education in full-time studies and bears direct costs and foregone earnings	3.3% (males) -0.8% (females)	10.6% (males) 8.1% (females)	7.4% (males) 2.7% (females)	n.a.
When an individual at the age of 40 begins the next higher level of education in full-time studies and bears no direct costs but foregone earnings	5.4% (males) 2.7% (females)	10.8% (males) 8.4% (females)	11.9% (males) 8.6% (females)	n.a.
Social internal rates of return for a tertiary degree or an advanced research degree, 2001:				
When an individual immediately acquires the next level of education	8.3% (males) 7.6% (females)	10.5% (males) 8.7% (females)	11.1% (males) 7.9% (females)	n.a.
When an individual at the age of 40 begins the next higher level of education in full-time studies	5.5% (males) 1.7% (females)	8.6% (males) 5.4% (females)	8.0% (males) 3.2% (females)	n.a.
When an individual at the age of 40 begins the next higher level of education in part-time studies (duration is doubled)	6.9% (males) -0.1% (females)	8.9% (males) 4.3% (females)	7.3% (males) 0.8% (females)	n.a.

Source: OECD (2004b)

A PhD study by James Dyal examined the private and social returns from investment in graduate education at the University of Illinois at Urbana-Champaign in 1970/1971. Dyal (1975) estimated the institutional, private and social costs of the resources invested in the production of MA and PhD degrees. Private costs incurred by students included the value of his or her time as the primary cost; direct out-of-pocket expenses such as payments for tuition, fees and books; and additional indirect living costs if the student resided on campus such as housing, food, clothing and transportation. The value of the time that students invest in graduate education was equivalent to the actual earnings foregone while attending graduate school. The costs to society of graduate education were the costs paid by the institution and the student, excluding the double counting of tuition and fees. Dyal (1975) also described the benefits of graduate education to students and society:

> People enter graduate school to invest in their long-run potential for achieving more satisfying work and leisure as well as to consume the immediate college experience. In addition to these private benefits, society as a whole gains from the research results of the degree recipient. Aside from the potential of raising society's current net economic welfare, graduate education obtained in one generation may also have a positive impact on the attitudes and educational attainment of the next generation. (pp. 100-101)

Given that most of the above benefits of graduate education were difficult to quantify, Dyal (1975) was only able to measure private monetary benefits. He calculated private monetary benefits as "the increment to the lifetime stream of personal disposable income attributable to the highest degree attained, minus the income that the student would have taken home had he only attained the next lowest degree" (p. 101). Additional net lifetime earnings and the accompanying increase in tax revenue were identified as the monetary returns to society. Using a cost-benefit approach to determine the private and social returns to investment in graduate education, Dyal (1975) found that returns to PhD degrees were quite high (and above those for MA degrees) and sensitive to differences in the length of schooling and the student's method of financing the degree. Private returns and social returns for PhD degrees averaged 2% and 1.7% respectively, compared to 1.5% and 1.3% respectively for MA degrees. Returns varied by field, with returns for PhD degrees highest in biological sciences, chemical sciences and mathematics, and lowest in physics, political science, economics and computer science. Although returns from graduate education calculated by Dyal (1975) were well below returns from university education calculated by the OECD, his study shows that returns for a PhD degree were greater than returns for a Masters degree.

7.4 Economic and non-economic impacts of human capital

Debate about the contribution of human capital to economic growth is said to have started in the 1950s when growth accountants like Fabricant (1954), Abramovitz (1956) and Solow (1957) argued that changes in the quality of the labour force could be the reason for changes in economic growth that couldn't be explained by the conventional capital and labour measures i.e. the **residual** (Griliches, 2000). Schultz (1963) found that the enormous increase in the estimated stock of education in the workforce was one of the factors that contributed to growth in national income in the United States between 1900 and 1957. As a result, he argued it is important to know about the stock of education, how the stock of human capabilities is changing, and whether these changes account for increases in output (Schultz, 1971).

Denison (1962) attempted to account for total economic growth, including the residual, in his study on the sources of economic growth in the United States between 1909 and 1957. He estimated that human capital investment accounted for at least 43% of national income growth (Sweetland, 1996). Similarly, Wykstra (1971) observed the most of the authors in his book (who were discussing the interdependencies between economic growth of a society and its stock of human capital) were attempting to explain human capital formation that was *buried* in the unknown residual or error term (R) in the production function:

$$Q = f(L, K, R)$$

Output (Q), Labor (L), Capital (K), Unknown residual or error term (R)

Nelson and Phelps (1971) who first wrote their article in 1966 which was reprinted in Wykstra (1971) were attempting to address the following hypothesis:

> … in a technologically progressive or dynamic economy, production management is a function requiring adaptation to change and that the more educated a manager is, the quicker will he be to introduce new techniques of production. To put the hypothesis simply educated people make good innovators, so that education speeds up the process of technological diffusion. (p. 95)

They introduced the notion of the theoretical level of technology, *A(t)*, which represented the stock of knowledge or body of technology that is available to innovators. In the production function it represented the "best practice level of technology that would prevail if technological diffusion was completely instantaneous" (p. 96):

$$Q = f\,[K(t), A(t)\,L(t)]$$

Output (Q), Labor (L), Capital (K), Technology in practice (A), Time (t)

The 1980s saw the development of endogenous growth models that sought to explain the roles of factors other than labour and capital in economic growth. Central to these models is a theory of technology where investment in R&D activities leads to new and better products and methods of production and the adoption of superior technologies (Barro, 1997). Lucas (1988) was concerned that the neoclassical model of growth did not adequately consider variations across countries in the level and rate of change in technology. He found that variations in technology were due to differences in the knowledge of particular people or particular subcultures of people. This finding led Lucas (1988) to develop a model that incorporated human capital, thereby considering the individual decisions to acquire knowledge and the consequences of these decisions on productivity. Romer (1990) also believed that human capital variables should be considered when explaining growth rates. His model found a connection between basic literacy and the rate of growth of income per capita and the rate of investment in physical capital. Romer (1990) proposed that the rate of growth of human capital variables such as educational achievement and scientific talent is also related to the rate of growth of output.

Yet other well known studies by Barro and Sala-i-Martin (1995), Benhabib and Spiegel (1994) and Barro and Lee (1996) concluded that human capital contributed very little to economic growth. For example, the analysis of cross-country estimates of physical and human capital stocks by Benhabib and Spiegel (1994) found that human capital has little effect on per capita growth rates. They did find that human capital influences the growth of total factor productivity by influencing the rate of domestically produced technological innovation and the speed of adoption from abroad.

The Oxford Encyclopaedia of Economic History (2003) identified four points to consider in any analysis of the influence of human capital on growth rates (pp. 5-6):

- Allowance should be made for other factors than human capital that influence growth rates as there is evidence of strong growth without sizeable increases in human capital stock or improvements in the educational attainments of a workforce.
- Human capital is thought to influence economic growth by increasing the rate of technological advance. However, consideration must be given to the groups that are most likely to influence technological advance in an economy and what specific forms their human capital investments should take.
- Human capital investments in general decision-making ability may have the greatest aggregate impact on growth rates than investment in specific skills.

- Economies with lower levels of human capital may experience higher rates of economic growth during some periods because of greater rates of catch-up or convergence to some international technological or productivity standard.

There are several non-economic or social benefits that are linked to human capital investment in education. The endogenous development model proposed by McMahon (1999) included not only the market-measured economic growth impacts of education (such as per capita economic growth) but also a number of non-market impacts: Better heath (reflected in lower infant mortality and increased longevity), lower fertility and population growth rates, democratisation (or development of civic institutions), human rights (measured as civil liberties), political stability, reduced poverty and inequality, environmental sustainability, and crime impacts (some positive and some negative). The OECD (1998a) stated that social benefits may be due to education "changing individuals' preferences, by changing the constraints that individuals face, or by augmenting the knowledge or information on which individuals base their behaviour" (p. 68).

Table 43 contains a selection of economic and non-economic indicators that may be linked to human capital investment in education including research training. These indicators have been assessed against two human capital measures that show a country's investment in a high skilled workforce – population with a tertiary type A/advanced research qualification and HRST stocks as a proportion of total employment.

Table 43: Possible indicators of economic and non-economic impacts of human capital

	Australia	Finland	USA	OECD
Economic indicators:				
Average annual growth rate of real GDP (%), 1995 to 2003	3.8%	3.6%	3.2%	3.2%
GDP per capita, USD, current prices, 2002	$28,068	$26,495	$36,121	$24,617
Average annual growth in business sector labour productivity (%), 1994 to 2003	1.9%	2.6%	2.1%	2.1%
Non-economic indicators:				
Relative poverty rates (proportion of individuals with disposable income less than 50% of the median income of the entire population)	11.2%	6.4%	17%	10.2%
Infant mortality (the number of deaths of children under one year of age expressed per 1,000 live births)	5.0 (2002)	3.0 (2002)	6.8 (2001)	6.6
Life expectancy	80 years (2002)	78.2 years (2002)	77.1 years (2001)	77.7 years
Persons convicted of, or committed intentional homicides per 100,000 inhabitants, latest year	2.35	2.15	4.91	1.87
Emissions of carbon dioxide (CO_2), tonnes per capita, 2002	17.4	12.1	19.6	9.4
Life satisfaction and feelings of happiness 1999-2002	85.9%	87.2%	86.2%	79.4%
Suicides per 100,000 persons	12.7 (2001)	21 (2002)	10.4 (2000)	13.9

Source: OECD (2005b)

The **economic indicators** of GDP growth rates, GDP per capita and labour productivity in the business sector have been assessed against the two indicators of human capital investment in Figure 49, Figure 50 and Figure 51 respectively. There appears to be no correlation between the human capital indicators and *GDP growth rates* (Figure 49) and *labour productivity in the business sector* (Figure 51). As discussed in the previous section, other factors other than human capital may be contributing to improvements in growth rates and labour productivity, such as convergence to international technological or productivity standards in those countries with relatively low levels of human capital investment and stocks. Figure 50 shows a positive correlation between the human capital indicators and *GDP per capita*. Those countries with higher levels of university educated people and HRST stocks tended to have higher GDP per capita.

Figure 49: GDP growth rates and human capital

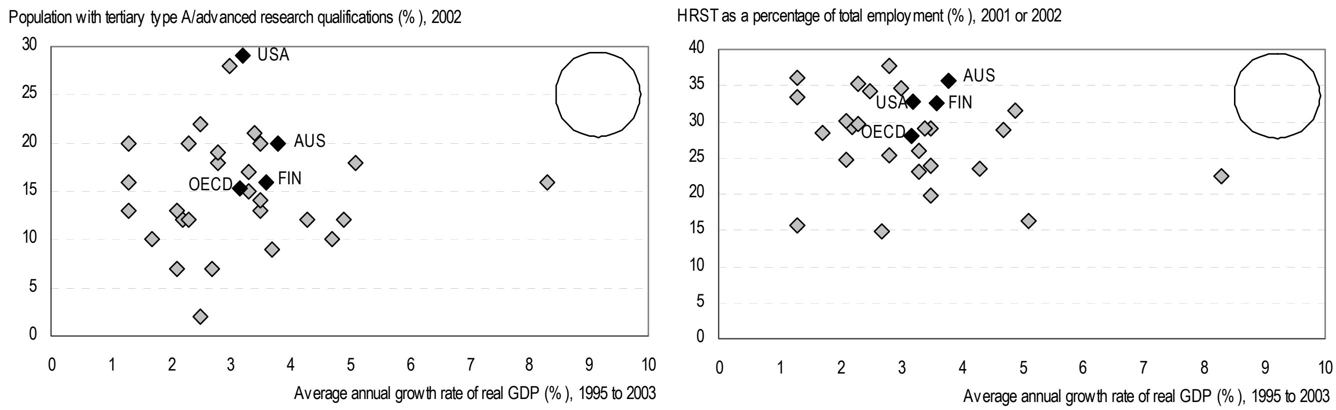


Figure 50: GDP per capita and human capital

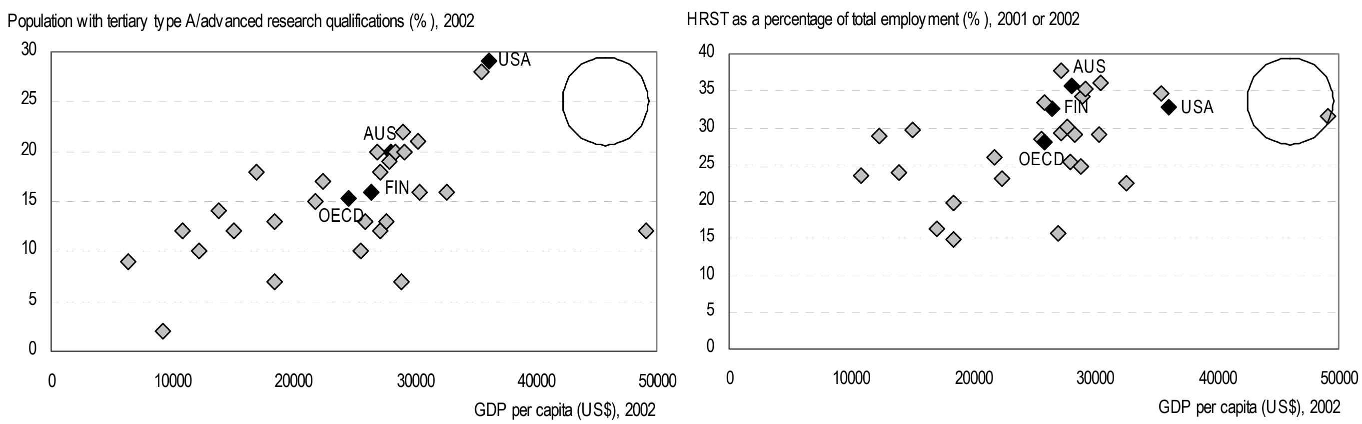
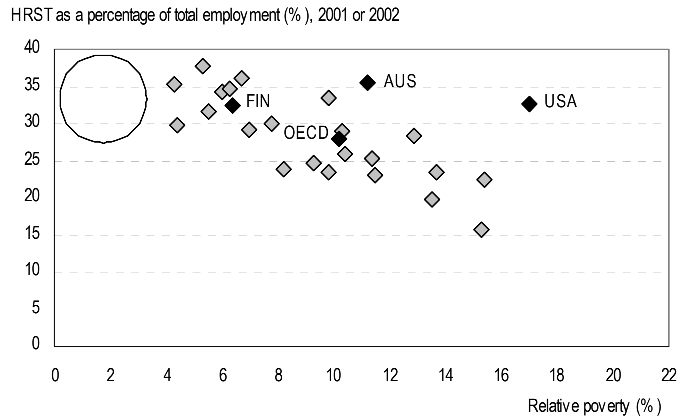


Figure 51: Labour productivity and human capital

Figures 52 to 58 assessed the two indicators of human capital investment against seven **non-economic or social indicators** – relative poverty, infant mortality, life expectancy, homicide conviction/committal rates, CO2 emissions, life satisfaction and feelings of happiness, and suicide rates. There appears to be no correlation between a country's level of university attainment and *relative poverty* but many countries with a high level of HRST stocks seemed to have lower relative poverty (Figure 52).

Figure 52: Relative poverty and human capital



There is a positive correlation between HRST stocks and to a lesser extent, university attainment, and *infant mortality* (Figure 53), *life expectancy* (Figure 54) and *homicide conviction/committal rates* (Figure 55) in many countries. This is not the case for the United States which has a relatively higher infant mortality rate and homicide conviction/committal rate and lower life expectancy despite having high levels of university attainment and HRST stocks.

Figure 53: Infant mortality and human capital

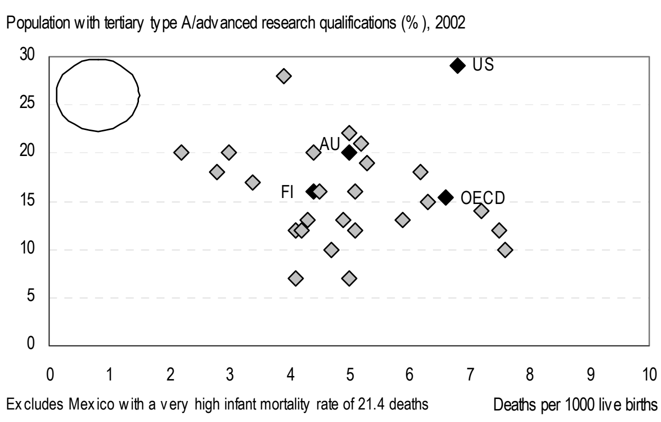


Figure 54: Life expectancy and human capital

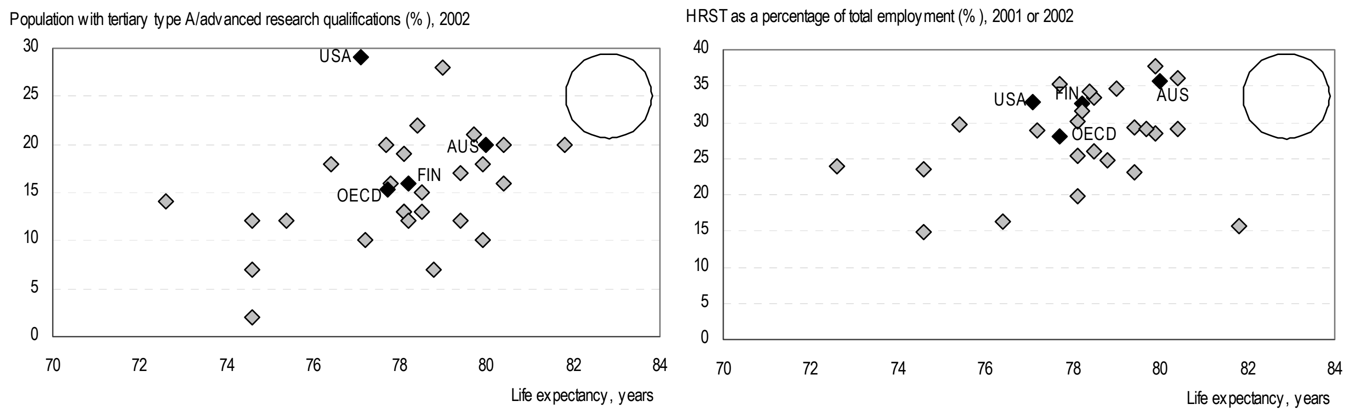
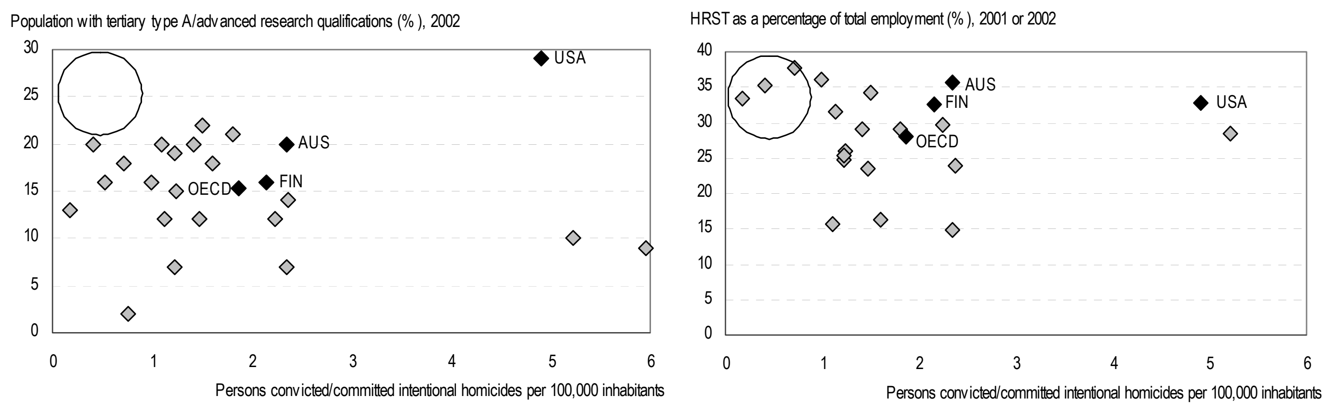


Figure 55: Homicide rates and human capital



There is no correlation between the two indicators of human capital investment and *CO2 emissions* (Figure 56) and *suicide rates* (Figure 58). Figure 57 suggests that countries with a high level of university attainment and HRST stocks have higher levels of *life satisfaction and feelings of happiness*.

Figure 56: Emissions of CO2 and human capital

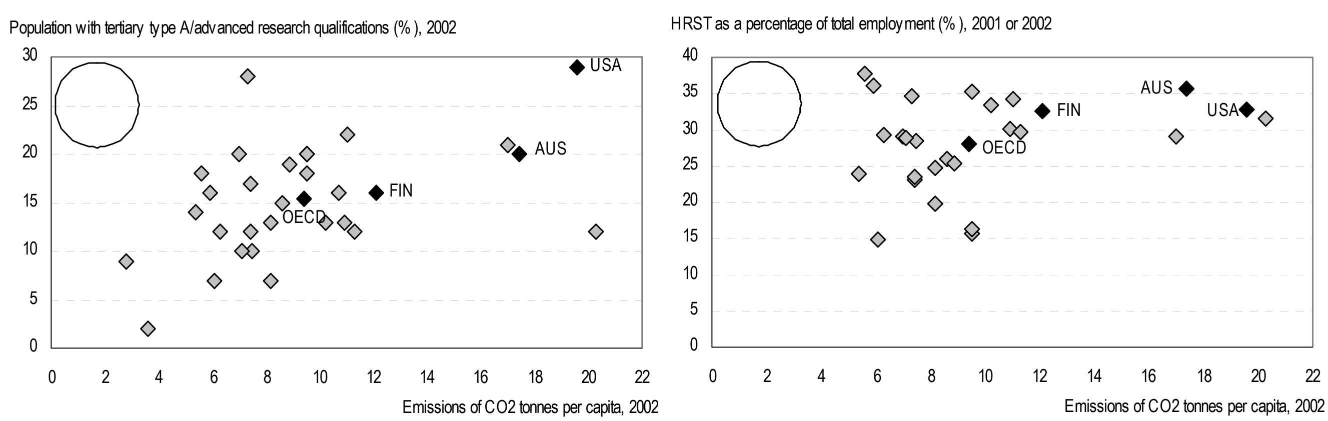


Figure 57: Life satisfaction and feelings of happiness and human capital

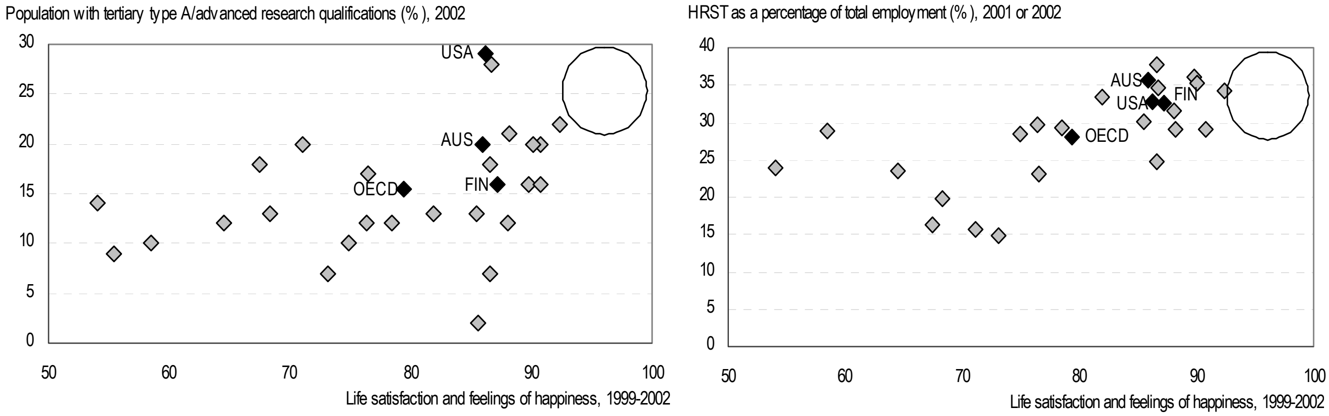
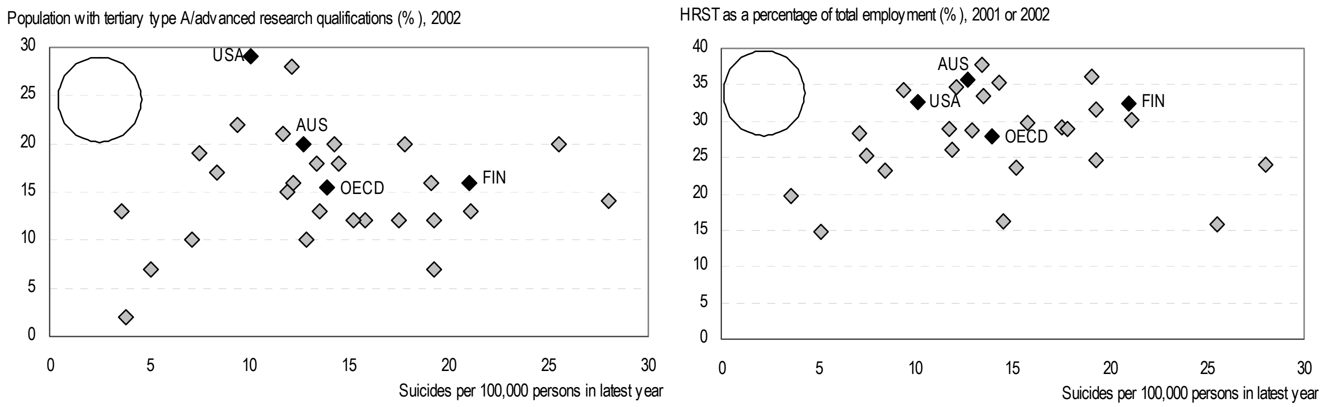


Figure 58: Suicide rates and human capital



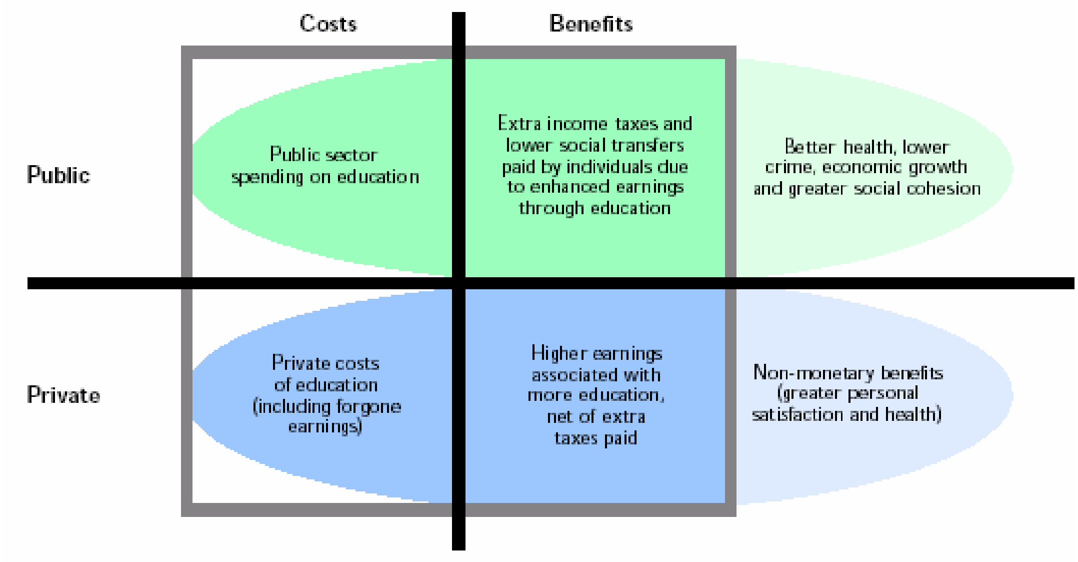
Source: OECD (2004a) and (2004b) and 2005(b), United Nations (2005), Figures 49 to 58

7.5 Results for Australia, Finland and the United States

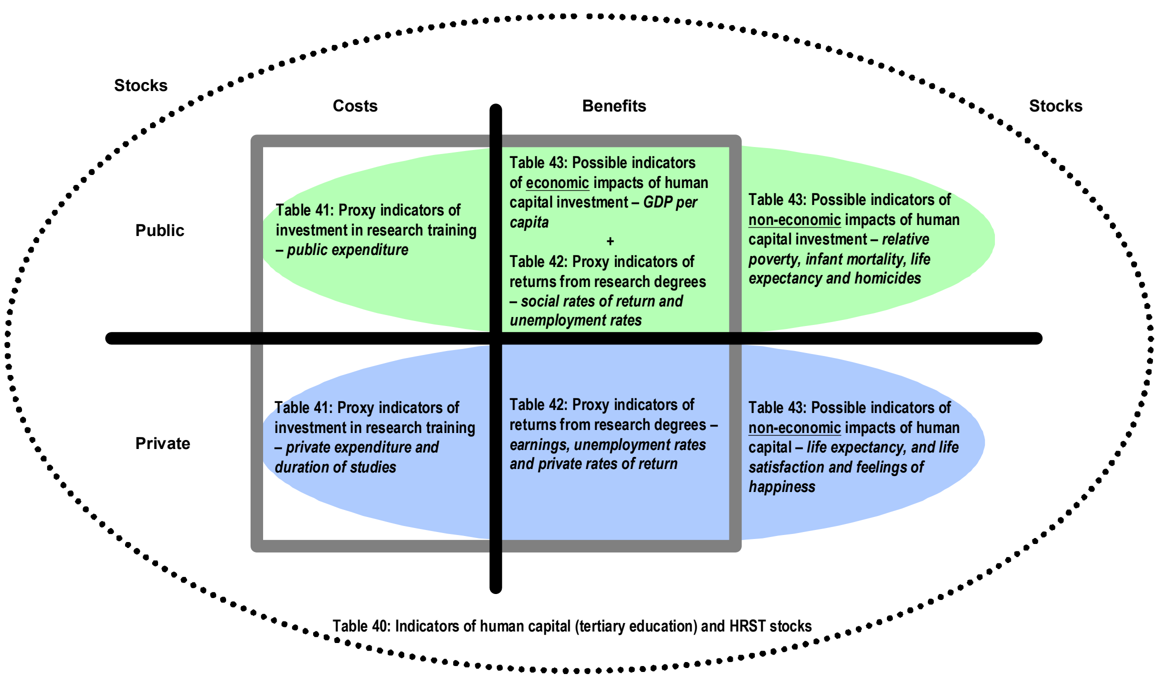
7.5.1 Approach

The literature review and statistical analysis presented so far in this chapter have confirmed a positive correlation between human capital investment in university education and some economic and non-economic indicators. A basic approach is now taken to present data on human capital stocks, investments and returns (Tables 40 to 42), correlated economic and non-economic indicators (Table 43), and other relevant data from country sources, within a customised version of the OECD framework of the key costs and benefits from human capital investment (Figure 59). This approach does not add much to the debate about whether human capital investment in education contributes to economic growth. Instead it brings together the relevant statistics for Australia, Finland and the United States.

Figure 59: Costs and benefits of human capital investment in education



Customised version of this framework



Source: OECD (1998a) p. 69

7.5.2 Human capital stocks

Nearly one third (29%) of the population in the United States had a university degree in 2002 which is well above that for Australia (20%), Finland (16%) and the OECD (15%). Finland's graduation rate for advanced research degrees of 1.9% was higher than Australia and the United States (both recording 1.3%) and the OECD country mean of 1.2%, indicating that a larger proportion of Finnish people with a tertiary type A qualification (as a proportion of the population) go on to complete an advanced research qualification. On average, those people who complete a research degree in Finland graduate at the age of 29 years compared to 28 years for the United States and between 25 and 29 years for Australia.

Table 44: Population that attained a university degree (type A and advanced research programs) by age group, 1996, 1998 and 2002

	1996				1998				2002			
Age	**FIN**	**AUS**	**USA**	**OECD mean**	**FIN (1997)**	**AUS**	**USA**	**OECD mean**	**FIN**	**AUS**	**USA**	**OECD mean**
25-34	13%	16%	26%	15%	14%	19%	27%	16%	21%	25%	31%	19%
35-44	13%	18%	26%	14%	15%	18%	26%	15%	17%	21%	29%	16%
45-54	12%	14%	28%	12%	13%	18%	29%	13%	14%	19%	30%	14%
55-64	7%	8%	20%	8%	8%	10%	22%	9%	11%	13%	26%	11%
25-64	**12%**	**15%**	**26%**	**13%**	**13%**	**17%**	**27%**	**14%**	**16%**	**20%**	**29%**	**15%**
Graduation rate advanced research programs (1)					2.3%	1.1%	1.3%	1.0%	1.9% (2001)	1.3%	1.3%	1.2%

(1) The proportion of the population at typical age of graduation with an advanced research qualification
Source: OECD (1998b), (2000) and (2004b)

Whereas Finland had a high proportion of university graduates in science and technology fields (28% in 2001), the rates for Australia (19.4%) and the United States (15.8%) were below the OECD country mean (21.8%) (Table 47). The dominance of engineering in Finland is waning with the field accounting for 20.8% of all graduates in 2001 compared to 24.2% in 1998. Women accounted for a small share of S&T university graduates in all OECD countries, particularly in the United States, and in Finland their share was falling. Australia continued to produce science graduates at a rate above that for OECD countries but, like the United States, it produces a small share of engineering graduates.

Table 45: University graduates in science and engineering, 1998, 2000 and 2001

TOTAL	**Science**				**Engineering**				**Total**			
	FIN	AUS	USA	OECD	FIN	AUS	USA	OECD	FIN	AUS	USA	OECD
1998	8%	11.5%	9.2%	9.6%	24.2%	7.9%	7.0%	12.4%	32.2%	19.4%	16.2%	22.0%
2000	7.9%	11.8%	9.3%	9.8%	24.0%	7.9%	6.5%	11.8%	31.9%	19.7%	15.8%	21.6%
2001	7.2%	11.9%	9.4%	10.0%	20.8%	7.5%	6.4%	11.8%	28.0%	19.4%	15.8%	21.8%
WOMEN	**Science**				**Engineering**				**Total**			
	FIN	AUS	USA	OECD	FIN	AUS	USA	OECD	FIN	AUS	USA	OECD
1998	6.5%	8.4%	7.2%	7.7%	7.9%	2.9%	2.4%	4.2%	14.4%	11.3%	9.6%	11.9%
2000	6.2%	8.6%	7.3%	8.0%	7.7%	3.0%	2.4%	4.4%	13.6%	11.6%	9.7%	12.4%
2001	5.3%	8.5%	7.3%	8.0%	6.5%	2.9%	2.4%	4.5%	11.8%	11.4%	9.7%	12.5%

Source: OECD (2004d)

The categories of human resources in science and technology (HRST) that are described in section 3.5 include: *HRST core* i.e. people with an S&T university qualification who are employed in S&T occupations; *HRSTQ* i.e. people with an S&T qualifications who are not employed in an S&T occupation; and *HRSTO* i.e. people who do not have an S&T qualification and work in an S&T occupation. These categories form a country's HRST stock. HRST data from the OECD shows that Australia has experienced average annual growth in HRST stocks of 3.07% between 1997 and 2001 (a ranking of 11th out of 27 countries) which is above that for Finland (2.32% between 1996 and 2001 and a ranking of 16th) and the United States (2% between 1995 and 2002 and a ranking of 21). HRST accounted for 35.6% of total employment in Australia in 2001, compared to 32.5% in Finland, 32.7% for the United States and an OECD average of 28% in 2002.

Australia's HRST stocks have increased significantly from 1,987,000 people in 1991 to 3,054,000 people in 2001 (Table 46). The HRST core has also increased significantly from 811,000 people in 1991 to 1,243,000 people in 2001. Of some concern is the increase in the number of people with selected qualifications only (i.e. HRSTQ) who are not working in selected occupations. In 1991, HRSTQ accounted for 34.5% of the HRST stock and by 2001 its share had increased to 38.8%, suggesting that more people with S&T qualifications are not pursuing S&T careers. Around 19,000 of the 68,000 people with a doctoral degree (27.9%) were not working in an S&T occupation in 2001. Overall, research graduates with a doctoral degree accounted for only 4% of the HRST core and 2.8% of all people with S&T qualifications in 2001.

Table 46: Persons with selected occupations and/or in selected occupations, Australia 1991, 1996 and 2001

	1991	1996	2001
HRST Core (with selected qualifications and in selected occupations)	811,000	1,033,000	1,243,000
HRSTQ (with selected qualifications only)	685,000	905,000	1,185,000
HRSTO non-core (in selected occupations only)	490,000	575,000	626,000
Stock of HRST (Total)	**1,987,000**	**2,512,000**	**3,054,000**

Source: Australian Bureau of Statistics (1999) and (2003)

Data from Eurostat shows that HRST stocks and the HRST core in Finland peaked in 2001 at 1,195,875 persons and 517,481 persons respectively (Table 47). In 2003, Finland recorded HRST stocks of 1,140,100 people and a HRST core of 515,116 people. Despite steady increases in the number of people with S&T qualifications, the number of scientists and engineers has fallen significantly since 2001.

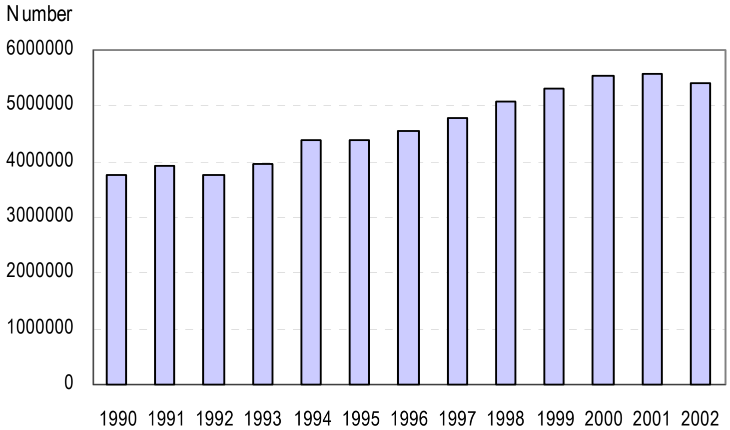
Table 47: HRST stocks, Finland 1998 to 2003

	1998	1999	2000	2001	2002	2003
HRST Core (with S&T qualifications and in S&T occupations)	430,110	464,869	494,178	517,481	510,116	515,116
HRSTQ (S&T qualifications)	804,391	868,147	907,295	913,504	915,882	929,624
HRSTO (S&T occupations)	686,975	731,922	763,698	799,852	728,665	725,592
Stock of HRST (Total)	1,061,256	1,135,199	1,176,815	1,195,876	1,134,431	1,140,100
Scientists and engineers	167,291	189,647	201,864	205,426	148,411	158,543

Source: Eurostat (2005)

Employment in S&E occupations in the United States rose consistently over the past decade until 2002 (Figure 60). The National Science Foundation estimated there were 5,412,000 people employed in S&E occupations in 2002. Of the 3,540,800 million people in the HRST core in the United States in 1999, 484,100 people (13.7%) had a doctorate. Further falls in employment in S&E occupations were expected in response to the decline in the inflow of foreign students and talent.

Figure 60: Employment in S&E occupations, United States 1990 to 2002



Source: National Science Foundation (2004)

7.5.3 Investment in human capital

Table 48 shows that the United States continues to invest significantly more than Finland, Australia and the OECD in tertiary type A and advanced research programs. Educational expenditure on these programs as a proportion of GDP was 2.7% in 2001, compared to 1.7% for Finland, 1.4% for Australia and an OECD country mean of 1.1%. In 2001, the United States invested $22,234 per student in these programs, well above investments in Finland ($11,143), Australia ($13,654) and the OECD ($9,495). Because of the longer duration of studies in Finland (an average duration of 4.5 years compared to 2.6 years for Australia), Finland invests more than Australia on a cumulative basis in tertiary type A and advanced research programs ($49,972 compared to $34,954). Expenditure on R&D at tertiary institutions as a percentage of GDP in Finland in 2001 of 0.62% (which represents R&D expenditure per student of $3,921) exceeded expenditure in Australia of 0.42% (or $3,488 per student) and the United States of 0.26% (or $2,136 per student). Private sources accounted for a small proportion of educational expenditure on tertiary type A and advanced research programs in Finland (3.5% in 2001) in contrast to 48.7% for Australia, 66% for the United States and an OECD country mean of 21.8%. Consequently, the higher private rates of return in Finland which are discussed in the next section were largely due to students not having to contribute very much to the costs of their education.

Table 48: Expenditure on tertiary type A and advanced research programs, 1995, 1997 and 2001

		1995	1997	2001
Percent of GDP	Australia	1.5%	1.5%	1.4%
	Finland	1.3%	1.4%	1.7%
	United States (all tertiary education)	2.0%	2.6%	2.7%
	OECD country mean	1.1%	1.1%	1.1%
Annual expenditure per student	Australia	$11,572	$12,024	$13,654
	Finland	$7,412	$7,192	$11,143
	United States	$19,965	$17,466	$22,234
	OECD country mean	$8,781	$8,434	$9,495
Cumulative expenditure	Australia	$30,086	n.a.	$34,954
	Finland	n.a.	n.a.	$49,972
	United States	n.a.	n.a.	n.a.
	OECD country mean	$36,494	n.a.	$47,894

Source: OECD (1998b), (2000) and (2004b)

7.5.4 Returns to human capital

Salary data from national sources shows that people with a research degree in Australia, Finland and the United States earn more than those with lower qualifications. OECD data on relative earnings, private and social rates of return, and unemployment rates for those people with tertiary type A and/or advanced research qualifications indicate that people with a university degree in these countries earn more and are less likely to be unemployed than those with lower qualifications. The issue of low salaries for researchers particularly in academia that is discussed in section 5.7 of this thesis is not adequately reflected in the following data.

Average annual income of employed persons with a doctoral degree in Australia of AUD $61,000 in 2001 was almost 30% higher than average annual income of employed persons with a Bachelor degree of AUD $47,000 (Table 49). It should be noted that most of those people with doctorates in Australia in 2001 were 35 years or over (88.2%). Average monthly earnings of people with a postgraduate degree in Finland were between 25.9% (for 25-29 year olds) and 54% (for 60-69 year olds) above earnings of people with an undergraduate degree. These figures show that earnings for people with a postgraduate degree in Finland increase with age, with new graduates aged between 25 and 29 years having the lowest monthly earnings of 2,748 euros a month in 2002 (Table 50). People with a doctoral degree in the United States (USD$89,965 for males) also earned more than those with a Bachelor degree (USD$55,929 for males) in 2001. However, males with a professional degree earned about 13% more than males with a doctoral degree (Table 51).

Table 49: Average annual income of employed people by level of education, Australia 2001 ($AUD)

	Advanced diploma	Bachelor degree	Graduate certificate	Graduate diploma	Masters degree	Doctoral degree	Total
Males	$47,000	$54,000	$59,000	$56,000	$60,000	$64,000	$54,000
Females	$33,000	$40,000	$47,000	$43,000	$50,000	$55,000	$40,000
Persons	$39,000	$47,000	$52,000	$48,000	$56,000	$61,000	$47,000

Source: Australian Bureau of Statistics (2003)

Table 50: Average monthly earnings by level of education and age, Finland 2002 (euros)

Age	Basic level	Secondary level	Lowest level of tertiary education	Undergraduate level	Graduate level	Postgraduate level
15-19	1,434	1,480	-	-	-	-
20-24	1,681	1,757	1,785	1,876	2,401	-
25-29	1,979	2,002	2,005	2,183	2,643	2,748
30-34	2,048	2,073	2,172	2,515	3,011	3,216
35-39	2,060	2,100	2,311	2,720	3,258	3,446
40-44	2,049	2,092	2,341	2,836	3,468	3,841
45-49	2,023	2,088	2,351	2,934	3,633	4,118
50-54	2,016	2,089	2,412	3,045	3,662	4,350
55-59	2,026	2,078	2,475	3,069	3,730	4,484
60-69	1,997	2,004	2,468	2,974	3,868	4,580

Source: Statistics Finland (2005)

Table 51: Median annual income of full-time workers 25 years and older by level of education, United States, 2001 ($USD)

	High school completion	Associate degree	Bachelor degree	Masters degree	Professional degree	Doctoral degree	Total
Males	$34,723	$42,776	$55,929	$70,899	$100,000	$86,965	$41,617
Females	$25,303	$32,153	$40,994	$50,669	$61,748	$62,123	$31,356

Source: National Center for Education Statistics (2004)

OECD data also indicated that those people with a university degree in the United States earned 95% more than those people with upper secondary education compared to differences of 81% for Finland and 48% for Australia. These figures equated to country rankings for the difference in relative earnings of 2nd for the United, States, 7th for Finland and 13th for Australia. Women with a university degree continued to earn slightly less than men with a university degree in the three countries.

Out of nine OECD countries that provided data on private rates of return from tertiary type A and advanced research qualifications, Finland recorded the second highest private rate of return for males (14.2%) and the highest private return for females (15.2%) (Table 52). Australia recorded the lowest private rate of return for males (6.6%) and the second lowest rate of return for females (6.5%). The private rate of return for males in the United States of 11% was well above the private rate of return for females of 7.9% in 2001. The social rate of return from university education in 2001 was higher for males than females in all three countries, with the United States recording the highest social rate of return for males of 11.1%. Finland recorded the highest social rate of return for females of 8.7% in 2001.

Table 52: Relative earnings (upper secondary education = 100) and rates of return for tertiary type A and advanced research qualifications

	Relative earnings			Private rate of return		Social rate of return	
	1995	**1997**	**2001**	**1995**	**2001**	**1995**	**2001**
Males							
Finland	187	189 (1996)	190	n.a.	14.2%	n.a.	10.5%
Australia	161	144	160	14%	6.6%	11%	8.3%
United States	183 (1996)	183 (1998)	202 (2002)	11%	11.0%	10%	11.1%
Females							
Finland	173	179 (1996)	172	n.a.	15.2%	n.a.	8.7%
Australia	139	154	159	21%	6.5%	13%	7.6%
United States	175 (1996)	180 (1998)	185 (2002)	12%	7.9%	11%	7.9%
Males + females							
Finland	185	186 (1996)	181	n.a.	n.a.	n.a.	n.a.
Australia	142	136	148	n.a.	n.a.	n.a.	n.a.
United States	183 (1996)	184 (1998)	195 (2002)	n.a.	n.a.	n.a.	n.a.

Source: OECD (1998b), (2000) and (2004b)

Unemployment rates for people with a tertiary type A and/or advanced research degree in Australia, Finland and the United States has remained below that for all levels of education (Table 55). Unemployment rates for males with a university degree in 2002 were slightly higher in Finland (3.1%) than in Australia (2.6%), the United States (2.8%) and the OECD (2.9%). For females with a university degree, the unemployment rate was the same as males in Finland (3.1%) but lower for females in Australia (2%) and the United States (2.1%).

Table 53: Unemployment rates by level of education, 1996, 1998 and 2002

	1996				1998				2002			
	FIN	AUS	USA	OECD	FIN (1997)	AUS	USA	OECD	FIN	AUS	USA	OECD
Type A and advanced research qualifications												
Males	6%	4%	2%	n.a.	4.6%	2.8%	1.7%	3.3%	3.1%	2.6%	2.8%	2.9%
Females	6%	3%	2%	n.a.	4.5%	3.0%	1.9%	4.6%	3.1%	2.0%	2.1%	3.3%
All levels of education												
Males	15%	7%	5%	n.a.	10.7%	6.6%	4.1%	5.7%	6.5%	4.5%	4.7%	4.6%
Females	16%	6%	4%	n.a.	11.5%	5.8%	3.8%	7.2%	6.2%	3.1%	3.3%	4.1%

Source: OECD (1998b), (2000) and (2004b)

7.5.5 Economic and non-economic impacts

The statistical analysis in section 7.4 shows a correlation between two indicators of a highly skilled workforce (proportion of the population with a tertiary type A/advanced research qualification and HRST stocks as a proportion of total employment) and the economic and non-economic indicators of GDP per capita, infant mortality, life expectancy, homicide rates, life satisfaction and feelings of happiness, and relative poverty (HRST stocks only). There appears to be no correlation between the two human capital indicators and GDP growth rates, labour productivity in the business sector, relative poverty (university education only), CO_2 emissions and suicide rates. Only those economic and non-economic indicators that show a correlation with either of the two human capital indicators are included in this *cautious* analysis of findings.

Australia's investment in a highly skilled workforce as indicated by a higher level of the population with a university education (20% compared to 15% for the OECD) and HRST stocks that account for a larger proportion of total employment (35.6% compared to 28% for the OECD) have contributed to above OECD average GDP per capita ($28,068), better life expectancy (80 years), greater life satisfaction and feelings of happiness (85.9%), and a lower infant mortality rate (five deaths per 1000 live births). However, the proportion of the population with disposable income of less than 50% of the median income (i.e. relative poverty) has increased from 9.3% in the mid 1990s to 11.2% in 1999, which is now above the OECD relative poverty rate of 10.2%. Homicides conviction/committal rates were also above the OECD average. Latest figures showed that 2.35 people out of every 100,000 people in Australia were convicted of or committed intentional homicides compared to an OECD average of 1.87 people.

Despite improvements in the proportion of the population with a university education (rising from 12% in 1996 to 16% in 2002) and above average HRST stocks (32.5% of total employment), GDP per capita in Finland is only slightly above the OECD average ($26,495 compared to $24,617). Whereas life expectancy (78.2 years) is just above the OECD average, human capital investment contributed to significantly lower infant mortality (three deaths per 1000 live births), lower relative poverty (6.4%) and higher life satisfaction and feelings of happiness (87.2%). Yet, the homicide conviction/committal rate at 2.15 people out of every 100,000 people was above the OECD average.

A strong commitment to university education (with 29% of the population having a university degree) and a high level of HRST stocks (32.7% of total employment) have contributed to very high GDP per capita in the United States ($36,121) and a high level of life satisfaction and feelings of happiness (86.2%). However, the relative poverty rate in the United States at 17% is the second highest of all OECD countries and is likely to be a major factor contributing to the above average infant mortality rates (6.8 deaths per 1000 live births), slightly lower than average life expectancy (77.1 years) and a very high homicide rate (4.91 people convicted of, or committed intentional homicides out of every 100,000 people).

7.6 Chapter summary

The start of this chapter provided a background to the nature of human capital and how it is formed and measured, which was followed by a discussion on the literature that examined the impact of human capital formation through education on economic growth. The literature review identified studies that found a direct link between the human capital and economic growth, whilst other studies produced inconclusive results. In addition, there are few studies that have focussed on the impact of, and returns from research training as advanced human capital formation. A basic analysis of two proxy indicators of research training – the level of the population with a university education and HRST stocks as a proportion of the population – against three economic indicators and seven non-economic indicators found varying degrees of correlation for some indicators (GDP per capita, relative poverty, infant mortality, life expectancy, homicide conviction/committal rates, and life satisfaction and feelings of happiness) and no correlation between other indicators (GDP growth rates, business productivity in the business sector, CO_2 emissions and suicide rates). Data on human capital stocks, investment levels and returns for Australia, Finland and the United States was supported by a basic analysis of possible economic and non-economic impacts. Results were presented within a customised version of the OECD framework of the key costs and benefits from human capital investment. The rest of this section presents key results for each country within this framework.

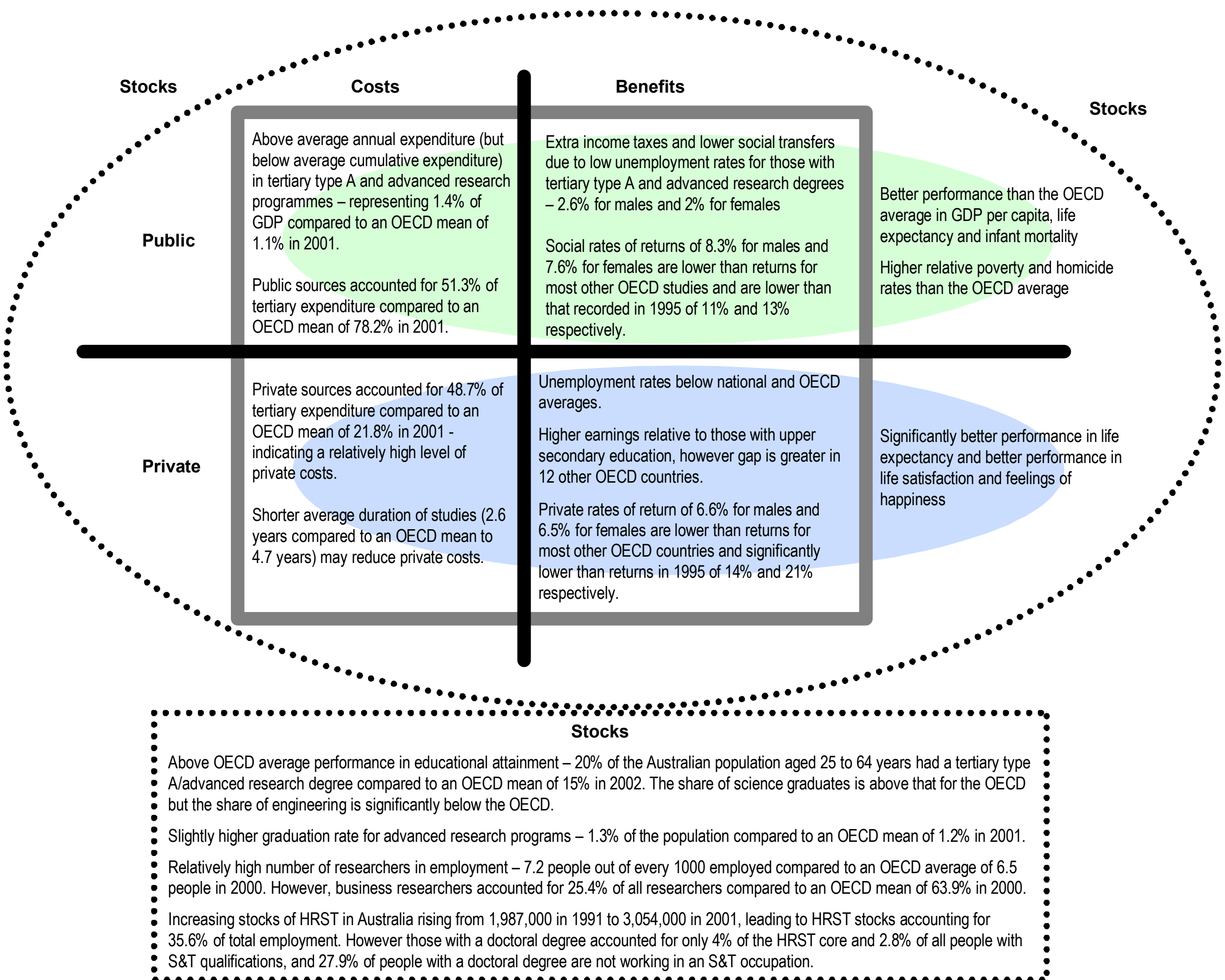
7.6.1 Australia

Twenty (20%) percent of Australians aged between 25 and 64 years had a university qualification in 2001 which was above the OECD mean of 15% (Figure 61). Only a small proportion of the population (1.3%) had an advanced research degree, and consequently those with a doctoral degree accounted for only 2.8% of all people with S&T qualifications and 4% of Australia's HRST core. Over one quarter (27.9%) of those people with doctoral degrees were not working in S&T occupations. Despite the apparent low level of research graduates in Australia's HRST stocks and core, the significant increase in stocks over the past ten years has contributed to HRST accounting for 35.6% of total employment in 2001.

Australia is investing more of its GDP in tertiary type A and advanced research programs, rising from 1.3% in 1995 to 1.7% in 2001, which was above the OECD mean of 1.1%. Annual expenditure on university students at $13,654 per student was also above the OECD mean but because students spend significantly less time in tertiary education, cumulative expenditure was lower than the OECD mean. This study has not looked at why students spend less time in Australian universities. One contributing factor may be that private sources are increasingly being used to finance university education. Latest figures show that private sources accounted for 48.7% of all expenditure on tertiary type A and advanced research programs, compared to 35.2% in 1995 and an OECD mean of 21.8% in 2001.

Similar to other OECD countries, university (and research) graduates in Australia earn more than those people with upper secondary education, pay more taxes, and are less likely to be unemployed and access social security. As a result, private and social rates of return are higher for those people who are university educated. This is the case for Australia, although returns are smaller, due to lower relative earnings and increasing private costs incurred in gaining this education. Data from the Australian Bureau of Statistics showed that research graduates in Australia earn more than those with lower university degrees. However, income foregone during the period they acquired their research degree, the relatively low starting salaries for researchers (as discussed in section 5.7.1), and relatively high attrition and slow completion rates suggest that private and social rates of return may not be that much higher for research graduates.

Figure 61: Summary of Australia's human capital performance and impacts

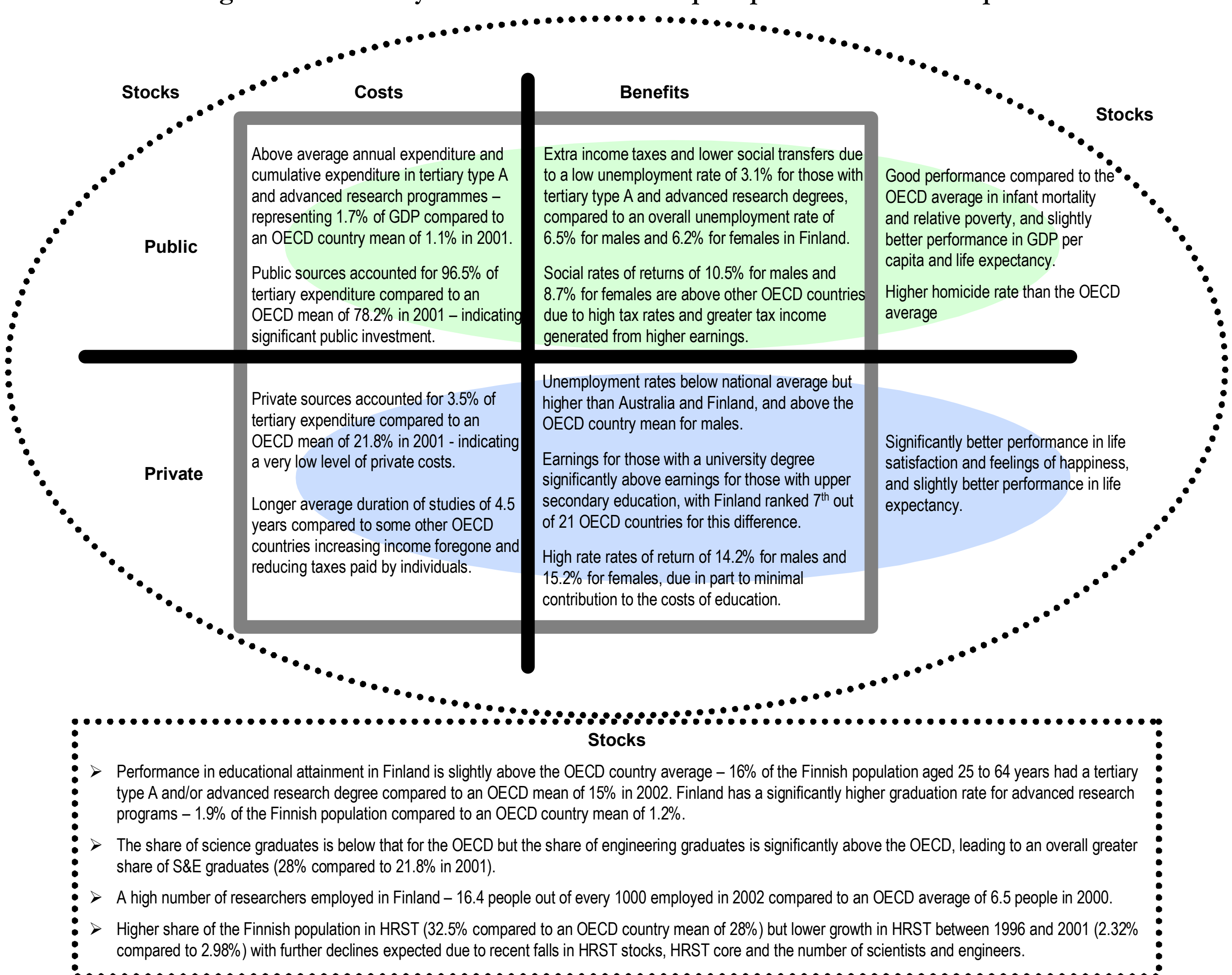


The relatively high level of human capital investment and stocks in Australia appears to have had a positive impact on GDP per capita, life expectancy, infant mortality, and life satisfaction and feelings of happiness. However, human capital investment appears to have negatively impacted on relative poverty and homicide conviction/committal rates, both of which are above the OECD average. The basic analysis did not find any correlation between the human capital indicators and GDP growth rates, labour productivity in the business sector, CO_2 emissions and suicide rates – and therefore have not been included in the country diagrams (Figures 61 to 63).

7.6.2 Finland

Indicators on educational attainment show that Finland is now producing more people with university degrees after performing below the OECD average for sometime. Although Finland produces less university graduates as a proportion of the population aged 25 to 64 years (16%) than Australia and the United States, a higher proportion of the population complete a research degree (1.9%) (Figure 62).

Figure 62: Summary of Finland's human capital performance and impacts



Finland produces a higher share of graduates in S&E fields than Australia, the United States and the OECD mean mainly due to its high number of engineering graduates. However, the declining share of engineering graduates in Finland in recent years has contributed to a fall in S&E graduates from 32.2% of all graduates in 1998 to 28% in 2001. HRST accounted for 32.5% of total employment in Finland in 2002 which was above the OECD average of 28%. HRST stocks, HRST core and the number of scientists and engineers in Finland have declined after peaking in 2001. These declines are likely to contribute to a further slowdown in average growth in HRST stocks which was 2.32% between 1996 and 2001 – a ranking of 16th out of 27 OECD countries.

University educated people in Finland earn significantly more than those people with upper secondary education and are less likely to be unemployed than the rest of the population. Data from Statistics Finland shows that people with a research degree earn significantly more than those with a Bachelor's degree. Higher earnings combined with the low cost of education have led to private rates of return for university educated people that are well above most other OECD countries. Higher taxation rates in Finland may have offset the significant public investment in education, leading to higher social rates of return for university educated people.

The proportion of the population with a university education in Finland has only recently surpassed the OECD mean and benefits in terms of slightly higher than average GDP per capita and life expectancy are being realised. Human capital investment in Finland has had a positive impact on lower infant mortality, lower relative poverty and higher life satisfaction and feelings of happiness. Similar to Australia, there appears to be a negative correlation between human capital and the homicide conviction/committal rate.

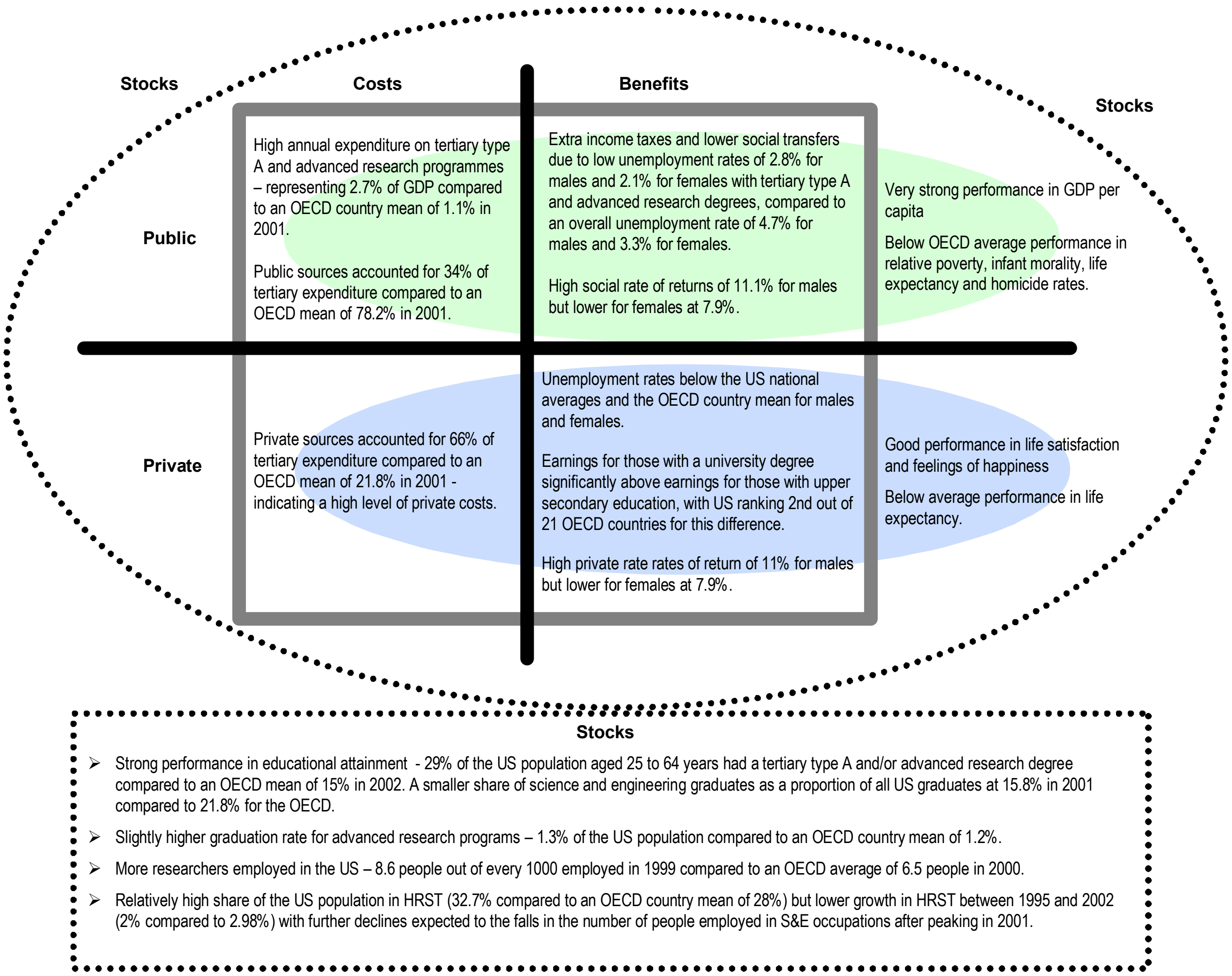
7.6.3 United States

The United States continues to invest heavily in university education as indicated by expenditure of 2.7% of its GDP and annual expenditure of $22,234 per student on tertiary type A and advanced research programs (Figure 63). Private sources accounted for almost two thirds (66%) of this expenditure in 2001. This investment has proved successful with 29% of the U.S. population having a university degree in 2002.

HRST stocks are enormous in the United States, with an estimated 5.4 million people working in S&E occupations in 2002 and 3.5 million people in the HRST core in 1999. After increasingly steadily until 2001, falls in S&E occupations have occurred due to the decline in foreign students and talent. University graduates in science and engineering fields have also fallen, from 16.2% of all graduates in 1998 to 15.8% in 2001 – which was also below the rate for the OECD of 21.8% in 2001.

As with Australia and Finland, those people with doctoral degrees in the United States earn more than those with lower degrees (except in the case of males with professional degrees) and are less likely to be unemployed. The difference in earnings between those people with a university degree and those people with an upper secondary education is significant in the United States. Private and social rates of return are high for males, indicating that the education costs incurred by individuals are offset by high earnings and these earnings are generating significant tax income for Government. However, significant earnings differences between males and females have contributed to lower (and falling) private and social rates of return for females in the United States.

Figure 63: Summary of United States' human capital performance and impacts



The analysis of the economic and non-economic impacts of the significant investment in university education made by the United States found more negative than positive correlations. On the one hand, human capital investments have contributed to the United States having one of the second highest level of GDP per capita of all OECD countries and a high level of life satisfaction and feelings of happiness. On the other hand, the United States is characterised by a high relative poverty rate, an above average infant mortality rate, slightly lower than average life expectancy, and a very high homicide rate.

In conclusion, the third element of the conceptual framework presented in this chapter has aimed to determine whether research training as human capital formation contributes to economic growth in Australia, Finland and the United States (Research Question 7). As already stated, the availability of data that separates out research degrees from other university degrees is limited and proxy indicators had to be used. The basic analysis of the economic and non-economic impacts of human capital investment in university education supports literature that has argued a link between human capital and GDP per capita and some non-economic or social indicators. A more thorough analysis of the relationship between research training and economic growth and other indicators is warranted. Therefore, further research in this area has been recommended in section 8.6 of the conclusion. Regardless of the debate surrounding the extent to which education contributes to economic growth and the lack of more suitable data to examine the impact of research training in particular, there is general consensus that research training along with other forms of education impacts significantly on the economic competitiveness and social wellbeing of countries - and therefore contributes positively to the performance of each country's national innovation system.

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Chapter 8: Conclusion

8.1 Introduction

The key research question or problem for the study is determining how research training (particularly in science and technology fields) contributes to national innovation systems in Australia, Finland and the United States. The inspiration to tackle the problem came from a line in the 1999 White Paper, *Knowledge and Innovation* about the important contribution of research students to the national research and innovation system made by the then Commonwealth Minister for Employment, Training and Youth Affairs, Dr David Kemp. Kemp (1999) was reflecting earlier comments by Roderick West in his review of Australia's higher education system. West (1998) described the impact of research training on the national economy and competitiveness and the major role of universities in providing highly trained and skilled people for knowledge-based industries. The Minister for Education, Science and Training, Dr Brendan Nelson also referred to research training as an increasingly important element of Australia's national innovation system by building skills and capacity and generating new ideas (Nelson, 2002a).

A search for literature in Australia and overseas on the role of research training in a national innovation system came up with few insights beyond what was said by Australian politicians and policymakers. The Commonwealth Government reformed Australia's research and research training system in 1999 in an attempt to better connect universities with the national innovation system. The Government believed that being *better connected* meant that research and research training activities by universities would occur in entrepreneurial environments. These environments would be characterised by local and international links and collaborations between higher education research and industry (as well as with other NIS actors) and a stronger movement of staff and research students across various academic and industrial settings. Clarke (1998)

Innovation and research training experts spoke about the role of research training in a national innovation system in terms of building capabilities for the research workforce, generating new ideas, facilitating academic and industry links, producing a large amount of the actual research work, creating substantial private and social rates of return that leads to faster growth, and encouraging independent thinking, creativity and originality to break new ground and innovate. Acknowledging that research students may contribute to a national innovation system through a patent, one innovation expert strongly stated that the major aim of research training is train people to enter the workforce. He also argued that connections between students and users will vary depending on the field:

> One way to contribute to the innovation system which is probably the least important, when they contribute to a patent. It is the most direct and obvious and it might be the least important. The most important is probably the fact they are trained, establish some capabilities and competence and go out and work somewhere where they get involved either directly or indirectly in process that end up in innovation … As someone pointed out the kind of relationships are extremely different in

> different parts of science, social science, natural science and technology, are very different things. PhDs will have different types of connections with users.

Another innovation expert spoke about the contribution of research training in terms of human capital formation and mobility:

> The question is really do research students contribute to national systems of innovation, specified in Finland and Australia. So the first question is how would they contribute? I would then say well the theories of how they contribute would be that you form human capital, so you contribute to your strength of your human capital, and these research students if they are immobile and stay within the country, they contribute directly. If I take that approach I quickly see that the big question is whether they contribute or not, has everything to do with mobility. If they leave the country they don't contribute, they contribute to other systems of innovation, other research systems. So my whole approach will have to be completely focused on mobility, hence on the mobility of the Finnish students and mobility of the Australians.

The enormous contribution of research students was recently described by the National Technology Agency of Finland in a preamble of a report produced by the author of this thesis (Haukka, 2005, p. 4):

> Research training has strong links to national innovation environments and innovation policies practiced in all countries. Directing substance learning, educating researchers in problems relevant to innovation policies and educating the workforce with skills needed by innovative industries can all be strongly affected by proper research training policies. Much of the actual innovation processes in countries are performed by research trainees, which provides research training policies a direct connection to innovation policies. Technology transfer from universities to industry commonly takes place in connection with research training.

A major literature review of innovation theories and approaches together with comments from innovation and research training experts informed the development of a conceptual framework consisting of the following three elements that represent how research training is likely to contribute to a national innovation system: International mobility and migration of research students and graduates; knowledge production and distribution by research students (examined through case studies of 30 research students in selected S&T fields); and the impact of research training as advanced human capital formation on economic growth. Section 1.6 in the introductory chapter included three key assumptions that are worth repeating. Firstly, the elements chosen were the most obvious and have been broadly examined in this study. Further research that examines these and other elements in greater depth should be undertaken. Secondly, findings should be relevant to Australia, Finland and the United States and other developed countries with well established research training and national innovation systems. The purpose of this study was to find out how Australia can improve the contribution of research training to its national innovation system. Thirdly, 30 research students from S&T fields which have strong connections to a national innovation system participated in case studies as part of this study. However, findings cannot be generalised to all students within these and other fields or to the entire research student population in each country. The three participating universities differ in research intensity, thereby impacting on the students' exposure to infrastructure and other resources – making comparisons across universities difficult.

This study agreed with the Commonwealth Government's vision of a research training system that is well connected to the national innovation system. Although this may be happening, this study found little evidence in the form of reports and data that indicates that research students in Australia were actively engaging with the potential users of their research results, developing their own strong international networks, and undertaking research outside of their department and discipline. The Commonwealth Government must have a clearer understanding of how research training contributes to a national innovation system in order to develop effective policies that carry such as purpose. This study aims to provide the Government with such insights that can be debated and further examined.

The rest of the final chapter presents findings for seven of the eight secondary research questions in Section 8.2 in order to reach conclusions about the key research question in Section 8.3. Key findings together with common responses to Research Question 8 have been drawn together to identify the features of a research training culture of innovation in Section 8.4. Section 8.5 discusses the implications of this concept and other key findings on theory, policy and practice. The limitations that arose during the study form the basis for further research that is recommended in Section 8.6.

8.2 Conclusions about secondary research questions

Research Question 1: What is meant by innovation, a national innovation system, research training and research students?

The purpose of Research Question 1 addressed in Chapter 3 was to provide a foundation to the study by explaining upfront the key concepts that are *words* or *terms* within or closely related to the key research question. After reviewing the theories and approaches of well known innovation researchers and the accepted international definitions and classifications in the OECD's Oslo Manual (1997), Frascati Manual (2002) and Canberra Manual (1995), key concepts for this study were defined as follows:

- **Innovation** is a technological product or process (new or significantly improved) innovation that has been implemented or an organisational innovation that has led to a measurable change in output.
- **A national innovation system** is made up of interacting market and non-market institutions that continuously learn how to generate, diffuse and use new knowledge to form product, process and organisational innovations. The role of Government is to provide a framework of policy instruments that support systems growth and address problems that restrict the functioning of the system.
- **Research training (in science & technology fields)** provides research students with a high level of knowledge and skills necessary to work as HRST professionals in and beyond their national innovation system.

- **Research students** are *researchers* who undertake independent and novel research to form a thesis or dissertation. When educated and employed in science and technology fields, they are a core part of the HRST stock and a critical component of a national innovation system.

The concepts of research training and research students were informed by a discussion on the meaning of research and development (R&D) and human resources in science and technology (HRST) drawn from the Frascati Manual and Canberra Manual, respectively.

Research question 2: What is the role of research training (particularly in science and technology fields) in a national innovation system?

The study did not find any innovation literature that talked about the role of research training in a national innovation system. The review of innovation theories and approaches and the features of a national innovation system highlighted the changing nature of the innovation process; the increasing reliance of scientific knowledge for major new technologies particularly in the areas of biotechnology, new materials and information technology; the importance of university-industry cooperation to innovation i.e. the interaction of knowledge producers and users; and the critical role of a highly skilled S&T workforce. Organisational and individual learning about economically-relevant knowledge is regarded as the core process in generating, diffusing and using knowledge in a national innovation system. The role of research training in a national innovation is very clearly the development of skills and capacity as part of a country's efforts to build a highly skilled S&T workforce. Research students also produce and distribute new knowledge through the learning process that can contribute to innovation. Based on these findings, the following response to Research Question 2 was provided in Chapter 3:

- The **role of research training** (particularly in science and technology fields) in a national innovation system is to build the competence of research students to produce knowledge by developing their ability to learn about, create and disseminate economically-relevant knowledge; and to interact with research users and other stakeholders.

Research question 3: What have been the major developments in, and performance of innovation and research training policies/systems in Australia, Finland and the United States?

Australia

The Commonwealth Government expanded the size of the research training system during the late 1980s and mid 1990s as part of its efforts to build a research workforce and encourage greater involvement by industry in research and research training. Major reforms announced in the 1999 White Paper, *Knowledge and Innovation*, were directed at improving the quality and outcomes of the research training system and enhancing the contribution of research and research training to Australia's national innovation system. The Commonwealth Government succeeded in expanding the research training system from 15,289 enrolments in 1988 to 47,309 enrolments in 2004. Research students are exposed to Australia's national innovation system by producing new knowledge within 44 universities (39 of which are public institutions), 72 Cooperative Research Centres, 11 Centres of Excellence and many other research and science organisations. The Australian Research Council's Linkage program is funding an increasing number of research students to undertake industry-oriented research training. Reports indicate that efforts by universities to address deficiencies in research training have led to more satisfied and better trained graduates. However, the latest *Postgraduate Research Experience Questionnaire* found that many research students were not satisfied with the intellectual climate in which they conducted their research, suggesting that the Commonwealth Government's vision of research students being trained in an entrepreneurial environment is yet to be achieved. Despite the significant increase in research degree completions, an estimated 36% of people who enrolled in a PhD between 1990 and 1997 have not completed their degree and 43% of those people who did complete took over five years to do so (Sinclair, 2004).

In 2001, the Commonwealth Government released *Backing Australia's Ability, an innovation plan for the future*, which was extended in 2004 to a ten year funding commitment of $8.3 billion until 2011. The strategy follows a series of innovation initiatives introduced from the early 1990s to build Australia's innovation capacity by addressing system weaknesses and developing features of an effective national innovation system. These efforts have led to increases in R&D expenditure, a larger research workforce, greater industry involvement in R&D, and improvements in patenting activity. Australia continues to be a high producer of scientific and engineering (S&E) publications. There are a number of serious and persistent issues that are impacting on Australia's national innovation system. Australia continues to perform below many OECD countries in gross and business investment in R&D (as a proportion of GDP), employment of business researchers, diffusion and commercialisation (as indicated by low patenting levels) and citations of publications. Gans and Stern (2004) found no gains in Australia's innovation capacity since 1996. The World Economic Forum's *Global Competitiveness Reports* show Australia's world rankings in the Growth Competitiveness Index, Business Competitiveness Index and National Innovation Capacity Index deteriorated between 2001 and 2004. These findings indicate that research students in Australia are being trained in a national innovation system that is not performing well enough and lacks scientific recognition around the world.

The full impact of *Backing Australia's Ability* and the *Knowledge and Innovation* reforms has yet to be realised. Some indication is given in the recently released *Global Competitiveness Report* for 2005/2006 that was released just before this thesis was submitted for examination. Australia moved up four places to 10^{th} place in the Growth Competitiveness Index due to improvements in institutional and technology indicators. The report praised Australia for "world-class public institutions, sound public finances and very low levels of corruption" and found that "Australian companies are harnessing new information and communications technologies extremely well" (World Economic Forum, 2005). The same report found that Australia slipped two places to 15^{th} place in the Business Competitiveness Index.

Finland

The Graduate School System and other research funding arrangements have succeeded in significantly expanding Finland's research training system. The number of doctorates awarded since the establishment of Graduate Schools rose from 765 in 1995 to 1,399 in 2004. Finland's commitment to the Bologna process is expected to increase the mobility of research students within Europe (including Finland) and further reduce the time taken to complete doctorates. Over 22,000 research students are now producing new knowledge within 114 graduate schools that operate in and across universities and research institutes. Many students are undertaking applied technical research and industrial R&D funded directly by industry or by Tekes in partnership with industry. Other students undertake their research within projects funded by the Academy of Finland (including the Centres of Excellence in Research Programme), the European Union and private foundations. There have been calls for greater efforts to ensure that research training better meets workplace needs through greater collaboration between universities, research institutes and businesses; new funding instruments to promote intersectoral mobility of research students; and improvements to scientific infrastructure to create internationally competitive research environments.

Efforts to create a coherent and efficient national innovation system have transformed Finland into a leading innovating nation. Finland invests significantly more in R&D than most OECD countries as indicated by high levels of gross and business expenditure on R&D as a proportion of GDP and the large number of researchers as a proportion of total employment. Patenting and S&E publishing activities on a population basis are also considerable, leading to increasing world scientific recognition as shown by a positive relative citation index. Finland remains a leader in the world competitiveness rankings in terms of its potential to attain sustained economic growth over the medium and long term; ability of its firms to create valuable good and services using efficient methods; and potential to innovate for competitiveness. The key challenge for Finland, particularly as a small country, is internationalising its national innovation system to ensure it can better manage the impact of globalisation and rapid international change on industrial structures, business models and competencies.

United States

Given that there is no one unified system of education across the United States, research training cannot be described as occurring within one system like Australia's Research Training System and Finland's Graduate School System. There are common features of research training arrangements that occur across its 50 States: Doctoral training takes at least three or four years after an undergraduate degree; typical funding mechanisms for research students include research and teaching assistantships, fellowships and support from large Federal agencies; and the location of research training in Doctorate-granting institutions as per the Carnegie Classification of Institutions of Higher Education. Many S&T research students in the United States are undertaking their research in universities with a large pool of scientific expertise and high quality research infrastructure made possible by massive Federal Government investment in university research during and after World War II. They are also exposed to environments that are well accustomed to linkages between academic and industrial research and research that is based on the needs of the local economy, particularly the agricultural industry. Similar to Australia and Finland, the United States is also aiming to improve attrition and completion rates (as indicated by the *PhD Completion Program*), equip students with the capabilities to work in different sectors, and encourage research training in multidisciplinary environments. Prior to the events of September 11, there was also concern about the rapidly increasing supply of foreign research students who remain in the United States after graduating.

The United States does not have a distinct *national* innovation system with a main coordinating body like Australia and Finland but rather a combined centralised and regionalised system consisting of many Federal agencies with R&D and commercialisation programs, and State and local government agencies with science and technology initiatives. Large investments in R&D by Governments and industry, a decentralised higher education system, intellectual property arrangements that encourage universities to patent Federally funded research and work closely with private firms, and the enormous scale of research training and the S&T workforce are prominent features of the U.S. national innovation system. These features have contributed to the United States being the largest and most innovative economy in the world, which is confirmed by strong world competitiveness rankings, the large number of high tech patents, and dominance in S&E publications and citations. The country is well known for cutting-edge research across many fields, strong capabilities to convert research into applied technology, support for highly technology start-ups, extensive venture capital markets, and its ability to attract foreign talent. A number of reports and articles stated that the United States is losing its competitive edge in scientific excellence and technological excellence. This situation is due not only to events of September 11 but also because of increased competition from countries for foreign talent, innovation and technology products and services; insufficient funding for technology infrastructure and basic science; coordination problems caused by system decentralisation; and tighter regulations governing science such as genetics and stem cell research.

Element 1: International mobility and migration of research students and graduates

Research question 4: What policies have been introduced in Australia, Finland and the United States to support the international mobility and migration of research students and graduates?

Research question 5: How has Australia, Finland and the United States performed in terms of brain drain, brain gain and brain circulation?

Australia

Linkage International and the Endeavour Programme are key initiatives of the Commonwealth Government that support the international mobility of research students and graduates through postgraduate and postdoctoral awards. There is also a range of mobility initiatives that are funded by other Governments, educational institutions and private organisations in Australia and overseas. Overall, international mobility opportunities were found to be limited and highly competitive. In terms of international migration, the Commonwealth Government has successfully encouraged greater permanent and temporary stays of skilled people by expanding the skilled migration program, allowing graduating overseas students to apply for permanent residence without leaving Australia, and reducing restrictions on temporary work visas.

Mobility data presented in Chapter 5 included enrolments of foreign students in research degrees in Australia, the movement of S&T professionals, and the movement of people who attained a PhD between 1996 and 2001. The number of foreign research students has increased steadily but not as fast as foreign enrolments in lower degrees. The net loss or *brain drain* of 12,152 Australian residents in S&T occupations between 1995/1996 and 2002/2003 was offset by continuing increases in settlers and visitors in S&T occupations, leading to a net gain of 38,119 people in S&T occupations. Similarly, the loss of 700 Australian residents who attained a PhD between 1996 and 2001 was offset by gains in migrants and the return of Australians with a PhD, resulting in an overall gain of 1,730 people.

The above data supports concerns about the loss or *brain drain* of Australian residents in S&T occupations. Some of the key reasons given for the brain drain include the *pull* factors of young Australians wanting to see the world, higher material rewards and greater research opportunities; and the *push* factors of scarce jobs in some scientific fields in Australia (Birrell et al., 2004) and the inability of Australia to acknowledge and reward high achievement. Most of these factors also contribute to people not returning. Stocker (1997) found that inadequate career opportunities in Australia contributed to young scientists leaving Australia or pursing other careers, representing a loss of investment in their training. Despite increases in postdoctoral fellowships and awards and growth in the research workforce, opportunities to gain such opportunities in Australia were also limited and highly competitive and the availability of significantly more research positions in industry has not occurred.

Wood and Boardman (1999) identified a number of obstacles to the international mobility of young researchers. Findings in Chapter 5 about fellowship and award schemes and the mobility experiences of the 10 RMIT research students supports their concern about the inability of young scientists to obtain overseas research training and career development. This situation is exacerbated by the lack of a central information and vacancy database. As part of efforts to build an internationalised research workforce, Australia needs to expand the number of opportunities available to research students and graduates so they can develop their own international networks and bring home the benefits of brain circulation.

Finland

Finland has a range of programs in place to facilitate the international mobility of research students and graduates. Key providers of mobility programs in Finland are the Academy of Finland and the Centre for International Mobility (CIMO). Programs funded by Tekes, the European Union and other Finnish and international organisations also facilitate international mobility. In addition, the Finnish Government has in place an *International Strategy for Higher Education* and a strategy for the *Internationalisation of Finnish Science and Technology*. These efforts are proving successful in encouraging greater international mobility of tertiary students to and from Finland through student exchanges. However, the number of research students participating in student exchanges or undertaking doctoral studies in Finland remains small. Also of concern is the downward trend in the number of Finnish teachers and researchers making overseas visits and the number of foreign researchers visiting Finland. Despite increases in the foreign born population, Finland has low migration rates and consequently, the share of foreign HRST remains below other European countries. This compares to Australia and the United States which have been very successful in attracting and retaining foreign research students and graduates.

Many of the foreign research students and graduates in Finland surveyed in 2004 were attracted to the high level research environment and satisfied with the quality of information and guidance. Nearly half of them intended to stay permanently in Finland. Friendships, personal contacts and recommendations led many of these foreign students and researchers to Finland. Therefore, Finland should continue its efforts to encourage more student exchanges but with a greater focus on attracting research students. These efforts should include more innovative approaches (including funding opportunities) to attract foreign research students and graduates to Finland, and greater encouragement of Finnish research students and graduates to work abroad where they can establish international networks. Although most of the Finnish research students who participated in this study had attended international conferences, workshops and/or courses, mobility initiatives should be longer in duration in order to establish strong and ongoing networks.

United States

Until recently, the United States was the world's primary destination for foreign research students and researchers. Strong inward mobility of foreign students can be partly attributed to the availability of financial assistance from different sources. In 2001, almost 94% of foreign doctoral graduates who were temporary residents in the United States had been funded through financial aid mechanisms such as those offered by universities (particularly research assistantships, teaching assistantships and fellowships) and mobility programs of American and international organisations. Data on stay rates of foreign recipients of U.S. S&E doctorates between 1990 and 2001 show an increasing proportion of graduates with firms plans to stay in the United States. As a result, the number of foreign born S&E postdoctoral researchers in U.S. universities rose steadily during the 1990s, accounting for 57.2% of these positions in 2001. There is also a range of international mobility programs available to local research students and graduates. OECD data on the net balance of international student exchange together with findings about mobility activities of the 10 UIUC research students suggest that the inflow of foreign research students into the United States significantly exceeds the outflow of U.S. research students to other countries.

Foreign talent has strengthened the country's comparative advantage in science and technology. Yet the dependency on foreign students and workers has restricted wages, thereby discouraging U.S. citizens from pursuing research careers. The decline in permanent and temporary visas issued by the United States caused by events of September 11 and increased competition from elsewhere in the world have led to serious concerns about how to sustain research training programs that rely heavily on foreign students and provide an ongoing supply of highly skilled S&T workers to the U.S. research workforce.

Element 2: Knowledge production and distribution by research students (30 case studies)

Research question 6: Is the R&D performed by 30 research students likely to contribute to an innovation?

The 30 research students were exploring and attempting to solve a real problem that was context-related and useful to industry, government and/or society at some point in time. In most cases, the students were undertaking research that can be considered as *learning-by-searching* where they were intentionally creating new knowledge that could contribute to an innovation in the near future. Specific examples include a rapid and cheap diagnostic test for the detection of mastitis in cows; proof of concept for a vaccine to combat necrotic enteritis in poultry; representation and interaction models for the delivery of location-based geospatial information services; embedded wireless devices for a range of applications; development of material models and simulations to avoid failure during the hot rolling process of aluminium alloys; and a new topographic technique for non-invasive breast cancer detection. The new (basic) knowledge produced by a couple of students was expected to contribute to an innovation in the longer term. For example, new knowledge about the genome responses in plants to auxinic herbicides will contribute to further research aimed at developing novel herbicides; new knowledge about molecular transport is expected to contribute to sensor design and electronic products; and new knowledge about how to improve the fertiliser value of swine manure is expected to lead to new farming practices. An unexpected innovation occurred as a by-product of research in two cases i.e. *learning-by-producing* and both students were applying for a patent at the time they were case studied. One student was developing a compact GPS speedometer and accelerometer with state-of-the-art accuracy and performance at low cost. Another student was patenting a non-invasive method for the detection of alcohol abuse.

Students were expected to disseminate their results through the traditional Mode 1 methods of reporting in journals or at conferences. Three to four refereed articles in international journals is a requirement at the University of Oulu. Some students were more active than others in disseminating their results through other methods due to their own initiative and/or the existence of networks and activities established by their supervisor, department and university. Most students interacted with, and disseminated their results to their scientific community. Students from the Department of Crop Sciences at University of Illinois at Urbana-Champaign (UIUC) regularly met with industry and were able to disseminate their results through extension specialists. Students (and employees) of the Centre of Wireless Communication (CWC) at the University of Oulu regularly reported relevant findings to industry sponsors. There was no case where a student actively organised their research around the context of application by interacting with, and disseminating results to all stakeholders throughout the production process. All students could interact with people from other disciplines through seminar series and the sharing of facilities. The three students from the UIUC's Beckman Institute were the only students who were directly involved in transdisciplinary research because they were in research groups made up of people from different disciplines and could easily access other transdisciplinary research groups that were located in the same building.

Most students were developing the economically-relevant knowledge of *know-what*, *know-why* and *know-how* in their research area. Only a small number of supervisors spoke specifically about helping their students to develop *know-who* i.e. the ability to co-operate and communicate with different kinds of people and experts. One reason for this could be that supervisors assume that students will develop their own networks and build relationships over the duration of their studies, and through attendance and presentations at conferences and other events. Most of the students from the University of Oulu and UIUC were funded to attend relevant events. UIUC students could easily access international networks as relevant events were usually held in the United States. Students from the University of Oulu mainly attended conferences, meetings and training courses in Europe, with some students (particularly those from the CWC) travelling beyond Europe. Most of the RMIT students were unable to attend international conferences due to funding difficulties. Only three of the 30 research students had undertaken actual placements at universities located outside their own country. The centre head of CWC spoke of his intention to introduce a system of *internal networking* to assist young researchers to learn how to network and build relationships.

In terms of capability development that met the needs of employers in knowledge-based economies, some supervisors spoke about the role of research training in developing generic skills, helping students to become independent researchers, and improving their ability to learn, solve diverse problems and generate ideas. The online generic modules at RMIT University and the Biobusiness Course at Biocenter Oulu are examples of programs designed to provide research students with more general skills required by employers. A department head at the UIUC discussed the need to ensure that the research training program provided students with the necessary skills to work as researchers, managers and/or directors.

Element 3: Research training, human capital and economic growth in Finland

Research question 7: Does research training as human capital formation contribute to economic growth in Australia, Finland and the United States?

The study had difficulty in addressing this question for three reasons. Firstly, there are few studies that have examined the economic and non-economic impacts of research training. Secondly, studies that have examined the relationship between human capital investment in education and economic growth have shown contrasting results. For example, Romer (1990) found a connection between basic literacy and per capita growth rates whereas Benhabib and Spiegal (1994) concluded that human capital stocks had little effect on per capita growth rates. McMahon (1999) identified a relationship between education and several non-economic or social benefits such as better health, human rights and political stability. The United States invests heavily in education and has very high GDP per capita yet has the second highest poverty rate of all OECD countries. Thirdly, OECD data on educational investments and returns does not adequately separate out advanced research degrees from all university degrees, making it very difficult to evaluate the impact of research training on individuals and society. Despite these limitations, this study assumes that research training helps to build a highly skilled workforce that directly contributes to innovation, thereby enhancing a country's competitiveness, level of economic growth and overall well-being.

Chapter 7 used a basic approach to identify possible correlations between two proxy indicators of research training (*level of the population with a university education* and *HRST stocks as a proportion of the population*) and three economic indicators and seven non-economic or social indicators. The analysis did not find any correlation between these human capital indicators and GDP growth rates, business productivity in the business sector, CO2 emissions and suicide rates. It did find varying degrees of correlation for GDP per capita, relative poverty, infant mortality, life expectancy, homicide conviction/committal rates, and life satisfaction and feelings of happiness. Those countries with higher levels of university educated people and HRST stocks tended to have higher GDP per capita. Correlated findings together with data on human capital stocks, investment levels and returns for Australia, Finland and the United States were presented within a customised version of the OECD framework of the key costs and benefits from human capital investment.

Data from the OECD showed that university educated people in Australia, Finland and the United States earn significantly more than those people with upper secondary education and are less likely to be unemployed than the rest of the labour force. Earnings data from national sources confirm that people with a research degree earn more than those with lower university degrees, except in the case of males with professional degrees in the United States who earn more than males with a doctoral degree. Private and social rates of returns for people with research degrees are probably just above rates given for the combined category of tertiary type A and advanced research degrees due to the relatively low salaries for early career researchers, high attrition and slow completion rates for research degrees, and the median age at which research students complete their studies (i.e. late 20s).

8.3 Conclusions about the key research question

Key research question: Does research training (particularly in science and technology fields) contribute to national innovation systems in Australia, Finland and the United States?

The study used a mixed methodology strategy consisting of historical research, case study research and statistical analysis to assess the contribution of research students to a national innovation in three ways represented as elements in a conceptual framework. This approach involved having a very good understanding of the background to, and current state of the research training system and national innovation system (and corresponding policies) in Australia, Finland and the United States. This section presents key assumptions and findings for each of these elements, before focussing on Australia.

Element 1: International mobility and migration of research students and graduates

Key assumptions

This element assumed that research students contribute to their national innovation system when they graduate by continuing their research career and remaining in their own country (they are *immobile*); migrating to Australia, Finland or the United States from another country (*brain gain*); returning home from another country (*brain circulation*); and/or leaving home but maintaining professional links and networks that encourage international flows of highly skilled workers and knowledge (*brain circulation*).

Key findings

Despite having well established systems for research training and innovation, all three countries could do more to enhance the contribution of research training to their national innovation systems. Australia and the United States have been very successful in attracting foreign students and talent. The issue for Australia is the brain drain of local talent. Dependency on foreign students and talent in the United States has restricted wages and discouraged local talent from pursuing research careers. Finland attributes the difficulty in attracting foreign talent to its strange language, harsh climate and high taxation. Finland actively encourages the internationalisation of its research students, whereas international mobility opportunities in Australia are limited and highly competitive. The availability of international events and positions in high quality research environments in the United States means many local research students and graduates are not taking full advantage of the benefits of internationalisation. Research careers is an issue in all three countries, continuing to be plagued by low salaries, intense competition for positions, difficulties in securing permanent positions, and limited research opportunities in the business sector – forcing talent to pursue non-research careers or not to undertake a research degree at all.

Issues for Australia

Australia is located a long way from the world's leading innovative countries, many of which invest heavily in R&D and as a result have more sophisticated infrastructure and opportunities for cutting-edge S&T research. The international mobility of highly skilled S&T people impacts on a country's innovation performance by increasing the flow of knowledge and stocks of available human capital. To compete on the world market, Australia needs an internationalised research workforce where researchers are encouraged to bring back knowledge, capacities and networks from abroad, and local and foreign talent are attracted to jobs in a research system known for its scientific excellence. If Australia is to internationalise its research workforce it must first address the basic issue of how to properly reward and recognise research talent.

<u>**Element 2: Knowledge production and distribution by research students (30 case studies)**</u>

Key assumptions

This element assumed that the contribution of research students to their national innovation system is enhanced when their research is characterised by a combination of Mode 1 and Mode 2 knowledge production and distribution i.e. their research considers the context of application, involves stakeholders and leads to transdisciplinary results; they effectively disseminate their research results to all stakeholders throughout the process of production beyond the traditional Mode 1 methods of journal and conference papers; and their research training program equips them with economically-relevant knowledge (*know-what*, *know-why*, *know-how* and *know-who*) and the capabilities to work in knowledge-based economies.

Key findings

The 30 research students who participated in this study were undertaking context-related research in high quality research environments where they were supervised by very experienced people with an international reputation in their research field. In most cases, research results were likely to contribute to an innovation at some point in time. Only three students were directly involved in transdisciplinary research. All students were expected to disseminate their results through the traditional Mode 1 methods of journal and conference papers and were interacting regularly with their scientific community. Some students were disseminating their results through other methods such as presentations to industry partners, attendance at industry meetings, and the provision of information to extension officers. Intellectual property and academic requirements did not provide students with sufficient incentives to widely disseminate their research results. There was no case where a student actually organised their research around the context of application by interacting with, and disseminating results to all stakeholders during the process of production. All students were developing economically-relevant knowledge of *know-what*, *know-why* and *know-how*. Conference, course and training attendance and other forms of interactions with members of their scientific community were the main methods used to develop a student's ability in terms of *know-who*. None of the research training programs had specific strategies in place to help students to co-operate and communicate with different kinds of people and experts.

Issues for Australia

The Commonwealth Government is very much aware of the critical role of knowledge to a country's innovation success. Research students generate a massive amount of new knowledge of benefit to Australia's national innovation system. More effort and incentives are needed to ensure that the principles to create and disseminate knowledge in Australia's national innovation system also apply to research students, many of whom are undertaking cutting-edge research that is funded by society. Research training must equip students with economically-relevant knowledge and the necessary capabilities so they can work effectively in different sectors in and beyond their national innovation system. Research graduates working in a wide range of industry sectors is a vital means of extending the national innovation system and embedding precepts of innovation more broadly.

Element 3: Research training, human capital and economic growth

Key assumptions

This element assumed that research training contributes to a national innovation system as it represents human capital formation at an advanced level; leads to relatively high private and social returns; and represents a significant investment in R&D activities by countries aiming to build a highly qualified workforce that directly contributes to technological advance and innovation. Therefore, it is likely that human capital formation through research training has a positive impact on economic growth and contributes to social benefits that result from human capital investment in education.

Key findings

Governments are expected to monitor and evaluate the effectiveness of the massive investment in education on the economy. Chapter 7 explained how countries measure their investment in, private and social rates of returns from, and economic and non-economic impacts of university education. This study was unable to properly analyse investment levels, returns and impacts of research training due to a lack of dedicated literature and data. Most of the indicators sourced from OECD's *Education at the Glance* combine research training with all university education where the Bachelor degree accounts for the bulk of awards. This lack of relevant information and data is disappointing given the critical role of research training in fuelling a country's highly skilled S&T workforce, the increasing number of research graduates, and the large amount of funding invested in research training.

Only a small proportion of the university-educated population go on to complete an advanced research degree. As a result, those people with a research degree in Australia, Finland and the United States account for a small proportion of HRST stocks. Private and social rates of returns to university education in Australia are falling and are lower than returns recorded by most selected OECD countries including Finland and the United States. Although people with a research degree earn more than those with a Bachelor degree, returns from research degrees are not expected to be much higher than returns from lower university degrees due to high attrition and slow rates of completion, relatively low starting salaries for early careers researchers, and the age at which students typically graduate i.e. late 20s. The study also found a positive correlation between human capital investment in university education and GDP per capita in the three countries but differences in the non-economic impacts of life expectancy, poverty, infant mortality, homicide committal/conviction rates, and life satisfaction and feelings of happiness.

Issues for Australia

These findings suggest that Australia is not maximising the returns from its investment in research training within the national innovation system nor does it properly understand the economic and non-economic impacts of its investment. It is highly recommended that dedicated studies are undertaken in Australia and elsewhere to identify the nature and extent of public and private investment in research training and the impact of research training systems in terms of HRST stocks, private and social returns, and economic and non-economic indicators. Such research is necessary in order to identify ways that Australia can increase the private and social rates of return from research training, thereby enhancing its contribution to a national innovation system. Research of this kind will also extend the debate about the relationship between human capital investment in education and economic growth to the research training level.

8.4 Research training culture of innovation

Research question 8: What is a research training culture of innovation?

Innovation and research training experts, supervisors and key university staff were asked during an interview what they believe is a *research training culture of innovation*. Most people described a research training culture of innovation in a research and research training environment. Here are some common responses:

- Excellent groups with superb leaders who are good researchers and mentors.
- A critical mass of high quality people from different disciplines who interact and learn from each other.
- A collegial and collaborative atmosphere of trust and friendship where ideas are discussed and shared, and new research opportunities pursued.
- Research training characterised by loose boundaries, flexibility, risk-taking and openness to failure.
- Positive attitudes towards innovation and commercialisation opportunities.
- Funding for different purposes, such as context-oriented or frontline research where people are solving problems that need to be solved, as well as long-term basic research.
- Students working abroad, in different sectors and with others outside of their research group to see how research is conducted in different environments or from different paradigms and to develop their own networks.
- Students are given a combination of freedom and direction (particularly at the start) then work through the problem themselves and are allowed to deviate – thereby motivating students to advance their own research.
- Students are treated like colleagues and "eventually the best graduate students run out in front of me".
- The research is challenging – "the culture of innovation is not going to work if you know success is granted and you don't have to take risks".

The above points are very valid to a research training culture of innovation at the university, research group and/or research training program level. Research and research training environments in this culture are internationally competitive i.e. characterised by high quality research infrastructure, a pool of world recognised scientific expertise working in multidisciplinary research teams, strong linkages with research users and other stakeholders around the world, and the international and intersectoral mobility of researchers. Students in research training programs create and disseminate new knowledge that is useful to industry, government and/or society (i.e. context-oriented) which can include basic research with long-term benefits that may not be as obvious. Students regularly interact with, and seek input from stakeholders, and widely disseminate transdisciplinary research results throughout the production process. Intellectual property arrangements and other incentives are in place to encourage research students to effectively create and disseminate new knowledge in this way. Research training programs in a research training culture of innovation equip students with economically-relevant knowledge (i.e. *know-what*, *know-why, know-how* and *know-who*) and the capabilities required by employers operating in knowledge-based economies. Ultimately, research training programs create highly skilled and internationalised researchers who are able to work in different sectors in and beyond Australia's national innovation system.

For Australia to enhance the contribution of research training to its national innovation system, a research training culture of innovation should also be characterised by the following features:

- Attractive research careers in different sectors that encourage people to pursue research careers and to remain in Australia, come to Australia and return to Australia.
- A national commitment to R&D with high levels of gross and business R&D expenditure and wide recognition of the importance of R&D and innovation to a country's economic and social well-being.
- High private and social rates of return from individuals' and society's investment in research training. Increases in returns can be achieved through better remuneration of researchers (who also pay higher taxes), more research training places with stipends particularly in industry (attracting more talent to research careers), and effective strategies to avoid unnecessarily high attrition and slow rates of completions (to minimise losses in research training investments). Wider distribution of, and inexpensive access to research results to encourage novel and unanticipated combinations of new knowledge to produce innovations (David & Foray, 1995), together with incentives to encourage researchers to commercially exploit new knowledge, will increase the social value of new knowledge produced with public funding.
- National and state research priorities that are complemented by national and state research training directions that are decided upon by Governments, universities and industry working in partnership. Setting such directions requires horizontal coordination between key organisations that create policy for, and invest in research training at the national level i.e. Department of Education, Science and Training (DEST) and the Australian Research Council; State and Territory Government departments that invest in research and research training; organisations that represent the interests of research students such as the Group of Eight universities, Australian Councils of Deans and the National Tertiary Education Union; key industry bodies that can influence the business sector to invest in research training and employ more research graduates; and representatives (including students) from universities, research institutes and Cooperative Research Centres.

8.5 Implications for theory, policy and practice

Innovation theories and approaches provide some insights into the role of research training in a national innovation system. Kline and Rosenberg (1986) talked about how innovation draws on science and innovation leads to new science. Dosi (1998) acknowledged the increasing reliance of advances in scientific knowledge for major new technologies. Porter (1990) found that highly educated and specialised people are both an advanced factor and specialised factor contributing to a country's competitive advantage. Etzkowitz (1998, 2001) described the strong role of universities and other knowledge producing institutions in the new environment for innovation, leading to a second academic revolution where academia and students assess the commercial and intellectual potential of their research. Resources, competencies and organisation of the R&D system represent one of the five elements of a national innovation system identified by Lundvall (1992). Nelson and Rosenberg (1993) believed that universities have a key role in the innovation system as both a training ground for scientists and engineers and source of research findings and techniques that can advance technology in industry. Gibbons et al. (1994) and David and Foray (1995) proposed ways to improve the effective production and distribution in national innovation systems that have serious implications for research and research training systems.

This study contributes the concept of a *research training culture of innovation* to the theoretical body of knowledge about innovation and knowledge-based economies. The features of this culture aim to enhance the contribution of research training to a national innovation system by ensuring that research training builds the competence of research students to produce scientific knowledge by developing their ability to learn, create and disseminate economically-relevant knowledge, and to interact with research users and other stakeholders. This must involve universities and other research training grounds proactively exposing research students to international mobility activities, high quality research infrastructure, transdisciplinary research environments, incentives to widely disseminate research results, and strategies to build their economically-relevant knowledge and capabilities to work effectively in different sectors. Therefore, the concept has a number of implications for national research training policy, innovation policy at a national and State level, and the nature and delivery of research training programs.

The current funding arrangements for the Commonwealth Government's *Research Training Scheme* indicate that the Government believes that encouraging universities to increase their research degree completions, research income and publications will enhance the contribution of research training to Australia's national innovation system. The formula for funding research training places will not nurture research training programs with the above features. The same can be said about the Government's other major research and research training scheme, *Institutional Grants Scheme*, that also aims to better connect research in universities to Australia's national innovation system through increases in research income, research student places and publications – incentives that are not directly aligned to the development of internationally competitive research and research training environments that produce highly skilled S&T graduates who can work in different sectors in and beyond Australia's national innovation system.

Just before this thesis was submitted for examination, the Commonwealth Government announced its preferred model for the *Research Quality Framework*. The model would be used to redistribute all funding from the Institutional Grants Scheme and at least 50% of funding from the Research Training Scheme to high quality research. The Research Quality Framework (RQF) will have the traditional *academic impact* focus of peer review and discipline development but also a focus on "the broader impact or use i.e. the extent to which research is successfully applied" (Nelson, 2005, p. 7). Nelson (2005) stated that the publication and income measures in the Research Training Scheme will be replaced with an RQF score.

The 50% weighting given to research degree completions is likely to be continued until further work in undertaken by DEST and the sector on the "formulation and trialing of alternative measures of research training quality, and the use of RQF ratings for future RTS funding" (Nelson, 2005, p. 19). Findings in this study should assist policymakers in their deliberations about the future of the Research Training Scheme.

8.6 Limitations and further research

The key justification for undertaking this study was the lack of literature and policy documents that explained the role and contribution of research training in a national innovation system. Interviews with innovation and research training experts were part of a consultation process to identify the different ways that research students contribute. The three key *ways* that were identified became elements in a conceptual framework to address the key research question or research problem. Limited data on international movements of research students and graduates and the impact of research training as advanced human capital formation meant that only a broad analysis of these two elements was possible. This study welcomes research that can address these limitations as well as more detailed research about the three elements and any other ways that research students contribute to a national innovation system. The following specific research studies should be undertaken with a degree of urgency:

- A national review of research careers and international mobility initiatives to determine the effectiveness of existing strategies to properly reward and recognise researchers and provide mobility activities that will internationalise research students and graduates.
- A detailed study on investment levels, private and social rates of return, and the economic and non-economic impacts of Australia's research training system together with an analysis of the impact of research training on HRST stocks and the HRST core.

The case studies of 30 S&T research students represent the research training experiences of these students only and are not representative of the experiences of other students in the three participating universities or other universities in the three countries. The purpose of the case studies was to analyse the experiences of the 30 research students within the context of national innovation systems to draw out insights for debate and possibly application - which is also the purpose of the entire study.

One last point …

On a personal note, this PhD study involved an international component that took an enormous amount of effort to arrange and used personal savings to support family members who were not covered by grants. Searching and applying for suitable funding sources from Australia, Finland and the United States was time consuming and at times, stressful. The incredible learning experience and the opportunity to meet so many inspiring people have made the journey very worthwhile.

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Table A1: Innovation and research training experts

Location	Expert and Organisation	Date
Australia	Dr Cliff Bott, Director, Science and Innovation Analysis Section, Economic Analysis and Evaluation Branch, DEST	12 May 2003
	Stephen Utick, Assistant Director, Research Policy Unit, Innovation Branch, Higher Education Group, DEST	12 May 2003
	Helen Tracey, Director, Office of the Chief Scientist, Science Group, DEST	12 May 2003
Finland	Kari Kankaala, Professia, Ex-Director, Sitra	3 November 2003
	Mika Nieminen, University of Tampere	27 November 2003
	Alpo Kuparinen, Ministry of Trade and Industry	28 November 2003
	Esko-Olavi Seppalo, Science and Technology Policy Council of Finland	28 November 2003
	Dr Liisa Savunen and Risto Andberg, Academy of Finland	1 December 2003
	Pirjo Kutinlahti, VTT Technology Studies	1 December 2003
	Dr Kari Sipilä, ex-Director of Foundation for Finnish Inventions	2 December 2003
	Dr Markus Koskenlinna, Eija Ahola and Pekka Pesonen, Tekes	2 December 2003
	Tarmo Lemola, Director of Advansis and Coordinator of the ProAct Initiatives for the Ministry of Trade and Industry	2 December 2003
	Petteri Kauppinen, Ministry of Education	23 January 2004
Europe	Dominique Foray, OECD (innovation and education expert)	10 October 2003
	Dr Stéphan Vincent-Lancrin, OECD (Future of Universities project)	10 October 2003
	Denis Dambois, European Union (patent attorney)	27 October 2003
	Sigi Gruber, European Union, Brussels (mobility expert)	28 October 2003
United States	Emeritus Professor Walter McMahon, UIUC (human capital expert)	5 & 10 March 2004
	Professor Paul Romer, University of California, Berkeley (human capital expert)	9 April 2004
	Dr Peter Henderson, Board on Higher Education & Workforce, National Research Council	26 April 2004
	Dr Steve Merrill, National Academies Board on Science, Technology and Economic Policy	27 April 2004
	Dr David Attis, Council of Competitiveness	27 April 2004
	Dr John Yopp, Council of Graduate Schools	27 April 2004
	Professor Richard Nelson, Columbia University (innovation expert)	28 April 2004
	Professor Henry Etzkowitz, State University of New York (innovation expert)	30 April 2004

Note: Academic advice about this study was obtained from three leading NIS academics who participated in the ETIC European Doctoral Training Programme on *Systems of Innovation and Technology Policy* at the University of Maastricht, The Netherlands, in October 2004:

- Professor Bengt-Åke Lundvall Professor at the Department for Business Studies, University of Aalborg and Research Manager for Danish Research Unit for Industrial Dynamics (DRUID).
- Professor Luc Soete, Professor of International Economics, Faculty of Economics and Business Administration, Maastricht University.
- Professor Keith Smith, Professor at the Institute for New Technologies, United Nations University and Visiting Professor at Chalmers University, Gothenberg, Sweden.

Table A2: Interview questions of innovation and research training experts in Finland

1. What is your background and current role?
2. Can you go back as far as you can remember (early 1990s if possible) and describe the key developments (events, policy releases, government initiatives) that have driven Finnish innovation and the development of Finland's national innovation system?
3. What have been the success factors in Finland becoming one of world leaders in innovation? What has it done well?
4. What specific challenges did Finland overcome in its drive to become an innovative country?
5. Turning now to research training, are you aware of changes to research training policy in Finland over the last decade?
6. What has driven these changes to research training policy?
7. Where to for Finland in terms of innovation? What are its key strengths and challenges?
8. Based on these future directions, what impact (if any) will these have on Finland's research training system?
9. Do you believe graduate (PhD) students in the fields of science and technology contribute to Finland's national innovation system?
10. What does the term "innovation" mean to you?
11. Do you believe that graduate (PhD) students should be encouraged to innovate?
12. If yes to question 11, what do you believe are the features of a research training culture or environment that encourage a research student to innovate?

Table A3: Case study participants

RMIT University, Australia	
Department of Biotechnology and Environmental Biology	
Xenia Gatsos	PhD student
Wendy McDonald	PhD student
Viraj Nawagamuwa	PhD student
Chitra Raghavan	PhD student
Beata Skiba	PhD student
Professor Peter Coloe	Supervisor, Professor of Biotechnology and Department Head
Associate Professor Margaret Deighton	Supervisor and Head of Microbiology Research Group
Dr Ben Fry	Supervisor and Head of Molecular Biology of Micro Organisms Research Group
Associate Professor Trevor Stevenson	Supervisor and Head of Plant Biotechnology Research Group
Dr Eddie Pang	Supervisor and Head of Plant Science Research
Dr Michael Dalling	Industry partner and Group General Manager, Research and Development, Nufarm
Department of Geospatial Science	
Kelly Hayles	PhD student
Paul Lamble	PhD student
Rushan Rozi	PhD student
Karen Urquhart:	PhD student
Jason Zhang	PhD student
Dr Ron Grenfell	Supervisor and Acting CEO and Business Development Manager, Geospatial Science Initiative
Dr David Fraser	Supervisor and Research and Development Coordinator
Professor Tony Norton	Supervisor and Department Head
Associate Professor Bill Cartwright	Supervisor and Associate Professor in Multimedia/Cartography
Associate Professor Kefei Zhang	Supervisor, Associate Professor of GPS/Geodesy and International Student Coordinator
Kirk Mitchell	Industry Partner and Regional Sales Director Webraska (Asia Pacific)
Dr Connie Spinosa	Industry contact and Land Information Analyst, Valuer General's Office
Saji Joseph	Industry Partner and Manager of Resource Knowledge Branch, Department of Land & Water Conservation, Murray Region of New South Wales
Research and Innovation Group	
Professor Neil Furlong	Pro Vice Chancellor, Research and Innovation
Professor Robin Usher	Coordinator of Research Training Group
Dr Robyn Barnacle	Research Training Group

University of Oulu, Finland	
Centre for Wireless Communication (CWC)	
Matti Hämäläinen	PhD student
Kari Hooli	PhD student
Jarmo Prokkola	PhD student
Raffaello Tesi	Licentiate student
Zach Shelby	PhD student
Dr Ian Oppermann	CWC Director
Professor Jari Iinatti	Supervisor and Project Leader
Professor Markku Juntti	Supervisor and Project Leader
Dr Timo Bräysy	Supervisor and Project Leader
Professor Petri Mähönen	Supervisor and Professor, Department of Wireless Networks, Aachen University, Germany
Professor Carlos Pomalaza-Raez	Full Bright Visiting Professor
Dr Tapio Repo	Infotech Oulu Graduate School Coordinator
Biocenter Oulu	
Antti Nissinen	PhD student
Outi Pakkanen	PhD student
Serena Donnini	PhD student
Satyan Sharma	PhD student
Niko Pursiainen	Masters student becoming a PhD student
Professor Markku Savolainen	Supervisor and Professor of Medicine in Department of Internal Medicine
Dr Johanna Myllyharju	Supervisor, and Leader of the Enzyme Group in the Collagen Research Unit
Dr André Juffer	Supervisor and Project Leader of the Biocomputing Group
Dr Pekka Kilpeläinen	Biocenter Oulu Graduate School Coordinator

University of Oulu, Finland (continued)	
Research and Innovation Services Group	
Dr Leila Risteli	Director
Pekka Räsänen	Innovation Manager
Dr Jouko Aho	Research Coordinator
Barbel Fink	2002 BioBusiness Program Manager

University of Illinois at Urbana-Champaign (United States)	
Department of Crop Sciences	
William Patzoldt	PhD student
Megan Patzoldt	PhD student
Federico Trucco	PhD student
Tamra Jackson	PhD student
Inés Davérède	PhD student
Professor Don Bullock	Professor of Crop Production and Graduate Program Coordinator
Associate Professor Pat Tranel	Supervisor and Assistant Professor of Molecular Weed Science
Associate Professor Brain Diers	Supervisor and Assistant Professor of Soybean Breeding and Genetics
Professor Terry Niblack	Supervisor and Professor of Soybean Cyst Nematode Management
Professor Bob Hoeft	Supervisor and Professor of Soil Fertility
Department of Materials Science and Engineering	
Blythe Gore	PhD student
Lakshminarayana Nittala	PhD student
Professor Ian Robertson	Supervisor, Department Head and leader of Electron Microscopy and Materials Characterisation Research Group
Professor Paul Braun	Supervisor and leader of Materials Chemistry and Photonics Research Group
Professor John Abelson	Supervisor and Professor of Materials Science specialising in thin films, coatings and solar cells mostly for electronics
Beckman Institute of Advanced Science and Technology	
Carla Heitzman	PhD student (Department of Materials Science and Engineering)
Rui Qiao	PhD student (Department of Mechanical and Industrial Engineering)
Adam Zysk	PhD student (Department of Electrical and Computer Engineering)
Associate Professor Narayana Aluru	Supervisor, and leader of Micro-Electro-Mechanical Systems (MEMS) Research Group
Assistant Professor Stephen Boppart	Supervisor and Assistant Professor of Electrical and Computer Engineering
Research Group	
Professor Charles Zukoski	Vice Chancellor of Research

Table A4: Interview questions of case study participants

Research students
Background interview
1. Tell me about your background. What were you doing prior to your studies?
2. What is your research topic?
3. Where did the idea for your topic come from?
4. What work have you done so far since enrolling in your PhD (major milestones)?
5. What are you currently doing, what do you plan to do from here, and when will you finish?
6. Has your topic changed since proposal stage?
7. Have there been risks or issues that have arisen or could arise with your research?
8. How relevant is your research to the needs of the industry/users? i.e. Who will benefit from your research?
9. What role, if any, has industry/users played in your research?
10. Have you undertaken any of your research in other universities or industry in the United States or overseas?
11. What will happen to your research/results?
12. How are you disseminating your results?
13. Have you (or are you considering) commercialising your research?
14. Any there any intellectual property issues?
15. Are there measures in place to protect the intellectual property of your research?
16. What are your career options after you finish your PhD?
17. Are you encouraged to generate new ideas by your supervisor/department? How do they respond to new ideas?
18. Does your department assess and manage risks related to your research?
19. Have you received any training during your doctoral studies related to your research or research management such as project management, IP, commercialising research?
20. What infrastructure do you use to undertake your research?
21. How adequate are these facilities?
22. How are you funded as a research student?
23. Is this funding arranging impacting on your ability to undertake your research?
24. How will you measure the success of your research (what will make you happy)?
25. What does the term "innovation" mean to you?
26. What is innovative about your research?
Video interview
1. What is your background?
2. What is your research topic (in plain English)?
3. Who will benefit from your research?
4. What is innovative about your topic research?

Supervisors and industry partners
1. Tell me about your background? (in the case of supervisors, the types of students you supervise?)
2. Where did the idea for the student's topic come from? (in the case of industry, why did you get involved?)
3. Has the research topic changed since proposal stage?
4. Why did you select this student to undertake the research? (in the case of industry, where you involved in student selection?)
5. Who will benefit from this research? (in the case of industry, how will you benefit from this research?)
6. What role, if any, have the users/industry played in the research? (in the case of industry, what role have you played?)
7. Has the student undertaken any of his or her research in other universities or industry in the United States or overseas? If yes, how was that arranged? Where there any particular benefits or issues?
8. Has the student attended any training during his or her doctoral studies related to their research or research management (such as project management, IP, commercialising research)?
9. What will happen to his or her research results? How will the results be disseminated?
10. Are their any commercialisation possibilities, intellectual property issues and IP measures in place?
11. What skills has the student developed as a result of the research training?
12. What do you think the student could do when he or she finishes?
13. Did you identify any risks that could or did arise with the student's research and how were they managed?
14. Are students encouraged to generate new ideas? How do you respond to new ideas?
15. What infrastructure does the student use to undertake this research? How adequate is this infrastructure?
16. How is the student funded? Is this funding arrangement impacting on the student's ability to undertake his or her research?
17. How will you determine the success of the student's research (i.e. what will make you happy?)
18. What does the term "innovation" mean to you?
19. What is innovative (if anything) about the student's research?
20. Do you believe that research students should be encouraged to innovate? If yes, why? If no, why?
21. If yes to question 20, what do you believe are the features of a research training culture or environment that encourage a research student to innovate?

Research training program managers/department or centre heads
1. What is your background and current role?
2. What are the characteristics of the PhD/doctoral program offered by your department? i.e. policies, courses offered, support provided, requirements of students, etc.
3. How does the department recruit students? (including how many apply vs how many are accepted)
4. How are these students funded? Are there any students paying fees?
5. What does the department do well in terms of PhD/doctoral training? Why do students apply to this school?
6. What are the weaknesses or challenges for the department in terms of PhD/doctoral training?
7. What are the future directions for the department in terms of PhD/doctoral training?
8. What does the term “innovation” mean to you?
9. Do you believe that research students should be encouraged to innovate? If yes, why? If no, why?
10. If yes to question 9, what do you believe are the features of a research training culture or environment that encourage a research student to innovate?

University research training policy advisors
1. What is your background and current role?
2. Can you describe your university’s research profile and performance? i.e. how it has developed/changed, strengths, weaknesses, future directions, etc.
3. Can you describe graduate (PhD) training at your university? i.e. how it has developed/changed, features, strengths, weaknesses, future directions, etc.
4. Can you describe your country’s graduate (PhD) education training system? i.e. how are students funded, strengths, weaknesses, future directions, etc.
8. What does the term “innovation” mean to you?
9. Do you believe that research students should be encouraged to innovate? If yes, why? If no, why?
10. If yes to question 9, what do you believe are the features of a research training culture or environment that encourages a research student to innovate?

Table A5: Question development extracted from Haukka (2003)

The Human Dimensions Working Group considered the attributes, skills and approaches to innovation for individuals and organisations. It found that innovation is a "social process made up of many roles and interactions" and that "a good innovator recognises his or her role and finds other people to fill the complimentary roles"' (1999, p. 3). The seven key roles are the creative person (who has the ideas), the innovator (who translates the idea into reality), the entrepreneur (who develops the product or service into profit), the intrapreneur (who pursues entrepreneurial innovation within the framework of a large organisation), the champion (who drives the idea to a successful outcome), and the sponsor (usually a senior manager who believes in the idea and the team, and who negotiates a clear path for the idea to pass through various stages of organisational scrutiny). The characteristics of an organisation with an innovative culture necessary to sustain a competitive advantage include an internal market for ideas, capital and talent; risks are managed; and innovation is a core competency entrenched within the culture of the organisation. These findings informed the following interview questions for research students:

Questions about research students as innovators

? Where did the idea for your topic come from?
? What has been involved in translating this idea into reality (from proposal to thesis)?
? What risks have you identified with your research and how have they been managed?
? What will happen with your research/results?
? How are you disseminating your results?

Questions about the innovative culture of research training environments

? Are you encouraged to generate new ideas by your supervisor/department?
? How do they respond to new ideas?
? How does your department assess and manage the risks related to your research?
? Who else is involved in disseminating and/or commercialising your research?

The *Systemic Mismatches in the National Innovation System* report of the Institutional Structures and Interfaces (ISI) Working Group referred to mismatches as "imbalances in the national innovation system due to systematic bottlenecks or strain" (1999, p. 6). The report attributed the mismatches to coordination and information failures and structural rigidities, and identified adverse features of the Australian situation: Private sector R&D is low relative to other countries; Australia is a weak R&D performer in medium and high technology industries relative to other countries; Australia does less engineering and software R&D than more innovative countries; public and private sector mismatch on R&D patterns; and Australia produces significantly less engineering graduates than major industrialised countries but more biologists (1999, p. 10). Referring to the **public-private linkage dilemma** (1999, p.19), the report identified linkage difficulties in Australia:

- Public sector's ability to match the research needs and outputs with local industry capability.
- Private sector's ability to match its skill base and commercial imperatives with the public sector.
- Different rationales of the public and private sectors i.e. the role of the public sector is to produce freely available information whereas the role of the private sector is the capture the highest returns from commercially exploiting knowledge.
- The extent that the public sector should behave like the private sector as mixed public/private outputs causes tensions between sectors about competition and cooperation.
- Cultural differences between the public and private sectors as the former is ideas driven and the later is market driven.
- Different incentives drivers i.e. publications and peer reviews for public sector researchers and commercial returns on innovation and R&D investment for the private sector.

The ISI Working Group's proposal to the Summit to establish an independent national body, *Innovation Australia* included barriers to improving the commercialisation of research from the public sector and universities. These barriers were the management of intellectual property within universities and research institutions; lack of encouragement of commercial research outcomes; lack of adequate technology diffusion mechanisms; lack of support of entrepreneurship and new technology-based enterprises; and developing and networking technology and business incubators (1999, p. 6) Findings about the public-private linkage dilemma and barriers to commercialisation raised the following interview questions:

Questions about research users

? How relevant is your research to the needs of the industry/users?
? What role, if any, has industry (i.e. the users of the research) played in your research?
? Have you (or are you considering) commercialising your research?
? Are there measures in place to protect the intellectual property of your research?

The final report of the Innovation Summit Implementation Group (ISIG), *Innovation: Unlocking the Future*, released in August 2000 included 24 recommendations in three critical areas that Australia must address to be an innovative nation: **Creating an ideas culture** by engendering a broad understanding of, and support for, the value of innovation, research and development; **generating ideas** through a world-class research base that will sustain long-term generation of ideas, the lifeblood of innovation; and **acting on ideas** by translating ideas into tradeable products, processes and services to ensure international competitiveness.

The Australian Science Capability Review that commenced in September 1999 was completed in November 2000 with the release of *The Chance to Change* by the Chief Scientist Dr Robin Batterham. The purpose of the review was to assess the capabilities of Australia's science, engineering and technology (SET) base to meet the needs of Australians in the 21st century. The report's recommendations are grouped according to the three primary elements of the SET base (People and Culture, Ideas and Commercialisation) and "complementary or indeed overlapping with those of the ISAG report, *Innovative-Unlocking the Future*" (Batterham 2000, p. 10). Chapter 5 *Investing in People and Innovation Culture* referred to OECD reports that proposed that "a knowledge-based economy requires a supportive, innovative culture, a culture in which entrepreneurship and enterprise are taught at all levels (primary through to postgraduate)" (2000, p. 49). It also raised the concern about attracting and retraining the best researchers, as many researchers are pursuing careers outside Australia that provide more attractive research environments, such as the United States. Chapter 6 *Investing in Ideas* highlighted the importance of the availability of high quality infrastructure to high quality research, defining infrastructure as 'buildings, equipment, libraries and databases, computing and communication systems and administrative support' (2000, p. 67). The report stated the cost of research infrastructure was increasing while funding for it is either static or declining. The ARC submission to the review found that the Research Infrastructure Block Grants Scheme for ARC supported research was 19 cents in the dollar compared to over 40% of total project costs in the U.S., Canada and the UK. The ISIG and Chief Scientist reports generated further interview questions:

Questions about infrastructure, location of study and career options

- **?** Have you received any training in innovation or commercialising research?
- **?** What infrastructure do you use to undertake your research? How adequate are these facilities?
- **?** Have you undertaken any placements/student exchanges in Australia or overseas as part of your studies?
- **?** What are you intending to do after finishing your research?

The Commonwealth Government announced in 2001 a five year strategy of initiatives to promote research, development and innovation called *Backing Australia's Ability, an innovation action plan for the future*. The strategy outlines additional Government investment of $2.9 billion from $159 million in the first year to $947 million in 2005-06 to fund major initiatives in the three key elements of the innovation process: Strengthening Australia's ability to generate ideas and undertaken research; accelerating the commercial application of these ideas; and developing and retaining Australian skills (2001, p. 14). It states that the private sector and educational and research institutions must accept responsibility to work in partnership with Government to enhance Australia's capacity for innovation. The *2002-03 Innovation Report* for *Backing Australia's Ability: Real Results Real Jobs* included the Australian Innovation Scorecard which benchmarks Australia's innovation performance against other OECD countries. Australia ranks among the top 10 countries for ten of the indicators, but is well below the OECD average for business investment in R&D, patenting and the size of the venture capital market (2002, p. 7).

A review of Australian higher education which commenced in early 2002 is considering the Commonwealth Government's objectives for higher education: Quality assurance; improving the responsiveness of universities to students and industrial requirements; and advancing Australia's knowledge base and contribution to national and global innovation. The review's first report, *Higher Education at the Crossroads*, included innovation as one of the principles for a higher education system: "Higher education institutions need to generate new ideas, solve problems, improve products or processes and adapt to new and changing environments. The need to be innovative relates not only to improvements in teaching and learning but also to the direction and commercialisation of research, and engagement with industry, research institutions and other education providers" (Nelson, 2002c, pp. 2-3). The first discussion paper, *Striving for Quality: Learning, Teaching and Scholarships,* was produced after public consultations about above review report. This paper released in June 2002 defines research training as 'the building of skills and capacity, and generation of new ideas' (2002a, p. 42) and states the research training 'is becoming an increasingly important element of the national innovation system' (2002, p. 42). The paper acknowledging the need to balance specialised skills with generic skills, found universities that were offering development opportunities, such as the five online modules offered to postgraduate students enrolled at Australian Technology Network (ATN) institutions: project management, entrepreneurship, leadership and communication, technological and commercial development, and public policy. The indicators of Australia's innovation performance and the current thinking about the skills of research students in a national innovation system, led to closing interview questions:

Questions about innovation

- **?** How will you measure the success of your research?
- **?** What does the term innovation mean to you?
- **?** What is innovative about your research?

Table A6: Example plain language statement and consent form for research students

Invitation to research students from Biocenter Oulu (University of Oulu) to participate in PhD research about your research

14 August 2003

Dear Research Student

I am a PhD student enrolled in the Department of Industry, Professional and Adult Education (IPAE) at RMIT University in Melbourne, Australia. I am also employed as a researcher and lecturer in this department, which is part of the Faculty of Education, Language and Community Services (FELCS). I am undertaking a student exchange at the University of Oulu from August to December 2003.

My research topic is investigating the contribution of research training to national innovation systems in Australia, Finland and the United States. The purpose of this topic is to determine how Australia can improve the contribution of research training to the national innovation system, whilst “assuring the quality and effectiveness of the research training system” (Kemp, 1999, p. 9). This involves looking beyond Australia by examining how effective linkages between research training and industry are already contributing to national innovation systems in other countries. Finland and the United States have been selected because of their successful approaches in nurturing research training and innovation that encourage collaborations between universities (as producers of research) and industry (as users of research), within a national innovation system.

Findings will provide stakeholders (such as policy makers, funding bodies, universities and research users) in each country with greater insight into the link between research training and innovation, how research students are innovative, and the conditions in research training environments that nurture innovation. These findings will inform what is meant by a **research training culture of innovation**. This may lead to changes to higher education and/or research training policy that benefit research students and their host university, as producers of research, and forge a closer relationship with the particular users of this research. In the longer-term, this thesis aims to strengthen the contribution of the research training to national innovation systems in Australia, Finland and the United States.

Your role and rights as a research student in this study

You are one of 30 research students who I am seeking to recruit from six research programs within three universities: RMIT University, University of Oulu and University of Illinois at Urbana-Champaign. You have been nominated and/or invited to participate in this study by **Dr Pekka Kilpeläinen** because you are (1) undertaking research that is regarded as 'innovative' and (2) enrolled in a research training program with an international reputation for innovative outcomes.

Over the next few months, I will observe and interview you in a natural setting (such as your classroom, laboratory, workplace and/or home) for up to 10 hours to gain your perspective on how your topic contributes to innovation. I would also like to view any written work that you have completed about your topic, such as your research proposal and key publications.

A typical **interview schedule** is as follows:

- September 2003 Session 1: Background interview to your topic including the collection of any written work and a CV
- October 2003 Session 2: Observation of your work in a natural setting (video recording)
- October 2003 Session 3: Video response to four key questions (video recording)
- December 2003 Session 4: Discussion about your draft case study
- Other activities: Attendance at other relevant program events, and further observation/interviews with you if required (such as a major development or milestone).

I will also interview your supervisor(s), the manager of your research training program and industry/ government representatives (who have been involved in your research or will use or benefit from it) to determine how they perceive your topic contributes to innovation.

Apart from being published in the thesis, you will be approached at times for permission to use your name, photograph(s) and video recording in other products. For example, your success story may be published in a university brochure or in a Compact Disc (CD) and/or uploaded onto your university website. I will also present conference papers and make university presentations that may disclose your identity. You may also be invited to present your research topic and experience at forums, such as those that aim to attract and motivate other research students. Inclusion in these “extra” publications or activities is strictly voluntary and I will not include or refer to you in these without your written permission for each publication or activity. If you **do not want your identity disclosed**, I will consider alternative methods to collect and present findings about you that will protect your identity.

During the observation and interview sessions, you may disclose **commercially sensitive information** that cannot be published and personal information when discussing your career/educational background that led to your research topic. If necessary, I will arrange for legal documentation that prevents any commercially sensitive information from being disclosed. All personal information is confidential and, if relevant to the research questions, will only be used with your permission.

Findings about how your topic contributes to innovation and what factors are impacting on and/or contributing to this innovation will be presented and published as an **interactive case study**. As you are one of five research students from your research training program who may participate in this study, the five case studies together with the findings from interviews with research training supervisors, program managers and industry/government representatives, will form a **collective case study** for your research training program. You will have the opportunity (known as "**member checking"**) to read and reflect on, and to make changes or additions, to your individual and collective case studies.

I will store information about you in a **secure database** (that is backed up regularly on CDs, with one CD kept offsite) and in hard copy format stored in a lockable filing cabinet. As required, all records will be kept for a period of five years after the thesis has been published. I am the only person who will have access to these files, and you may access your own file.

In Summary

I would like to request that you be part of this study. A summary of the PhD Research Proposal is attached for your information. If you agree to participate, please sign the attached consent form.

Your involvement in this study is voluntary and you may withdraw consent to participate and discontinue participation at any time. You are also able to withdraw any information that you provided that has not been processed.

If you would like to discuss the study or any aspect of this statement, please contact Sandra Haukka on the below telephone numbers or email address. If you have any questions regarding ethical issues you can contact RMIT University's Human Research Ethics Committee on 613 9925 1745.

Thank you for your interest.

Sandra Haukka
M. Soc. Sc. (Careers Ed), Grad. Cert. IET, B. Admin.

Telephone: 0408 338 919 (mobile)
Email: sandra.haukka@rmit.edu.au

Any complaints about your participation in this project may be directed to the Secretary, RMIT Human Research Ethics Committee, University Secretariat, RMIT, GPO Box 2476V, Melbourne, 3001. The telephone number is (03) 9925 1745. Details of the complaints procedure are available also from the above address.

RMIT HUMAN RESEARCH ETHICS COMMITTEE

Prescribed Consent Form For Persons Participating In Research Projects Involving Interviews, Questionnaires or Disclosure of Personal Information

FACULTY OF	Faculty of Education, Language and Community Services
DEPARTMENT OF	Department of Industry, Professional and Adult Education (IPAE)
Name of participant:	
Project Title:	Research training and national innovation systems in Australia, Finland and the United States
Name(s) of investigators:	Sandra Haukka Phone: 0408 338 919 (mobile)

1. I have received a statement explaining the interview/questionnaire involved in this project.
2. I consent to participate in the above project, the particulars of which - including details of the interviews or questionnaires - have been explained to me.
3. I authorise the investigator or his or her assistant to interview me or administer a questionnaire.
4. I acknowledge that:
    (a) Having read Plain Language Statement, I agree to the general purpose, methods and demands of the study.
    (b) I have been informed that I am free to withdraw from the project at any time and to withdraw any unprocessed data previously supplied.
    (c) The project is for the purpose of research and/or teaching. It may not be of direct benefit to me.
    (d) The confidentiality of the information I provide will be safeguarded. However should information of a confidential nature need to be disclosed for moral, clinical or legal reasons, I will be given an opportunity to negotiate the terms of this disclosure.
    (e) The security of the research data is assured during and after completion of the study. The data collected during the study may be published, and a report of the project outcomes will be provided to each participating university.

Participant's Consent

Name: ____ Date: ______________
(Participant)

Name: ____ Date: ______________
(Witness to signature)

Where participant is under 18 years of age:

I consent to the participation of ______________________________ in the above project.

Signature: (1) ________________ (2) ________________ Date: ______________
(Signatures of parents or guardians)

Name: ____ Date: ______________
(Witness to signature)

Participants should be given a photocopy of this consent form after it has been signed.

Any complaints about your participation in this project may be directed to the Secretary, RMIT Human Research Ethics Committee, University Secretariat, RMIT, GPO Box 2476V, Melbourne, 3001. The telephone number is 61 3 9925 1745.

Table A7: Initiatives funded in *Backing Australia's Ability*, January 2001

Strengthening our ability to generate ideas and undertake research
• Double funding by an extra $736 million over the next five years for national competitive grants administered by the ARC to support internationally competitive research, improve the competitiveness of researcher's salaries and increase the support available under the Discovery and Linkage elements of the grants program. Emphasis will be on areas in which Australia enjoys, or wants to build, a competitive advantage.
• More than $337 million over five years towards increased project-specific infrastructure to support ARC and National Health and Medical Research Council grants.
• $246 million over five years to upgrade basic infrastructure of universities, such as scientific and research equipment, libraries and laboratory facilities.
• $176 over five years to establish Centres of Excellence in ICT and biotechnology. With strong industry participation, the Centres will undertake world-class R&D, focusing on commercialisation and encouraging spin-off companies.
• $155 million towards establishing collaborative Major National Research Facilities to provide researchers with the most up-to-date equipment and facilities.
• In addition to the existing 125 per cent R&D tax concession, companies that undertake additional R&D will be able to access a premium rate of 175 per cent on the additional investment. This premium targets the labour-related components of R&D expenditure.
• Effective-life write off will apply to the Government's existing R&D tax concession scheme to simplify the application of the scheme and provide a consistent treatment between R&D and other capital items in the tax system.
Accelerating the commercial application of these ideas
• 80% or $227 million increase over five years for the Cooperative Research Centres Program to continue and enhance the spin-off opportunities from industry research collaboration, establish larger CRCs, and provide small and medium enterprises with greater access to the program.
• Double funding by an extra $40 million over four years for the Commercialising Emerging Technologies (COMET) Program to provide early assistance to firms by improving their commercialisation skills.
• $100 million over five years for an Innovation Access Program to enhance Australian firms' access to new technologies, accelerate the use of e-commerce business solutions, especially for small and medium enterprises, showcase Australian science and technology overseas, and develop international bilateral agreements that support strategic science and technology.
• $78.7 million over five years as pre-seed funding to help commercialise public sector research by assisting universities and public sector research agencies to take proposals to a venture capital ready stage.
• Double the Biotechnology Innovation Fund by an additional $20 million to encourage the development of new biotechnology firms.
• An additional $21.7 million over five years for the New Industries Development Program to accelerate efforts to improve Australia's performance in the development and commercialisation of new agribusiness products, services and technologies.
• Monitor the impacts of the new business taxation arrangements, in particular entity taxation, on domestic and overseas investment in Australian venture capital to ensure recent changes to the tax system will encourage venture capital investment.
• Develop regulation business advice tools and review the regulatory framework to determine how it can be improved to ensure Australia has a regulatory environment that maximises the outcomes of innovation.
• Strengthen Australia's IP protection system by increasing awareness and understanding of IP, for example by developing an IP Internet portal, improving IP management in public research agencies, and quickly implementing IP reforms such as introducing a "grace period" to the Patents Act and acceding to the Madrid agreement regarding international registration of trade marks.
Developing and retaining Australian skills
• $151 million over five years for an additional 2,000 university places each year, with priority given to ICT, mathematics and science, area where Australia faces shortages.
• Establish an income-contingent loan scheme for postgraduate fee-paying students providing loans of some $995 million over five years to encourage lifelong learning and to help Australians upgrade and acquire new skills.
• Attract and retain leading researchers in key positions by introducing 25 new Federation Fellowships worth $225,000 a year for five years, doubling the number of Australian Postdoctoral Fellowships from 55 to 110, and improving the remuneration for postdoctoral fellowships, as part of the new funds provided for national competitive research grants.
• An additional $130 million over four years to Government schools in those States where the Enrolment Benchmark Adjustment (EBA) is triggered to foster scientific, mathematic and technological skills, develop school based innovation and build supportive school environments.
• $34 million over five years to help develop online curriculum content in schools to enhance student access to quality learning opportunities and provide experience of ICT as a learning tool.
• Adjust immigration arrangements to attract more migrants with skills in ICT to help meet the demand for ICT skills.
• $35 million over five years to implement a National Innovation Awareness Strategy (including the development of new ways to measure our national innovation performance) to raise understanding of the importance and commercial potential of science and technology, particularly amongst young people.

Source: Howard (2001) pp.15-21

Table A8: Strengths, weaknesses and complementarities in Australia's national innovation system

Strengths	• Development of scientific knowledge, as indicated by level of publications • Heavy investment in "public good" research and evidence of commercial and non-commercial benefits • Some large firms performing well in organisational innovation using ICT to improve business performance • IP protection framework is among world's best practice • High rate of growth in the biotechnology sector • Improvement in collaboration and linkages between researchers in universities, and publicly funded organisations and firms and other research users in Australia • A broad human capital base to underpin science and innovation • A relatively high level of government expenditure on R&D
Weaknesses	• Scientific standing at risk, as indicated by a lower citation impact of research publications • Limited visibility and impact of Australian science and patented technology on the development of world technologies • low levels of business innovation involving R&D and development of new technology, as indicated by low levels of BERD in GDP • low investment in the development of strategic ICT capability • low overall performance in commercialising new ideas, products and technologies • Lack of a strategic approach to coordination of support for international S&T collaboration and insufficient funding mechanisms to support these collaborations • Research infrastructure under pressure in terms of investment and maintenance, and in leveraging access to international research infrastructure, including challenges in building broadband infrastructure to support participation in e-science • Declines in participation in most science subjects in Year 12 and in S&T subjects at an undergraduate level; anticipate shortage of maths, science and ICT teachers in schools; and predicted high demand for workers with science qualifications • Shortage in the number of Australians with entrepreneurial skills and experience in management, marketing and business development, especially in high grow start-ups • Barriers for regional areas in participating in the science and innovation system • low ranking amongst OECD countries in R&D investment as a proportion of GDP • Support from national, state and territory governments has concentrated on building R&D capacity rather than enhancing commercialisation and strengthening skills development
Complementarities between governments	• Need for increased cooperation particularly in the areas of research infrastructure and emerging sciences and technologies • Data limitations in the areas of business innovation, research infrastructure, and utilisation of the outcomes of research and innovation undertaken primarily for "public good" purposes.

Source: Nelson (2003a)

Table A9: Recommendations from the sixth triennial review of the Science and Technology Policy Council of Finland, *Knowledge, Innovation and Internationalisation*

- The national line of development, which has proved successful, will be continued and further strengthened. In keeping with that, input will be made into the production of technological and social innovations and into the expansion of internationally successful business built on it. The set of measures thus determined will form the core of the future national strategy.
- Finland will make systematic input into international science and technology cooperation both in Europe and globally with a view to increasing knowledge, know-how and innovation. Similarly, internationalisation of education will be intensified by means of the research cooperation models.
- The foremost strengths in knowledge – *national competencies* – will be developed further. Moreover, it is especially important to invest in promising research fields and to achieve a sufficient volume and quality level in them. Such fields are the life sciences, the environment, information technology and software, the well-being cluster and knowledge-intensive services.
- Input will be made into removing obstacles to efficient commercial utilisation of research. The renewal of the traditional industrial fields will be accelerated through the promotion of the use of technological and social innovation in enterprises. Ministries will assume more responsibility as strategic development organisations and as users of social innovation which supports development.
- With a view to strengthening innovation and favourable conditions for it, measures will be taken to enlarge the resources of the Academy of Finland and Tekes to enable them to take care of their growing responsibility for the development of new growth fields, research-based innovation and innovation environments. Ministries' research and development and expert resources will also be strengthened and partly redeployed.
- Research organisations will be developed as active and dynamic partners with a view to strengthening linkages between research and business. At the same time, care will be taken to ensure a balanced development of their resources. Cooperation rules and procedures will be clarified and developed to provide more incentive.
- University legislation will be amended to provide incentives for universities to actively develop education, researcher training and research and to promote the utilisation of research. The stress will be on the universities' own responsibility and capacity for renewal. University core funding will be strengthened with a view to the implementation of the national strategy and as part of the development of a humane information society.
- The flexibility of the innovation system will be improved through an increase in the competitive science and technology funding through the Academy of Finland and Tekes. Their operations will be developed and redirected, if necessary, based on the ongoing evaluations. Ministries will increase collaborative cluster programs and their financing. The Science and Technology Policy Council will follow the structural development of the public research system and assess it by the end of 2004.
- It is time to move on to larger and more concrete foresight projects. What is needed is a foresight exercise from the Finnish viewpoint, to be conducted by the existing foresight network and geared to supporting the implementation of the national strategy and finding new development paths.
- Input will be made into achieving the target of basic information society skills. The measures for enhancing mathematical and scientific knowledge will be continued on the basis of the international evaluation. Input will be made into postdoctoral research careers, and career prospects will be improved in keeping with the findings of the PhD review of the Academy of Finland.
- Research and development and innovation funding will be increased to speed up the internationalisation of the innovation system and to further develop innovation in Finland. There are three main targets for the development of funding: (1) education, the development of research careers and broad-based increases in researched knowledge; (2) the strengthening of social and technological innovation; and (3) flexible, expert development of innovation funding.
- Measures geared to enhancing regional development will be maintained and improved with a view to ensuring sustainable and balanced development throughout the country. Higher education institutions and local units of research institutes have a special task in adding to the knowledge and social capital of the region and making it available to users. National and international networking will be enhanced by public and private partners in collaboration in order to utilise knowledge and know-how available elsewhere and especially to improve innovation services needed by small and medium-sized enterprises.

Source: Science and Technology Policy Council of Finland (2002), pp. 35-41

Table A10: Finland's science and technology policies

Finnish science policy is designed to ensure positive development in science and scholarship. The aim is to raise the level, ensure the comprehensiveness, enhance the social impact and promote the international penetration of Finnish research. The key aims and priorities in Finnish science policy are as follows:

- Effect a substantial increase in research funding and maintain the GDP share of R&D at a world top level. The additional funding will be allocated to strengthen basic research, researcher training and research infrastructure, to promote research careers and to boost social innovation
- Step up the development of centres of excellence
- Promote national, European and international networking in research to make use of EU research programs, other international research schemes and bilateral arrangements
- Support research especially in fields relevant to knowledge-intensive industries and services, such as biotechnology
- Intensify cooperation between the users of the research system and research findings and the diffusion of research findings
- Promote the commercialisation of research findings and the creation of new business and the utilisation of research findings and technology
- Make input into impact analysis and the evaluation of the state and performance of the research system.

Science policy is the responsibility of the Ministry of Education; the most important research financing organisation is the Academy of Finland. Publicly funded research is mainly conducted in universities and research institutes.

Finnish technology policy is designed to strengthen the competitiveness of technology-based enterprises. Technological progress is used to create new business opportunities and promote the growth of existing business. Technology policy is a central component in industrial policy. The aims of Finnish technology policy are as follows:

- Develop the national innovation system with a goal of generating new knowledge and promoting knowledge-based production and services
- Increase and expedite the utilisation of growing research results and to promote the emergence and growth of new companies
- Effect a substantial increase in public R&D funding, which will be allocated to R&D and commercialisation of results in the services sector and in new production fields and to innovation promoting sustainable development
- Restore an upward trend in public R&D funding
- Promote national, European and other international networking in R&D
- Support national technology policy priorities and a more effective use of research resources through bilateral and multilateral cooperation
- Support regional development through technology
- Evaluate regularly the performance and impact of technology policy
- Enhance research into technological change and innovation and their social impact
- Ensure that the technological infrastructure, national quality policy and the technological safety system meet international standards and promote business competitiveness
- Disseminate information to decision-makers and the general public on the results and the impact of public R&D funding.

Technology policy is the responsibility of the Ministry of Trade and Industry. The responsibility for measures geared to develop and disseminate new technological knowledge has been assigned to agencies in the Ministry's sector. The most important organisation financing technological R&D is the National Technology Agency (Tekes).

Source: Finland Science and Technology Information Service (2005)

Table A11: Strengths, weaknesses, opportunities and threats in Finland's national innovation system

Strengths	Weaknesses
• Innovation performance in high-technology manufacturing is positively correlated with performance in low-technology manufacturing – countries like Finland, Sweden and Denmark that have innovative high-technology industries tend to perform well in lower-tech industries as well. This suggests that dynamic high-tech sectors are important drivers across entire national economies. • High-tech patenting • Innovation co-operation • low labour costs of R&D staff compared to most research-intensive countries • High qualification levels and expertise in the labour force (high number of population with tertiary degree) • High internet penetration	• Innovation expenditures in services • low attractiveness as a location of FDI • Small number of innovative SMEs • low employment in medium tech industries • low level of entrepreneurship
Opportunities	**Threats**
• Productivity potential and increased usage of ICT in the non-manufacturing sector • Small size of the innovation system and close relationships between the actors involved in the innovation system, allow rapid changes in priority setting. • Globalisation	• Globalisation • Dynamics of economy

Source: European Commission (2004a) p. ii

Table A12: Strengths, weaknesses, opportunities and threats in the U.S. national innovation system

Strengths	Weaknesses
• Cutting edge science research across a wide range of fields. • Strong capabilities in converting research into applied technology. • Support at all levels in both public and private sectors for developing high technology start-ups. • Extensive venture capital markets, making start-up funding relatively simple when compared with other developed economies. • Relatively open labour markets, especially for immigration of S&T personnel from other countries.	• Education and training (K-12, vocational training) • Lack of U.S. students entering science and engineering graduate programs. • Dearth of funding for basic science creating a long-term gap in capabilities. • Limited R&D coordination across states leading to some duplication of efforts.
Opportunities	**Threats**
• Expansion of global supply chain and technology centres to lower-income regions within the U.S. • The U.S. must work to ensure that innovative capacity of local workers in low income and rural areas is increased by R&D investments. • Worker re-training and science/technology programs outside the four-year university system.	• The ability of companies to outsource high skilled jobs to low-wage workers in developing countries will only continue to grow. • EU and Asian innovations, as measured by journal articles and patents, are beginning to close the gap with the U.S. • Limited high-skilled labour force due to demographic shift and educational costs.

Source: European Commission (2004b) p. ii

Table A13: Recommendations from the 2004 U.S. National Innovation Summit

Recommendation 1: National Innovation Leadership Network

Innovation is a process of shared responsibilities requiring motivation and integration of many different resources within and among firms, the private sector and governments at all levels. The 21st Century Working Group recommends creation of a National Innovation Leadership Network consisting of members drawn from public sector, industry, research, labor and academia. The purpose of the Network is to provide an on-going mechanism to urgently address the need for more effective innovation policies and metrics to reflect today's knowledge-based, dynamic and globally networked economy.

Innovation will be the principal driver of economic growth, standard of living and national competitive advantage in the 21st Century. The Leadership Network will be a transformational force aimed at ensuring that the U.S. continues to be the most fertile and attractive environment for innovation in the world. The major activities of the Leadership Network include:

- producing a biennial Innovation Scorecard assessing the nation's innovation performance in the global economy. High quality, relevant and timelier metrics that recognize the globally interrelated features of the innovation will enhance public understanding, help policymakers benchmark and monitor the nation's performance, and thereby, improve policymaking and business strategies.
- establishing a public-private partnership for a National Innovation Medal and Prize recognizing outstanding innovation performance by businesses (large and small), government entities, research and educational institutions that have contributed to the development and diffusion of new products, services and processes. The Medal would be presented by the President of the United States with the private sector providing innovation criteria, independent evaluators and prizes.
- giving rise to an Innovation Commons to sustain long-term public support for innovation, build dynamic collaboration within the innovation ecosystem and undertake aggressive Outreach and Advocacy to inform continuously the media, public and policymakers on the benefits of innovation and strategies to realize these benefits.

This initiative should be holistically framed and managed across all stakeholders and coordinated when appropriate with international organizations. The Leadership Network should be launched as a private sector initiative.

Recommendation 2: Building Innovation Skills for the Future

Innovation within all enterprises, both large and small, whether public or private, is key to the future wealth and stability of the United States. Yet, we are currently not providing our students and workforce with the up-to-date skills they need to contribute creatively every day in their workplace. Innovation can be learned, but only through experience. We propose a National Support Network with the long-term goal of providing every student in high school and college the opportunity to gain these vital skills. Based on the proven pedagogy of Problem-Based Learning (PBL) the network will harness the power of the Internet to solve the major structural and resource barriers currently preventing this necessary major addition to the education of the nation. Up to ten regional universities, already committed to innovation education, will form the backbone through *innovation learning centers*. These centers will support the educational jurisdictions in their region by:

1) agreeing on and acquiring an information infrastructure to support the network

2) installing course management software and PBL course materials at each node

3) creating Innovation Learning Centers at each node for training the trainers

4) establishing and supporting outreach at each node to the following communities of interest – departments of education, school districts, 2 and 4 year colleges, teachers and faculty

5) documenting the institutional barriers to adoption of PBL at institutions of higher education with case studies of successful implementation while developing marketing and outreach on the success of PBL and the models that support its adoption

6) offering assistance to States to review academic standards for high school graduation to incorporate and highlight the importance of PBL and innovation.

Open access to this supportive "train-the-trainer" model will spread innovation learning across the nation at all levels by significantly reducing the barriers to change and, through sharing of materials and best practices, minimize the investment needed to implement this vital addition to the nation's education. The centers will also support workforce retraining in innovation skills.

Recommendation 3: Government Policy Coordination for Innovation

Innovation policy is the new pathway to building prosperity and national competitive advantage for advanced industrial nations. The 21st Century Innovation Working Group recommends an aggressive public policy strategy that energizes the environment for national innovation. We believe that innovation is an issue that merits the time of the President. We recommend that the President establish a focal point within the Executive Office of the President to frame, assess, and coordinate strategically the future direction of the nation's innovation policies. This could be either a Cabinet level interagency group, or a new distinct mission assigned to the National Economic Council.

We recommend that the President give consideration to the following action items:

- Establish an explicit innovation agenda. Direct his Economic Advisors to analyze the impact of current economic policies on U.S. innovation capabilities and identify opportunities for immediate improvement.
- Direct his Cabinet Officers to undertake a review of Department programs and policies to determine their impact on the nation's innovation performance. Use this as an opportunity to break down *stovepipes* and foster closer collaboration among the agencies to meet clear national needs.
- Clarify and expand the role of existing mechanisms, such as the National Economic Council, the Office of Science and Technology Policy, the Domestic Policy Council and the National Security Council to upgrade and strengthen the consideration of policy choices on innovation.

Recommendation 4: Retooling Skills for Innovation

Education, both at the college level and in K-12, needs significant changes to prepare students to be leaders and innovators in the coming years. The system needs to be realigned to promote a competitive, 21st century definition of student achievement. One essential target for reform is in the area of curriculum, where creative and integrative instruction based on Problem-Based Learning (PBL) should be developed and implemented within multi-disciplinary and diverse teams, including distributed teams where possible. Additionally, Standardized Technology Platform(s) to support PBL using interchangeable course modules should be developed and deployed to solve the scalability, and complex course management issues that PBL raises. New methods of teacher training, school organization, governance, incentives and accountability must also be addressed to support and sustain the newly-aligned system.

Recommendation 5: Catalyzing Collaborative Investments in Innovation

Innovation requires research investment and collaboration between many parties, including large, medium and small companies, universities, and government. Collaborative arrangements can result in higher innovation productivity. Effective collaboration demands new mechanisms. The 21st Century Working Group's recommendations in this area include:

- strengthening knowledge networks between appropriate partners, both virtual and real by establishing a National Innovation Portal, an open-source forum for innovation that matches companies with appropriate partners.
- enhancing federal and state funding for research and innovation, especially merit-based programs (cf. NSF, NIH, DOD, DOE, DOC, and state programs) that match or provide funding in all technology areas according to technological and commercial promise.

Source: Council on Competitiveness (2004b)

Table A14: Commonwealth Government of Australia's Endeavour postgraduate/postdoctoral awards

Endeavour Awards	Description	Number of awards in 2006	Participating countries
Endeavour International Postgraduate Research Scholarships (IPRS)	Aims to attract top quality international postgraduate students to areas of research strength in Australian higher education institutions; and support Australia's research effort. Available for a period of two years for a Masters by Research degree or three years for a Doctorate by Research degree. The Scholarship covers tuition fees and health cover costs for Scholarship holders, and health cover costs for their dependents.	330 Postgraduate research students (Masters or PhD)	All countries, except New Zealand
Endeavour Research Fellowships	Provide financial support for postgraduate students and postdoctoral fellows from Canada, Egypt, Taiwan and participating countries from Europe and Latin America, to undertake short-term research, in any field of study, in Australia. The research project must be taken in one block and cannot be broken into two or more visits to Australia. Award holders are expected to return to their home country at the conclusion of their award. Awards are valued at up to A$25,000.	19 Postgraduate and Postdoctoral Research Fellows	Latin American, European Union Member States, Norway, Switzerland, Croatia, Egypt, Canada and Taiwan
Endeavour Iraq Research Fellowships	Provide financial support for postgraduate students and postdoctoral fellows to undertake short-term research, in any field of study, in Australia. The research project must be taken in one block and cannot be broken into two or more visits to Australia. Award holders are expected to return home at the conclusion of their award. Awards are valued at up to A$25,000.	3 Postgraduate and Postdoctoral Research Fellows	Iraq
Endeavour AusAid Iraq Research Fellowships	Provide financial support for postgraduate students and postdoctoral fellows to undertake short-term research in Australia in the field of Agriculture. The research project must be taken in one block and cannot be broken into two or more visits to Australia. Award holders are expected to return home at the conclusion of their award. Awards are valued at up to A$25,000.	5 Postgraduate and Postdoctoral Research Fellows	Iraq
Endeavour Europe Awards	Provide financial support for postgraduate students from designated European countries to undertake, in any field of study an Australian higher degree or research in Australia towards a higher degree in their home country. Awards are valued at up to A$50,000.	16 Postgraduate students	European Union member states, Norway, Switzerland, Croatia
Endeavour Asia Awards	Provide financial support for postgraduate students from designated Asian countries to undertake, in any field of study, an Australian higher degree or research in Australia towards a higher degree in their home country. Awards are valued at up to A$50,000.	14 Postgraduate students	Malaysia, Taiwan, Korea, Thailand, Indonesia, Singapore, Vietnam, India
Endeavour Japan Awards	The Endeavour Japan Awards provide financial support for postgraduate students from Japan to undertake, in any field of study, an Australian higher degree or research in Australia towards a higher degree in Japan. Awards are valued at up to A$50,000.	5 Postgraduate students	Japan
Endeavour Cheung Kong Awards for Australian Scholars	Provide financial support for Australian postgraduate students and postdoctoral fellows to undertake short-term research in Asia. The research project must be taken in one block and cannot be broken into two or more visits to Asia. Award holders are expected to return Australia at the conclusion of their award. Awards are valued at up to A$25,000.	20 Postgraduate students	Australia
Endeavour Cheung Kong Awards for Asian Scholars	Provide financial support for Asian postgraduate students and postdoctoral fellows to undertake short-term research in Australia. The research project must be taken in one block and cannot be broken into two or more visits to Australia. Award holders are expected to return their home country at the conclusion of their award. Awards are valued at up to A$25,000.	20 Postgraduate and Postdoctoral Research Fellows	China, Hong Kong, India, Indonesia, Japan, Korea, Malaysia, Singapore, Thailand and Vietnam

Source: Department of Education, Science and Training (2005b)

Table A15: Reasons given by male and female respondents for emigration, Australia

Reasons ranked by popularity of response (n = 2,072)	Males %	Females %	Persons %
Reasons for emigration			
Better employment opportunities	49.3	34.2	42.6
Professional development	42.9	27.4	36.1
Higher income	38.2	25.1	32.4
Promotion/career development	28.9	17.2	23.7
Lifestyle	22.2	23.8	22.9
Marriage/partnership	17.0	29.1	22.3
Overseas job transfer	23.1	14.7	19.4
Education/study	16.0	12.5	14.5
Partner's employment	4.6	21.4	12.1
To be close to family/friends	4.4	7.0	5.6
To establish/expand business	4.3	0.8	2.8
Separation/divorce	1.2	2.1	1.6
Reasons for not intending to return or undecided (n = 1,022)			
Better employment opportunities	51.5	37.5	45.4
Established in current location	44.5	36.2	40.9
Career and promotional opportunities here	45.9	34.2	40.8
Higher income here	46.3	32.8	40.4
Marriage/partnership keeps me here	34.0	43.1	38.6
Lifestyle more attractive here	32.4	28.3	30.6
Partner's employment here	18.0	37.3	26.4
Family/friends here	25.0	24.7	24.9
More favourable personal income tax regime here	28.6	15.7	23.0
Children grown up here	22.7	22.9	22.8
No equivalent jobs in Australia	19.8	14.2	17.3
Cost of relocating back to Australia	15.1	19.1	16.8
Business opportunities here	22.0	9.2	16.4
Better educational institutions for training here	6.6	8.5	7.4
Better employment and work based training here	6.6	6.5	6.6
More favourable business tax regime here	8.7	2.5	6.0
Custody of children	2.4	3.1	2.7
Events or incentives required to bring respondents back to Australia (n = 871)			
Better job/salary	41.0	41.5	41.2
Children/family reasons	18.8	30.2	23.9
Not an option/not likely	9.1	8.2	8.7
Change in personal situation/finances	8.9	3.9	6.7
Changes to tax/retire benefits/strong $A	7.5	3.6	5.7
Citizenship/visa issues	6.2	4.1	5.3
Changed conditions in Australia	5.0	4.9	4.9
Global war/terrorism	3.5	3.6	3.6

Source: Hugo et al. (2003)

Table A16: Researcher mobility programs in Finland

Academy of Finland

Grants to research students and postdoctoral researchers

The aim is to upgrade the standard of research and to promote the international mobility of researchers, especially at the postdoctoral stage. Grants are awarded to researchers with a PhD for purposes of work abroad and to researchers working on their doctoral dissertation for purposes of researcher training lasting at least one semester. If the researcher works in a research team, the grant for work abroad may also be awarded as part of project funding, in connection with other research funding. Funding for researcher training abroad is granted primarily in fields where there is not enough training available in Finland. Among postdoctoral researchers moving to EU countries, subsidies are granted primarily to those who have received partial funding from other sources, such as the EU's framework programme for research. This form of funding is also open for application to researchers moving to international research institutes such as the IIASA (International Institute for Applied Systems Analysis), CERN (European Organisation for Nuclear Research), EMBL (European Molecular Biology Laboratory) and EUI (European University Institute). The subsidy paid may include:

- a personal grant in accordance with the Academy of Finland's grounds for grants
- term fees and other similar fixed payments
- travel and other expenses incurred from the research, as decided upon separately in each case.

If the period of training or research abroad lasts at least six months, the travel expenses of accompanying family members may also be remunerated. Researcher training abroad is also supported by the EU and NordForsk, for instance. Applications shall be filed between 30 August and 30 September 2005. Applications shall be submitted by the individual researcher.

Research training at the Europe University Institute

The European University Institute (EUI) in Florence, Italy, is run jointly by the EU Member States. The Institute arranges postgraduate training and provides research facilities for advanced researchers. The Institute has four departments: History and Civilization, Economics, Law, and Political and Social Sciences. The language of instructions within the three-year doctoral programme is normally English, in some programs French. Applications for EUI doctoral programs shall be made on EUI application forms and sent in three copies by registered mail directly to the EUI in Florence in January. One copy of the application shall be sent simultaneously to the Academy of Finland. A shortlist of candidates shall be drawn up by the EUI together with the Academy of Finland. The shortlisted candidates will be invited to an interview in Florence in March/April. The Institute's Entrance Board will make the final decision in May. The Academy of Finland supports persons who from the very start complete their doctorate at the EUI. Researchers who are admitted to the Institute's doctoral programme shall apply to the Academy of Finland for a grant for researcher training abroad either online or using the Academy application form. The monthly grant awarded to the postgraduate researcher is 1,600 euros. If the researcher has under-age children, the grant is 2,000 euros a month. The researcher's and any accompanying family members" travel costs shall also be remunerated.

Bilateral Agreements

The Academy of Finland awards funding for research cooperation and to support the mobility of researchers with the following countries: Argentina, Belarus, Bulgaria, China (including Taiwan), the Czech Republic, Estonia, Germany, Hungary, India, Iran, Japan, Latvia, Lithuania, Poland, the Republic of Korea, Romania, Russia, Slovakia, Slovenia, and Ukraine. Applications for all other types of subsidy, except for joint research projects with Japanese and Chinese researchers, shall be filed between 30 August and 30 September 2005. Subsidy for joint research projects can be applied in connection with the application round for general research grants (30 April-13 May 2005). Regarding funding promoting researcher mobility, applications shall be filed by the researcher travelling abroad or by the researcher inviting a foreign researcher to Finland. The applicant is required to have at least a higher academic degree. An invitation or a statement of acceptance from the receiving institution is necessary. Since the aim is to promote researcher training and to support joint research projects, priority is given to applicants who are currently in researcher training and/or who have recently earned their doctorate or who carry out joint research projects.

Foreign researchers in Finland

Foreign researchers may be hired to work on all projects funded by the Academy of Finland. If this is associated with a research project, funding shall be applied for in connection with the application for project funding. A university or a research institute may apply for a separate grant for the work of a foreign researcher in Finland when the visiting researcher is actively involved in the research team and provides scientific instruction. The funds are usually awarded in the form of a grant for a minimum of three months or a maximum of twelve months of work. In addition, funds may be granted for research expenses and travel costs and for the travel costs of accompanying family members if the visit lasts more than six months. The grant period must not exceed one year. The funding period begins immediately upon the decision, or according to agreement. Applications shall be submitted by the university or institute inviting the foreign researcher. They may be submitted at all application times.

Subsidy for a researcher's return to Finland

This subsidy may be granted for purposes of covering the salary costs of a Finnish researcher who has been engaged in research abroad for at least two years without interruption and who has no employment contract in Finland. The purpose is to advance these researchers' careers by supporting their commitment to the Finnish research community. Applicants are required to have the permission of the receiving Finnish institution to work at the institution for a fixed period. The institution will also be responsible for providing the basic facilities required by the researcher. The subsidy is intended for covering salary costs only. Funding for other research expenses may be applied in connection with the May round of applications for general research grants.

Other Finnish and international organisations

Centre for International Mobility

CIMO grants scholarships to Finnish and foreign university students, postgraduate students and researchers as well as to scientific and cultural experts. Scholarships are granted for studies, postgraduate studies and research work in Finland and abroad. Finnish university students, researchers and experts in arts and different scientific fields can apply for scholarships that are intended for studies and specialisation abroad. CIMO offers scholarships to the following countries: Australia, Austria, Belgium, Bulgaria, the Czech Republic, China, Denmark, Egypt, France, Germany, Greece, Holland, Hungary, India, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, Mongolia, Norway, Portugal, Poland, Romania, Slovakia, Spain, Sweden, Switzerland and Turkey. CIMO also administers the Nordic Council of Ministers" scholarship programme to the Baltic states and North-western Russia.

Foundations

Several Finnish and foreign foundations support researcher mobility such as the British Wellcome Trust.

Support from Nordic organisations

The objective of the Nordplus programme is to provide wide and intensive cooperation between Nordic universities and to promote teachers' mobility. The Nordplus programme provides students' mobility grants, teachers' grants, grants for short-term visits by other staff, joint courses and participation in courses.

NordForsk, Nordic Research Board, is a new Nordic research institution, established on January 1 2005. From the same time, NorFA has become part of NordForsk. NordForsk is an independent institution operating under the Nordic Council of Ministers responsible for Nordic cooperation within research and research training. NordForsk during 2005 is expected to distribute grants of NOK 60 - 70 million for Nordic co-operation in research and research training, including activities earlier funded by NorFA. Projects that apply for funding from NordForsk should include at least three Nordic countries (Denmark, Finland, Iceland, Norway and Sweden) or autonomous areas (the Faroe Islands, Greenland and the Aland Islands). Many NordForsk activities are open to all countries in the Nordic region, which in addition to the Nordic countries includes the adjacent areas of Estonia, Latvia, Lithuania and North-Western Russia. Research training environments in these adjacent areas are offered the opportunity to take part in NordForsk activities both at institutional and personal levels.

Support from European and other international organisations

For example, British Council, Marie Curie Fellowships, Max Planck Gesellschaft, Fullbright Center, National Science Foundation.

Source: Academy of Finland (2005b)

Table A17: SWOT analysis of the internationalisation of Finland's R&D activities

Strengths	**Opportunities (and means)**
- Finland has become an active partner in international co-operation quite recently but rapidly: currently, a very high rate of participation in the activities of international organisations - Science, technology and innovation policy has been implemented on a long term basis; investment in R&D is regarded as important - Well-functioning education, research and innovation systems - Openness, intensive co-operation and competitiveness of the innovation system - A high share of competitive R&D funding - A high level of education among the population - Brain-drain relatively small - A high share of women among researchers and PhDs by international standards - A well-functioning graduate school system - A large number of researchers and their share of the employed high - Research volume, quality and impact at a good international level - Active international patenting - Finland has a good reputation: reliable, safe - Large-scale participation in EU research programmes by R&D organisations - Research and knowledge-intensive business has remained in Finland - Good co-operation between business enterprises and public research - Business enterprise R&D have rapidly increased from the mid 1990s onwards - Finnish enterprises are internationally networked.	- The effective and efficient national innovation environment boosts competitiveness - Enhancing the knowledge base and R&D environment attracts new foreign investments and intellectual resources (international excellence) to the country and improves Finland's position as an attractive region for business operations - Looking for competence where it is best: global and diverse international co- operation, going beyond the EU - Compensating for the small size and geographical remoteness with active, strategically sound co-operation policy - Prioritised pooling of limited, fragmented resources - Open-minded and sufficient support for creativity and innovation - Enhancing foresight activities and their linkage with decision-making and strategic steering - Implementing and productising social innovations - Enhancing positions in international co-operation institutions and R&D organisations - Improving the organisational and functional structure of the innovation system and the division of tasks; internationalising activities and organisations within the system - Developing business and marketing competence - Increasing the number of foreign researchers and students - Creating a favourable business environment and promoting entrepreneurship - Supporting the creation and growth of businesses that focus on R&D and exploitation of leading-edge expertise
Weaknesses	**Threats**
- A small domestic market area and population - Economy strongly dependent on global and EU trends - Remote from global market centres, geographically distant from the centres of Europe - A small language area and severe climate - A relatively low level of internationalisation by European standards - Limited economic and intellectual resources: a low volume of knowledge and competence in many fields, the cutting-edge of scientific research in the hands of a select few - Problems with venture capital (amount, availability, matching of demand and supply) - Deficiencies in marketing and business competence and knowledge and innovation management - Few spin-off businesses from universities and research institutions - Fragmented research activities: resources allocated to a large number of small units - A small number of foreign students and researchers - The number of foreign highly-educated experts and their share of the labour force are small - Businesses (including R&D-intensive operations) are moving abroad - Instability of business R&D spending in recent years - The inflow of foreign direct investments is low (in relation to GDP); a negative balance of investment.	- International economic recession and continuous decline in Europe - Finland does not attract foreign direct investments, R&D investments, researchers and students - Finland less active in the EU and global R&D co-operation - The operational foundations of the EU become weaker: more internal conflicts, less commitment and co-operation - National interests are overemphasised in international co-operation - Focus still missing: participation in too many projects with scarce resources - International co-operation is steering national decisions too much and consumes resources - The links between research, economic development, employment, well-being and innovations become weaker - Diminishing age groups and aging population undermines the balance of the public economy and the room for economic manoeuvre - The regulatory framework does not support the transfer of research results from R&D organisations to businesses and the commercialisation of results - Availability of competence in the labour market is insufficient: education does not meet labour market needs - The number of new R&D-intensive businesses declines - The favourable development of public R&D funding stagnates - Business R&D expenditure starts to decline - Businesses increasingly move their operations abroad - Brain drain increases: high competence moves abroad.

Source: Science and Technology Policy Council of Finland (2004), p. 5

Table A18: Researcher mobility programs in the United States

Foreign graduate (including doctoral) students

Home-Country Source: Government scholarship programs, regional assistance programs, local or third-country organizations or businesses, banks, or religious institutions that may offer aid to graduate students.

U.S. Government Assistance: The Fulbright Program, founded to encourage mutual understanding between the people of the United States and other countries, offers awards for graduate study. There are many different types of awards, from travel grants to grants that pay maintenance and study costs; their availability varies from country to country. Applicants must apply to and be approved by appropriate agencies in the home country. In some developing countries, support for short-term graduate study or master's level degree study may be available through programs sponsored by the U.S. Department of State. Eligibility for these programs varies, but in general, local institutions nominate employees for training or education that promotes a specified development goal. Some scholarship programs operate on a regional basis. In sub-Saharan Africa, for example, the U.S. Agency for International Development (USAID) funds a program called ATLAS - Advanced Training for Leadership and Skills.

Private U.S. Sources and International Organizations: Private U.S. agencies, foundations, business corporations, and professional associations often award financial aid in the interest of furthering international exchange. International organizations such as the United Nations and the Organization of American States (OAS) are other possible sources of financial aid. Many awards and grants are directed toward particular groups such as women, engineers, or journalists. Greater foundation support usually is available for students in the social and natural sciences and in the humanities.

U.S. Universities: About one third of international graduate students finance their studies through financial aid from U.S. universities. However, availability of financial assistance varies by field of study, level of study, and type of institution (research universities are likely to have the most funds available). Also, some universities will give aid to students only after they have successfully completed their first semester or first year of study. Also, all students, including international students, are required to pay U.S. income tax on certain forms of graduate financial assistance. The main types of financial aid available from universities are as follows:

Fellowships: Departments and institutions award fellowships on the basis of academic merit, normally after the first year of study. Graduate fellowships may be modest, covering only tuition and fees, or full grants, providing the cost of tuition, fees, and monthly stipends for maintenance. Fellowships rarely cover the total cost of living and studying.

Assistantships: Assistantships are the most common form of financial aid at the graduate level. Assistantships are cash awards that require the performance of services related to the field of study, usually about 20 hours per week. Sometimes an assistantship carries with it a waiver (a remission or reduction) of tuition and fees. Awards may range from as little as $500 to as much as $30,000 (or higher, if high tuition costs are waived) for an academic year. Competition for all types of assistantships is intense, since only limited numbers are available at any one institution. International applicants must compete with U.S. students. In general, doctoral students are more likely to receive support than master's candidates. Most awards for graduate study are made one year at a time. Renewal is not automatic and depends on performance and the availability of funds. There are several types of assistantships:

- *Teaching assistantships* may be available for the first year of graduate study in university departments with large numbers of undergraduates in introductory courses. Teaching assistants (TAs) supervise undergraduate laboratory classes, lead discussion groups, or teach small classes. Increasingly, universities require that applicants achieve a high score on the Test of Spoken English (TSE) before receiving a teaching assistantship. Often universities require teaching assistants to complete training programs that prepare them to teach in the U.S. educational milieu.
- *Research assistantships* involve performance of research services related to the field of study. The advantage of a research assistantship is that it can be related to the thesis or long-term academic interests. Research assistants (RAs) are chosen for their demonstrated research and interpersonal skills. Computer ability, writing skills, and experience working as part of a team are three essential qualifications.
- *Administrative assistantships* usually require 10 to 20 hours per week working in administrative offices of the university, such as the International Student Office.

Employment: Other types of aid for full-time students include part-time employment on campus of up to 20 hours per week. Present U.S. immigration regulations restrict employment outside the university or both international graduate students and their spouses; in many instances, spouses cannot engage in any kind of employment, on or off campus, throughout the entire period of study. On-campus employment is limited and competitive, and the relatively low salaries do not cover the cost of tuition and living expenses. In addition, graduate students are often so involved with their academic work that they do not have the time required for a part-time job. Employment in the United States cannot be used to demonstrate how you will pay the costs of study when applying for a student visa.

Loans: A few reputable agencies make loans available to international students.

Foreign scholars

The Fulbright Visiting Scholars Program: Under the auspices of the Fulbright Program, international senior scholars come to the United States to do a year of research or to lecture at U.S. academic institutions. U.S. scholars also travel outside the United States on this program. The U.S. Department of State funds and administers the Fulbright Program; however, many other countries also share in the funding. Approximately 120 countries around the world participate in the Fulbright Program, and the program operates differently in each country. The Fulbright Program is an open competition for which scholars apply through the local Fulbright Commission, the U.S. Educational Foundation, the public affairs section of the U.S. embassy, or other designated office. After preliminary local selection, recommended applications are forwarded to the U.S. Department of State and the J. William Fulbright Foreign Scholarship Board in the United States for final approval. The Council for the International Exchange of Scholars (CIES) in Washington, D.C., assists with the implementation of the program by arranging university affiliations for senior Fulbright scholars at U.S. academic institutions. Once scholars are in the United States, CIES assists in program administration and support.

The Hubert H. Humphrey Fellowship Program: The Hubert H. Humphrey Fellowship Program, also administered by the U.S. Department of State, provides opportunities for a year of study in the United States for accomplished midlevel professionals from developing countries around the world. The Humphrey Program awards fellowships competitively in the fields of natural resources and environmental management; public policy analysis and administration; law and human rights; finance and banking; economic development; agricultural development/ economics; human resource management; urban and regional planning; public health policy and management; technology policy and management; educational planning; communications/journalism; and drug abuse epidemiology, education, treatment, and prevention. Fulbright Commissions, U.S. embassies, and binational centers nominate candidates. The Institute of International Education (IIE) reviews nominations with the assistance of independent selection committees and makes recommendations to the J. William Fulbright Foreign Scholarship Board, which approves final selections and awards fellowships. In contrast to many fellowship opportunities, the Humphrey Program does not have as its goal the attainment of a degree. Rather, in cooperation with Humphrey Program coordinators on college and university campuses, fellows devise individually tailored plans for their one-year program, combining academic work with professional development and internship activities.

College and University Affiliations Program: The U.S. Department of State's College and University Affiliations Program provides three-year grants to partnerships formed by higher education institutions in the United States and abroad to conduct exchanges of faculty members in the humanities and social sciences.

University Invitational Positions: University departments often have invitational positions, usually to be held for one year, for visiting scholars, researchers, or lecturers. U.S. universities normally provide a salary and, in addition, may provide research facilities.

Other Arrangements: Scholars and researchers anticipating a sabbatical or wishing to conduct research in the United States often learn of opportunities by speaking or corresponding with colleagues in the same field or by attending professional meetings. Professors may also learn of colleagues with similar research interests from former students who are in the United States, from U.S. university faculty or administrators who are visiting the country, through e-mail discussion lists in their academic area, or from papers in scholarly journals. Sometimes scholars and researchers negotiate directly with a department or research center. The probability of arranging a research sabbatical in the United States is higher in business, scientific, and technological fields than in the humanities, social sciences, and the arts.

Obtaining Funding: Arrangements for funding visiting researchers and scholars vary greatly. Often the scholar's home institution pays a regular salary while the scholar is on sabbatical. Occasionally, scholars come to the United States using their own funds. Some foundations and organizations provide grants to support scholarly research in the arts, sciences, humanities, and health-related fields. Although competition is intense, foreign nationals as well as U.S. citizens are often eligible to apply. Grant proposals are generally reviewed by a committee of people active in the field, who are selected by the donor organization. Usually the grant is for a specific amount and supports research at a particular facility or center. Many grant applications specify that scholars present not only a research plan, but also an agreement with a research institution before they will fund a grant. Usually such arrangements arise through personal correspondence between the people involved. There is no central source for information of this type.

U.S. graduate (including doctoral) students and postgraduate researchers

Alexander Von Humboldt Foundation: Fellowships for Applicants in Germany, Fellowships for Applicants Outside Germany, German Chancellor Scholarships for U.S. Scientists and Scholars, Post-Doctoral Fellowships for U.S. Scientists and Scholars, Summer Research Fellowships for U.S. Scientists and Scholars, Research Awards for Outstanding and Internationally Recognized Scholars of All Disciplines and Nationalities

American Academy in Rome: Rome Prize - Pre- and Postdoctoral Fellowships for Gifted American Artists and Scholars.

Academy for Educational Development: National Security Education Program (NSEP): David L. Boren Graduate Fellowships for the Study of Languages, Cultures and World Regions that are Critical to U.S. National Security, Including Study Abroad

American Councils for International Education: Undergraduate and Graduate Programs in Languages and Area Studies in the Newly Independent States (NIS) of the Former Soviet Union (Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan)

American-Scandinavian Foundation: Fellowships and Grants for Study in Scandinavia

American School of Classical Studies at Athens: Graduate Fellowships

Atsumi International Scholarship Foundation: Atsumi Graduate Scholarships Tenable at Schools Located in the Kanto Area in Japan

Australian Research Council: Federation Fellowships

Bill and Melinda Gates Foundation: The Gates Cambridge Scholarships, The Gates Award for Global Health

British Council – United States: Educational Opportunities at All Levels

Eisenhower Exchange Fellowships: USA Program

The European Commission: Marie Curie Fellowships

Ford Foundation: International Fellowships Program (IFP) for Formal Graduate-Level Study

Foreign and Commonwealth Office, United Kingdom: British Chevening Scholarships for Overseas Students to Study in the United Kingdom, British Marshall Scholarships, Commonwealth Scholarships and Fellowships for Men and Women from all Commonwealth Countries

German Academic Exchange Service: Funding Opportunities and Scholarships

Henry Luce Foundation: Stipends and Internships for Young Americans to Live and Work in Asia

International Institute for Applied Systems Analysis (IIASA): Luis Donaldo Colosio Pre- and Postdoctoral Fellowships for Mexican Citizens, Postdoctoral Fellowships, Young Scientists Summer Program

KCC Japan Education Exchange: Fellowships for Graduate Students Who Have a Record of Teaching Effectively about Japan

Kosciuszko Foundation: Competitions, Grants and Scholarships

Maureen and Mike Mansfield Foundation: Mike Mansfield Fellowships for U.S. Federal Government Employees to Develop an In-Depth Understanding of Japan

Organization of American States (OAS): Graduate Fellowships, Leo S. Rowe Pan American Fund Student Loans

Radiochemistry Society: International Undergraduate Scholarships and Graduate Fellowships for Full-Time Students World Wide

Rhodes Scholarship Trust, Oxford University: Rhodes Scholarships

Robert Bosch Foundation: Graduate Fellowships for Study in Germany for Students in Business Administration, Economics, Journalism and Mass Communications, Law, Political Science and Public Affairs/Public Policy

Rotary Foundation: Ambassadorial Scholarships

Social Science Research Council (SSRC): International Dissertation Field Research Fellowships

Thomas J. Watson Foundation: Thomas J. Watson Fellowships for Study Abroad by Graduating Seniors

U.S. Department of Education: Foreign Language and Area Studies Graduate Fellowships, Fulbright-Hays Doctoral Dissertation Research Abroad Program in Modern Foreign Languages and Area Studies, International Education and Graduate Programs

U.S. Department of State: Fulbright and Related Grants for Graduate Study and Research Abroad for U.S. Citizens, Fulbright Postdoctoral Fellowships for U.S. Citizens

U.S.-Ireland Alliance: George J. Mitchell Scholarships for Graduate Study in Ireland

U.S. National Science Foundation (NSF): Opportunities for Graduate Students Who Are U.S. Citizens or Permanent Residents Enrolled at U.S. Institutions, MPS Distinguished International Postdoctoral Research Fellowships in Mathematics and Physical Sciences, International Research Fellowships, NSF-NATO Postdoctoral Fellowships for Scientists from NATO Partner Countries

Winston Churchill Foundation: Winston Churchill Scholarships for a Year of Graduate Study in Engineering, Mathematics, and Science at Churchill College, Cambridge University

World Bank: Japan/World Bank Graduate Scholarships in Subjects Related to Economic Development, Robert S. McNamara Postdoctoral Fellowships in Socioeconomic Development

Source: Education USA (2005) and Tomei (2005)

Table A19: Australian Research Council (ARC) postdoctoral fellowship and award schemes

The Australian Research Council (ARC) funds research fellows under Discovery, Linkage and Centre programs within the National Competitiveness Grants Programs:

Australian Postdoctoral Fellowships (APD) provide opportunities for researchers at the postdoctoral level to undertake research of national and international significance, and to broaden their research experience. Australian Postdoctoral Fellowships are available to researchers with up to three years research experience since the award of the PhD or equivalent research doctorate.

Australian Research Fellowships (ARF) and Queen Elizabeth II Fellowships (QEII) provide opportunities for established researchers to undertake research of national and international significance. Australian Research Fellowships (ARF) and Queen Elizabeth II Fellowships (QEII) are available to researchers with 3 to 8 years research experience since the award of the PhD or equivalent research doctorate. QEIIs encourage research in Australia by postdoctoral graduates of exceptional promise and proven capacity for original work. ARC Centre Fellowships (ACF) are also available under the ARC Centres of Excellence Scheme.

Australian Professorial Fellowships (APF) provide opportunities for outstanding researchers with proven international reputations to undertake research that is both of major importance in its field and of significant benefit to Australia. Australian Professorial Fellowships (APF) are available to researchers with more than 8 years research experience since the award of the PhD or equivalent research doctorate.

Federation Fellowships (FF) are designed to attract and retain in key positions in Australia researchers of the highest international standing. Preference will be given to Australian citizens, currently working in Australia or abroad. However, up to five of the fellowships each year may be awarded to high-profile non-Australian researchers from overseas. Up to 125 Federation Fellowships with a standard tenure of five years were funded under *Backing Australia's Ability* in 2001. In 2002, 25 fellowships with a salary of $225,000 each year for five years (totalling $1.125 million for the life of the fellowship) were awarded.

The **Discovery Indigenous Researchers Development Scheme** aims to develop the research expertise of Indigenous Australian researchers to a level that is competitive with that of other researchers applying for mainstream research funding. Funding is made available for research projects, training in research methods and preparation of research applications. Funding may be sought either as a chief investigator or as a Research Cadet-Aboriginal and Torres Strait Islander. Cadetships enable Indigenous researchers who have completed their doctorate studies to establish research track records strong enough to equip them to compete for APD. Grants are awarded for one to three years while the cadetship is for one or two years" full-time employment on an approved project.

Salaries for **Australian Postdoctoral Fellowships Industry (APDI)** are funded as part of linkage projects involving collaborative research projects between higher education researchers and eligible partner organisations (primarily private industry). Research grants under Linkage Projects may be awarded for one to five years. In 2004, Linkage Industry Fellowships were awarded for the first time. These fellowships provide support for the costs involved in a temporary transfer of a researcher from a higher education institution to a partner organisation or vice versa for a period of three to 12 months.

Linkage Australian Postdoctoral Fellowships (CSIRO) provides a training opportunity which exposes early career researchers to the strategic research framework within which the Commonwealth Scientific and Industrial Research Organisation (CSIRO) operates, as well as the fundamental research framework of university research. Linkage-APD (CSIRO) offers salaries for postdoctoral researchers working in collaborative teams of researchers from one or more universities and one or more CSIRO divisions. The scheme is co-funded by the ARC and CSIRO. Applications were sought in 2002 for this pilot scheme but no funding rounds were conducted in 2003 or 2004.

Linkage International supports movement of researchers between Australian research institutions and centres of research excellence overseas. It supports two types of grants: Fellowships under international agreements for the reciprocal exchange of postdoctoral and senior researchers (i.e. France, Germany and South Korea); and awards to build links between research centres of excellence in Australia and overseas by funding extended collaborations.

Source: ARC (2005a) and (2005b)

Table A20: Summary of R&D work of 30 research students

RMIT University: Department of Biotechnology and Environmental Biology

Student 1: Development of a vaccine for the prevention of necrotic enteritis in poultry

Necrotic enteritis (NE) is a disease that affects poultry world wide. The etiological agent of the disease is the bacterium *Clostridium perfringens*. This bacterium is commonly found in the lower intestines of fowl and is well known for its multitude of toxin proteins. One of these, alpha cytotoxin, initiates the infection and is responsible for tissue destruction observed during outbreaks of necrotic enteritis. To date, an effective vaccine to combat the disease has been unsuccessful. Current treatment of the disease involves antibiotic supplementation. There has been a public backlash because of the use of antibiotics in food animals. The possibility of bacterial resistance to antibiotic treatment also exists.

The objective of this research is to develop a vaccine targeting the alpha cytotoxin of *C. perfringens* to combat necrotic enteritis and thus eliminate the disease from the fowl population. The vaccine proposed will be directed against the alpha toxin of *C. perfringens*. This has involved developing three vaccines based on the truncated toxin gene: toxoid treatment, a traditional method for protecting organisms against lethal toxins; an attenuated vaccine delivered via salmonella; and DNA vaccine, where vectors containing eukaryotic promoters and the antigen of interest are delivered to certain cells via indirect injection of DNA or by using a carrier such as an aro salmonella mutant. The efficiency of each vaccine will be evaluated via challenge trials and an enzyme-linked immunosorbent assay (ELISA) measuring immunoglobulin and cytokine levels. This research will also allow for further investigation into the possibility of developing a multi-valent vaccine targeting many more of the pathogens affecting poultry. This in effect will result in many cost cuts in the current prevention of many poultry diseases.

Student 2: Examining the major causes of mastitis in dairy cows to develop a rapid diagnostic test

Mastitis is an inflammatory disease of cow mammary glands that reduces milk yield and leads to poor quality milk at a cost to the Australian dairy industry of more than $130 million per year. Mastitis is usually caused by bacteria entering the teat canal to the udder where they multiply and cause infection. *Streptococcus* spp. including *S. agalactiae*, *S. dysgalactiae* and *S. uberis* are major causes of mastitis. Veterinary laboratories currently use a range of biochemical tests and serotyping to identify the different *Streptococcus* spp. Conventional methods are protracted and labor intensive employing up to 20 biochemical tests that require 3 to 7 days incubation for a final result, serogrouping is expensive and both can lead to misidentification. Molecular identification of bacterial species using DNA based testing is proving to be both rapid and accurate and the technology readily adapted for use in diagnostic laboratories.

This research is characterising *Streptococcus* spp. that cause mastitis using species-specific genes. The key outcome will be the development of improved diagnostic tests for the detection of mastitis pathogens. The development of rapid, robust and cheap molecular tests using species-specific DNA sequences will allow timely identification of species of streptococci that differ in pathogenicity and provide information for appropriate treatment and control of mastitis.

Student 3: Bacterial germ, *Campylobacter*, in the paralytic disease Guillian Barré syndrome

The bacterial germ *Camploybacter* is the leading cause of gastroenteritis or diarrhoea throughout the world, particularly in developed countries like Australia, the U.S., Canada and many European countries. There is ample evidence that the germ is transmitted through undercooked poultry products, sausages and related products. Research in many countries found that up to 98% of commercially available chicken is contaminated with *Campylobacter*. *Campylobacter* is very sensitive to heat so if the chicken is cooked properly the germ will die and won't infect any person. However, when chicken is barbequed, the exterior appears brown (and cooked) but the interior is still raw and the bacterium still survives the heat process. It is then transmitted to the human system and causes diarrhoea. In some situations, this bacterium has been associated with the development of a paralytic disease called Guillain-Barré syndrome (GBS) which causes severe and sometimes fatal paralysis. In the post-polio era GBS is the most common paralytic disease and *Campylobacter* has become the most common cause of GBS. Affected people have been unable to work for up to two years, and the disease has led to the deaths of old people, young children and infants, and people with an immune system that isn't quite functional, such as people with AIDS. It's become a major health and economic burden.

This research is mainly focused on discovering how *Campylobacter* causes Guillain-Barré syndrome. This has involved researching the virulence factors and examining the genetics of this bacterium in order to determine how it causes this syndrome and paralysis. The findings will allow researchers to devise treatments and curative strategies like drugs and vaccines.

Student 4: Genes in grasspea controlling resistance to fungal disease, *ascochyta blight*

Field pea is the second most important pulse grown in Australia in terms of area sown and the volume of production. The grain is marketed as a source of high protein for livestock and human consumption, and the crop is important in cropping management as it is rotated with cereals and canola as a means of controlling diseases and weeds. The nitrogen-fixing capacity of field pea assists in maintaining soil fertility is an added benefit to including field pea in the cropping system. A major limiting factor in achieving higher yields of field pea in Australia is the fungal disease, *ascochyta blight*, caused primarily by *Mycosphaerella pinodes*. This disease leads to leaf, stem and pod lesions, as well as root rot. In Australia, yield losses of 15% are common. Extensive research to identify sources of resistance in field pea has failed to produce commercial cultivars with effective resistance to *M. pinodes.* However, resistance to *asocochyta blight* has been reported in the closely related grass pea (*Lathyrus sativus*). Although it is known how many genes may be responsible for resistance to the fungal disease in grasspea, the location of these genes and how these genes act in grasspea are unknown.

This research involved finding out how many genes are involved in resistance to *ascochyta blight* in grasspea, what genes control resistance to *ascochyta blight* in grasspea, and what are the mechanisms of resistance to *ascochyta blight* in grasspea. This involves mapping the grasspea genome and locating genes/regions that were responsible for conferring resistance to ascochyta blight. This topic is an extension of research started over a decade ago to identify the genes that control resistance in field peas. It aims to contribute in the longer-term to a more resistance field pea crop.

Student 5: Examining the whole genome response in plants to auxinic herbicides

Auxinic herbicides have been widely used to kill weeds, but many aspects of their mode of action remain unknown. This research is determining the mode of action of these auxinic herbicides at a molecular level. It will lead to an understanding of how various biochemical pathways in the plant change on exposure to herbicide 2,4-D and other widely used auxinic herbicides. The small flowering plant, *Arabidopsis thaliana* (is a member of the mustard family which includes cabbage and radish) has been chosen for the study as it is a model organism for studies at molecular levels. The microarray technique is being used to analyse the effects of 2,4-D herbicide on gene expression of this plant. Microarray analysis is a very fast technique as it can determine the expression level of a large number of genes at once.

Findings should enable the development of better weed management techniques. A crop plant of interest may be genetically modified in such a manner that it is not affected by the herbicide. The results are expected to be the basis for developing novel herbicides with a targeted mode of action for killing weeds at low concentrations with a fast mode of action without causing harmful effects to the environment. This research is being undertaken in collaboration with one Australia's largest crop protection company.

RMIT University: Department of Geospatial Science

Student 6: Representation models for the delivery of useful, interactive geospatial information services via the mobile Internet

Geospatial data can now be accessed over a telecommunications network using portable, online wireless devices, including mobile cellular phones and Personal Digital Assistants. The information delivered via these devices is limited by the physical constraints such as screen size, resolution, bandwidth, processing and storage but also by the potential context of use (literally "anywhere, anytime"). This necessitates careful consideration in presenting the user with only the most relevant information, based on time and location.

Location-Based Services (LBS) is the term used to describe this new form of geospatial information, having emerged as a result of recent advances in, and the convergence of, wireless communications, Internet-enabled mobile devices, positioning technologies and Geographical Information Systems (GIS). Using the derived location of a device, LBS deliver applications that exploit geographic information regarding the user's surrounding environment, their proximity to other objects in space and/or distant objects. Although the challenges of this new medium for the representation and presentation of geospatial information, and its interactive use, have been recognised, very little published material deals extensively with the methods for doing so.

This research is employing user-centred design techniques to develop representation and interaction models for the optimal delivery of location-based geospatial information services, via wireless handheld devices, for the purposes of Australian travellers. To date the studies concerning LBS have been based on European users and have concentrated on the technical aspects of applications for city-based tourism. The choice of Australian travellers for this research will provide a focus on the uniqueness of travel within our own vast country. In doing so it will address the interests and representation needs of average Australians, and may possibility have implications for the global market. Another key outcome of this research to the LBS industry will be the provision of guidelines for optimal representation, presentation and interaction techniques.

Student 7: Data integration – an application in rural property valuation

Current methods used to appraise property involve the comparison of other similar properties within an area and deals with locational, physical, social and economic factors. In rural areas, land size, soil type, crop production, irrigation, and distance to transport services are some of the key factors that influence property value. In addition, water and wind erosion, dryland salinity, fire, flood, drought and pest plants and animals can pose serious problems to agriculture production and to the future capabilities of the land. This research aims to utilise a database created from various data sets to determine a valuation estimate for rural properties in the Wellington and Wimmera catchment management regions of Victoria. Regression techniques will be utilised to obtain coefficients for each property variable and these will be tested to determine the level of price explanation in the developed regression equations.

The use of a more automated approach to determine a property value within the rural community may lead to a time saving on current valuation techniques and possibly a higher degree of accuracy in the prediction of that value. This research aims to develop more advanced integration techniques and a property valuation tool to determine and re-evaluate the value of a rural property over different stages throughout the term of a loan. The ability of a tool to interpret answers to questions, arrive at a value and report on the degree of accuracy of the prediction is beneficial to the finance and business industries.

Numerous data sets are required to develop a tool to forecast rural property values. However, the use of multiple scale data and integration of these to a common scale, incomplete or inaccurate data sets or differences in storage formats are some of the data integration problems that may arise during development of this tool. This research will develop a framework, which describes the concepts of the integration, including a set of techniques and methodology, to address those problems that may arise with the synthesis of often numerous, disparate and sometimes large data sets.

Student 8: Creation of a predictive model for salinity risk in the Murray Valley Irrigation Region of New South Wales

The Murray-Darling Basin spans four states in eastern Australia and extends over 1.06 million square kilometres, or 14% of Australia. It includes much of the nation's best farmland, but is a naturally saline environment in terms of the soils, geology, surface water and ground water. Land use changes since European settlement, particularly land clearing and irrigation, have resulted in greater volumes of water percolating to the water table, dissolving the salts and bringing them to the land surface and into the rivers. In the Berriquin-Denemein Irrigation District (within the Murray Valley Irrigation Area of southern New South Wales) the water table has risen on average 27 cm per year. In 1987 it was estimated that 96,000 hectares were affected by saline soils and this is predicted to rise to 1.3 million hectares by 2040. The amount of salt mobilised in the Murray River valley is expected to rise from current levels of 190,000 tonnes to 290,000 tonnes per annum by 2050. The widespread salinisation of productive agricultural land incurs substantial economic costs to the community and the nation through lost agricultural production and damaged infrastructure.

A strong research effort has occurred in mapping and predicting soil salinity, particularly using remote sensing. Remote sensing, together with other spatial data sources, can be used to map and predict soil salinity as well as other key features such as irrigated land or salt affected soils. However, predictive modelling for salinity in irrigation regions of Australia has been limited to a few localised irrigation districts. Previous research has indicated the potential for such a model over the whole Murray Valley Irrigation Region. This research aims to build a Geographical Information Systems (GIS) based predictive model for salinity risk. The risk model considers variables such as groundwater salinity, elevation, groundwater depth and the change in groundwater in estimating the risk of salinisation. Predictive capability for the risk model is derived from a regression based model for groundwater within the irrigation districts. The groundwater model provides estimates of the predicted groundwater depth and the predicted change in groundwater. These estimates are then used in the risk framework. One of the main advantages of the risk framework is its flexibility, with the capability to facilitate outputs from simple or complex groundwater models as well as salt transport models, depending on the level of detail required in the modelling and the available data.

Student 9: Creating sustainable cities – the role of green systems and biodiversity in urban environments

Green systems play an important role in improving urban environment quality by reducing noise, increasing air and water quality, protecting biodiversity, protecting water corridors, creating micro-environment, and upgrading social values of the built environment. Sustainability of the built environment is regarded as a global issue, and the environmental problems and approaches to the sustainable environment are different in various regions in the world. Although Australia is one of the most urbanised countries in the world (with 85% of its population living in urban areas), its governments have developed few approaches to achieving a sustainable built environment. The rate of urban growth has resulted in severe environmental and social consequences which threaten the quality of life currently found in Australian towns and cities.

This research selected Metropolitan Melbourne as a case study for its diversity of the parks and waterways, and their importance in the history of urban development in the region. It examined the history of selected green systems in Melbourne to determine their ecological, environmental and cultural contributions to the built environment to the region. To do this involved collecting data from organisations and research institutes, such as Melbourne City Council, Department of Infrastructure, Department of Natural Resources and Environment, and the Australian Research Centre for Urban Ecology. As part of the literature review, the concept of metabolism, its use in the sustainable built environment, and its relationship with green systems were investigated. The literature includes contemporary theory and practice on sustainable urban development, metabolism of urban settlement, organic city and garden city, studies on parks, waterways and biodiversity, town planning and urban design. Major environmental problems and approaches in sustainable built environment all over the world were also reviewed.

Overall, this research is developing an approach to advance the goal of sustainability. It is hoped that metabolism of the sustainable built environment and the role of green systems and biodiversity in the region of Metropolitan Melbourne can be better understood through this historical and comparative study. Also it is anticipated that the protection and vitalising of current green systems and biodiversity, and developing new green systems using natural resources can be regarded as an important means to achieving a sustainable built environment. These changes should improve the quality of life of residents in Melbourne and other urban settings in Victoria.

Student 10: Development of a miniaturised real time kinematic GPS system with high accuracy, velocity and acceleration

The Global Positioning System (GPS) is a space-based radio navigation system that provides a 24 hour three-dimensional position, velocity and time (PVT) information to suitably equipped users anywhere on or above the Earth's surface. While high precision real time kinematic (RTK) GPS systems have been widely applied in land surveying, they have the potential to also be used for position, velocity and timing related applications. A typical RTK system requires a base station to broadcast RTK correction messages to a rover receiver via a wireless data link. The rover calculates its precise position while moving, using these corrections applied to observations it makes directly from the GPS satellites. In typical RTK applications, the system is designed with the rover calculating, recording and otherwise utilising its position. It is evident that some applications would benefit from an "inverted" or reverse dataflow RTK system, whereby the rover transmits raw observations to the base station and the base station determines the rover's position on-the-fly. In such applications, high precision real time velocity and acceleration is equally, if not more, vital than position itself. System miniaturisation, low cost, and a high output data rate are also required in many such applications. Such "remote monitoring" applications challenge the receiver hardware, telemetry and algorithms used in current RTK systems.

This research aims to develop an innovative, compact GPS speedometer and accelerometer with state-of-the art accuracy and performance at low cost. This RTK system with inverted data-flow option, and the functionality to determine velocity and acceleration at the same time as position, is not available in the current GPS market. This kind of system could have widespread use in industry and the public sector where accurate, real-time remote monitoring at a base station or in the office of a moving object is required. The industry partner, the Australian Institute of Sport, believes his research will contribute significantly to the development of an intelligent, low-cost, miniaturised and reliable athlete monitoring system to be used by Australian athletes.

University of Oulu: Centre for Wireless Communication

Student 1: ***Physical layer issues of ultra wideband systems***

Ultra wideband (UWB) radio communication utilises huge frequency band to transfer information between the transmitter and receiver. The used bandwidth is much larger than is needed for the transmission of the information signal. The Federal Communications Commission (FCC) in the United States limits the use of UWB technology to imaging systems, ground penetrating radar systems, through-wall imaging systems, surveillance systems, medical systems, vehicular radar systems, and communications and measurement systems. The same regulations also specify the allowable frequency bands and power levels for each application. The FCC will reconsider these regulations after more co-existence studies are available. The European Telecommunications Standards Institute (ETSI) is also working towards corresponding regulations for the European Union. Once these regulations are in place, the market will offer equipment based on UWB systems. However given the huge bandwidths there will be an overlapping between the UWB systems and other radio systems. "Coexistence of these systems is a very important issue. If we know the mechanism and how the UWB signal goes and what is the impact of the signal on different radio systems, we can try to make devices which interfere as less as possible with other radio systems".

The main goals of the PhD research are to clarify the difference in the performance of the several types of UWB systems and find out the UWB impact on some specified radio systems. In other words, how different radio systems interfere with the co-existing UWB systems, and vice versa. The huge frequency band required for UWB transmission meets lots of different interference sources in the propagation channel. Not only the other radio sources but also the other UWB systems will cause interference to the studied UWB communication link. As a result, interference is forming a major part of the research. The research is also examining carrier-less methods for generating the UWB signal, and the performance of the UWB system in the realistic environment of a short range indoor communication system with interference. The UWB systems concepts to be considered are based on time hopping and direct sequence models.

At present, tens of millions of IEEE801.11a and b enabled WLAN devices (e.g. laptops, PDAs) have been installed worldwide representing a huge investment in a popular wireless technology. Due to the huge bandwidth of the UWB devices they have been seen as a threat to those other existing systems. The research will also discuss and undertake experiments on the impact of UWB on IEEE801.11b and Bluetooth networks in his thesis. This will be the first PhD research in the field of ultra wideband technology in Finland, and will contribute to the small number of UWB focused PhD studies completed in the world to date.

Student 2: ***Equalization in WCDMA terminals***

Third generation cellular networks have been designed to fulfil the future demands of mobile communications. With growing popularity and usage of the third generation networks, the cost efficient optimisation of network capacity and quality of service will become essential to cellular operators. This is achieved with careful network planning and operation, improvement in transmission methods, and advances in receiver techniques.

The rake receiver is the most commonly used receiver in CDMA (code-division multiple access) systems, mainly due to its simplicity and reasonable performance. Third generation networks are designed so that rake receivers can be used. However, the performance of the rake receiver is degraded by multiple access interference (MAI), that is, interference induced by other users in the network. Any means to suppress or to avoid MAI increases the capacity of CDMA networks. For this reason it is of great interest to develop enhanced receiver techniques.

In the third generation wideband code division multiple access (WCDMA) and CDMA 2000 systems, the terminal receiver performance is directly linked to the capacity of the system. Improved capacity of the system appears to the operator as a higher number of users it can support and, thus, higher revenue. The user pays in higher battery consumption and higher price of the mobile. Therefore low complexity is crucial. For the user, the receiver provides a higher quality of service and likely higher data rates in a wider region when compared to the conventional rake receiver.

The purpose of the PhD research is to develop novel receivers for WCDMA air interface that provide performance enhancement over conventional rake receivers with an acceptable increase in complexity. Performance was then validated under WCDMA downlink conditions. Two adaptive channel equalizers based on the constrained minimum output energy (MOE) criterion and sample matrix inversion (SMI) method have been developed. An existing equalizer based on the matrix inversion lemma was also developed further to become a prefilter-rake equalizer. The student found that the linear channel equalizers are feasible in WCDMA networks and they provide significant performance improvements with an acceptable increase in complexity. They provide substantial advantages over the rake receiver, such as a decrease in overall interference in the WCDMA network resulting in higher network capacity. Also the data rate of the connection can be increased, or the coverage of a high data rate service can be extended for the same level of transmit power. Of the equalizers developed, the SMI-based equalizer proved to have the lowest complexity. The receivers proposed are likely to be considered when ASICs (microchips) are redesigned in the near future.

Student 3: ***Performance study on ad hoc networks and MAC-layer techniques***

An ad hoc (or ‘spontaneous") network is a collection of wireless nodes forming a temporary network without any existing infrastructure (such as base stations) or centralized control. A node is a connection point, either a redistribution point or an end point for data transmissions, which can forward transmissions to other nodes. A multi-hop ad hoc network is where there is no direct path between pairs of nodes so an intermediary node is used, such as in the case of rural and emergency communication systems and tactical radio systems. Multiple access protocol coordinates the access of a common, shared channel among several nodes.

Ad hoc networks have been considered as a topology for future wireless networks. In most of the research done so far, the focus has been on routing protocols and performance in terms of mobility and network size. Very little research has been undertaken on important issues such as traffic characteristics and lower layer techniques. With increasing traffic load, the performance of ad hoc network collapses quickly. Bursty data traffic leads to serious congestion which causes a large number of collisions and increased transmission delays and packet loss. Simulations carried out by Jarmo and other team members show that the nature of multi-hop communication causes all problems to be multiplied. Therefore, significant loss of performance is observed in an ad hoc environment. Currently the biggest problem seems to be with the MAC-layer (Medium Access Control) which performs badly especially in heavy traffic situation.

Research already carried out imply that the bottleneck is not the routing protocol but on the used IEEE 802.11 MAC-layer which is mainly designed to work in a centralized control environment. Still, changing only MAC would probably not help much, because there should be also a strong interaction between layers. These findings suggest that more attention should be focused on simultaneous MAC and routing layer research to make ad hoc networks more efficient and applicable to robust communication.

This PhD research is different to most other studies as it examines the performance of ad hoc networks as a whole starting from the physical layer, through to link and network layers, to the source traffic models of the application layer. It aims to improve the efficiency of ad hoc networks by presenting new performance metrics to reveal the real problems and propose new methods for correcting these problems. The origins of this PhD research came from a research project for the Finnish Defence Forces. It is now part of the Centre for Wireless Communication’s Future Radio Access (FUTURA) project funded by Nokia, Elektrobit, the Finnish Air Forces, Instrumentointi Oy, and the National Technology Agency of Finland (Tekes). The aim of this project is to develop basic technology knowledge and expertise needed in creating communication systems to be used within 10 to 15 years. The project’s three research areas are radio air interface solutions, transceiver techniques and wireless networks.

Student 4: *Physical layer evaluation and analysis of Ultra Wideband communication systems*

Ultra Wideband (UWB) is a wireless technology for transmitting large amounts of digital data over a wide spectrum of frequency bands with very low power for a short distance. For example, UWB transmits across an extremely wide bandwidth of several GHz around a low centre frequency, using very low average power of ~100μW. In contrast, traditional wireless technologies transmit across a narrow bandwidth up to a few tens of MHz using a much higher average power of ~100mW. UWB is a quite new technology in the field of commercial communication applications. Similar to CDMA (code-division multiple access), it has been widely used in military applications since the 1960s, including secure communication and radar applications. Due to the progress in silicon technology, UWB is currently being customised for commercial markets.

Using dedicated new wires is the traditional way for implementing high bit rate applications. However, this method is problematic when used in the home environment. Existing houses and buildings are often expensive and hard-to-wire locations. Intensive wiring also implies a significant burden on installation and configuration. Present proposals for UWB technologies are conventional as they do not use modern channel coding, modulation or MIMO channel signal processing methods. Several U.S. companies have released some commercial communication systems based on UWB concepts, but there is a lack of information about this new technology and a lack of academic research related to theoretical and application matters.

The main goal of this Licentiate research is to analyse, perform and validate the physical layer of a wireless indoor connectivity system based on the UWB technology. Such a system will have a competitive high data rate in order to support the multimedia services already implemented for narrow band systems. High quality audio, video and broadband multimedia content, optimised in terms of throughput, range and performance for indoor environments, including a high quality of service, will be the main targets for these new systems.

Since commencing his research in early 2001, the student has studied and implemented several modulation and spreading techniques mainly in indoor simulation environments affected by noise and fading. Since UWB transmission is a novel technique for personal wireless communications, an important part of the research has been upon coexistence problems. The student has tested several UWB systems and their performance in the presence of different interfering transmissions, using different interfering approaches, and in different interference environments such as GSM transmission and UMTS transmission.

Student 5: *Alternatives to routing for wireless embedded networks with mobility*

An embedded wireless device is a very small device that is built for a specific application. It is often placed inside another device or connected to other equipment for the purpose of collecting and then transmitting information to a local or remote server. This means any device that includes a programmable computer but is not itself a general purpose computer such as printers, mobile phones, televisions, household appliances, and automobiles (engines, dash, brakes). Characteristics of embedded systems include sophisticated functionality, real-time operation, low manufacturing cost, low power, complex and multiple algorithms, and a simple or non-existent user interface. Wireless embedded networking refers to the science of communication between embedded devices for automation, control, sensing, pervasive computing and military applications.

There has been a lack of research into simple, cheap, low power wireless technologies for use in embedded networking. Bluetooth is one of the closest technologies, yet it still lacks in almost all respects. Many wireless solutions exist, but there have been no Medium Access Control (MAC) developed for them, as they are for point-to-point proprietary solutions. This PhD research aims to find a suitable balance between the power consumption, bandwidth and performance of wireless embedded networking by undertaking wireless networking research. This will involve the studying and developing of algorithms for efficient wireless physical technologies. Suitable physical technologies may include ISM band single chip solutions, IR techniques, ultra wideband, etc

Wireless MAC is not much use on its own without networking many together. The research will also develop efficient protocols for use in ad hoc (infrastructureless) environments. These protocols should be low bandwidth, robust and easy-to-use without relying on a structured network.

Embedded networking applications can benefit from a range of algorithms. The student is also examining techniques which are applicable at many layers of the ISO stack from MAC to application. These techniques include positioning (including distributed positioning calculations and relative or local positioning systems), security, clustering (which allow large groups of distributed sensors to collaborate), and the energy efficiency of embedded networks at different layers and as a whole. As routing is also important, his research also touches on the interaction between the Internet and embedded networks using gateways.

University of Oulu: Biocenter Oulu

Student 6: Phosphatidylethanol (PEth) as a marker molecule and a cellular factor

Alcohol affects many organ systems of the body, but perhaps most notably affected are the central nervous system and the liver. Almost all ingested alcohol is metabolized in the liver and excessive alcohol use can lead to acute and chronic liver disease. Liver cirrhosis resulting from alcohol abuse is one of the ten leading causes of death in the United States. While alcohol usually disappears within a day after drinking, Phosphatidylethanol (PEth) has been detected from human blood two weeks after cessation of drinking. Therefore, PEth is regarded as one of the most promising new markers of alcohol abuse. However, the early methods to detect PEth are relatively insensitive and time consuming for clinical analysis.

The overall goals of this PhD research are, firstly to develop a method for screening of alcohol abuse and secondly, to understand the mechanisms that possibility connect PEth formation to liver disease, pancreatitis and Fetal Alcohol Syndrome. In the student's words, "we are studying the effect of alcohol on those diseases at the point of immunological response".

The study is divided into two sub-projects. The first project will focus on the development of a rapid detection method for PEth formation in human blood. The second project will evaluate the role of PEth as an abnormal cellular constituent in the pathogenesis of alcohol related diseases. With the cooperation of medical personnel from the Northern Ostrobothnia Hospital District, he will collect samples from about 100 patients in different stages of liver disease or Pancreatitis and with different patterns of alcohol consumption.

With these results, the student will develop a simple, sensitive and rapid immunoassay method for testing the blood samples of patients to detect the level of alcohol consumption. When asked in an interview what is the difference between current blood tests for alcohol consumption and his proposed test, the student stated: "We are not testing alcohol but a product of alcohol metabolism. This metabolite is not formed if ethanol Is not present. Our method gives an extended view to patient's alcohol consumption". If the detection method proves to be successful it will provide the health care system with a tool to identify those people who are at the high risk of getting alcohol related liver disease or Pancreatitis. This study will also give insight into a question why some people get alcohol related disease with smaller alcohol consumption.

Student 7: *Type I, II and III prolyl-4-hydroxylase knock-out mice, and properties of modified recombinant fibrillar collagens and their fragments*

Collagens are the most abundant proteins in human body. They are structural building blocks of connective tissues, e.g. skin, bone, cartilage and tendons. There are 27 different types of collagens. The most abundant ones are *Type I*, which is the principal component of bone, skin, and tendons; *Type II* found in cartilage; *Type III* found in embryonic tissues, blood vessels, the uterus, and the GI tract; and *Type IV* found exclusively in basement membranes. The student is working in the Collagen Research Unit which focuses on the molecular biology of collagens and enzymes of collagen biosynthesis.

Prolyl 4-hydroxylase (P4Hs) catalyses the formation of 4-hydroxyproline by the hydroxylation of proline residues in peptide linkages. Two families of P4H are known today: collagen P4Hs (C-P4Hs) that have a central role in the synthesis of all collagens, and HIF-P4Hs that play a key role in the regulation of oxygen homeostasis. Inhibitors of C-P4Hs are regarded as attractive candidates for the development of drugs which inhibit collagen formation in fibrotic disease, while inhibitors of HIF-P4Hs are expected to have a major impact on the treatment of many diseases characterised by ischemia, such as stroke, diabetes and peripheral vascular disease. The student is studying the C-P4H enzymes that have a central role in collagen biosynthesis. P4H catalyzes the hydroxylation of proline residues to 4-hydroxyproline that are essential for the formation of stable collagen molecules. She is currently working on the first two enzymes, type I and type II, and will do some work at a later stage on type III.

The first part of the PhD research involves generating knockout mice to understand the biological significance and function and to study the specific expression patterns of the different isoenzymes (which are related forms of enzymes but with differing chemical, physical or immunological characteristics). Knockout mice is where a specific gene in inactivated through a technique called "gene targeting" i.e. one gene sequence is replaced with a related sequence that has been modified in the laboratory to contain a mutation. Knockout mice models are widely used to study human diseases caused by the loss of gene function. In the student's words: "We started using knockout mice models to see how these isoenzymes are distributed and if they are expressed in different development levels". The second part of her PhD research involves producing recombinant collagens and their fragments in yeast and studying their assembly and hydroxylation. This will lead to more efficient expression of recombinant collagens that will have numerous scientific and medical applications. This PhD research receives funding from FibroGen Inc., a San Francisco based company that produces collagen and gelatin products based on scientific results.

Student 8: *Protein-ligand interaction: affinity calculations*

Proteins are complex organic compounds. The basic structure of protein is a chain of amino acids that contain carbon, hydrogen, oxygen, and nitrogen. Protein is the main component of muscles, organs, and glands. Every living cell and all body fluids, except bile and urine, contain protein. The cells of muscles, tendons, and ligaments are maintained with protein. Children and adolescents require protein for growth and development.

The biological functions of proteins almost invariably depend on their direct, physical interaction with other molecules. A fundamental aspect of the interaction of the protein with a ligand is the affinity of the two for each other, which is the measure of the overall free energy of association. The magnitude of the affinity determines whether a particular interaction is relevant under a determined set of conditions. Several methods based on different theoretical approaches have been developed to perform free energy calculations. These range from statistical mechanical approaches coupled with atomistic simulations to methods based on empirical parameters. Only in defined ranges of applications, physical methods can give reasonable predictions.

The purpose of this PhD research is to investigate protein-ligand association reactions using computational methods. In the student's words: "This interaction of proteins is very important in basically all the processes that happen in the human body. Whatever reaction is going to happen, it always involves an interaction between two different proteins. I am studying how well proteins interact with each other by using a computer to calculate the forces and energies that are involved in this interaction".

The student is also comparing theoretical approaches with data obtained experimentally to determine the quality of the underlying theoretical model for the calculation of affinities and interpreting the results produced by experimental and bioinformatical approaches for specific classes of problems. For every system the relative importance of the determinants of binding (electrostatics, hydrophobic effect, conformational entropy, etc) is different. By mean of biocomputing techniques, she is dissecting such contributions and making statements about their relative importance.

The ultimate goal of this PhD research is to explain quantitatively why and how ligands bind to protein molecules, in terms of dynamics, structure and thermodynamics. At the same time, detailed information at the molecular level concerning the binding process may become available. Her research will benefit other researchers in the biological and medical fields, and will contribute to the improvement of computational tools used by drug designers.

Student 9: Theoretical studies on prostate specific proteins

The prostate is a gland in the male reproductive system just below the bladder. The prostate surrounds part of the urethra, the canal that empties the bladder, and produces a fluid that forms part of semen. Prostate cancer is a disease that affects the cells of the prostate. Normally, cells grow and divide in an orderly way. This is how the body grows and stays healthy. Sometimes this normal process of cell growth can go wrong. If abnormal cells continue to divide when they're not supposed to, they can form a tumour. Cancerous prostate tumours can, if untreated, spread to other parts of the body. Prostate cancer is the most common cause of cancer in men.

A blood test measures prostatic acid phosphatase (an enzyme found primarily in men in the prostate gland and semen) to determine the health of the prostate gland. Prostate dysfunction results in the release of PAP into the blood.

This PhD research aims to characterise the structure-function relationship of Prostatic acid phosphatase (PAP). PAP is relatively well-characterized tyrosine phosphatase enzyme. Though it is intracellular a major amount of PAP is secreted. There are many lacunae in the understanding of exact functioning of PAP. His study involves computational and structural bioinformatics approaches to search the probable molecules it could bind(ligands)in vivo and act upon them. As part of his research, the student is also studying two important aspects of the enzyme functioning. There is a lack of understanding of the detailed mechanism of the enzyme action. A lot of work has been published regarding the mechanism of low molecular weight phosphatase and phosphatases with metal ion in the reaction center(active site). PAP is a high molecular weight phosphatase and lacks a metal ion. So it has a totally different mechanism. With the advantage of having obtained the structures, we would be looking into the mechanism of the enzyme using a quantum simulation technique. The other aspect which is of interest is to explore its functioning as dimer, wherein two PAP come together and function much better. Essential dynamics analysis of molecular dynamics simulation trajectories has shown that the enzyme has a peculiar motion in one of its loops at the dimer interface.

The student's results have shown for the first time how a set of peptides bind to PAP. Peptides are chains of amino acid residues with remarkable biological functions, ranging from hormonal regulation to antibiotic activities. There has been a study done by some pharmacologists who wanted to design some inhibitors and have shown experimentally some properties of the inhibitor. This research has found different complexes which not only tell what are possible ligands but also their mode of binding. These findings should be of considerable interest to drug designers.

Student 10: Interactions of SCP-2L and TPR-domain of PEX5 at the molecular level

Organelles exist to concentrate enzymatic reactions, separate competing metabolic processes, and segregate harmful products from the rest of the cell. The organelle systems include the nucleus, which is responsible for segregating replication and transcription; the mitochondria, which concentrates energy-producing reactions; the secretory system, which is responsible for organizing the synthesis, transport, and quality control of proteins and lipids; and the peroxisome.

The peroxisome is a single-membrane organelle present in nearly all eukaryotic cells. One of the most important metabolic processes of the peroxisome is the b-oxidation of long and very long chain fatty acids. The peroxisome is also involved in bile acid synthesis, cholesterol synthesis, plasmalogen synthesis, amino acid metabolism, and purine metabolism. The importance of the peroxisome and these processes is underscored by the existence of numerous genetic disorders associated with defects in the peroxisome.

Almost every protein imported into peroxisome includes one of the two Peroxisomal Targeting Signals (PTS). PTS1 is more common than PTS2, and PTS1 can be found in such proteins as glyceraldehydes 3-phosphate dehydrogenase, several phosphoglucose isomerases and dihydroxyacetone kinase. Peroxine 5 (PEX5) is a receptor for both PTS1 and PTS2 and it binds PTS1 with its seven tetratricopeptide repeats (TPR) found in the carboxyterminal TPR-domain. This receptor-cargo protein complex binds to membrane proteins and is transported to the peroxisome. One of the proteins with PTS1 is SCP-2L, a carboxyterminal domain of Multifunctional Enzyme Type 2 (MFE-2). A previous researcher in the Biocomputing Group found that PTS1 of the SCP-2L is buried within the protein if the protein bound ligand is removed. This indicates the possibility of disrupting the binding of SCP-2L and PEX5 within the time frame of the simulation.

The student was able to rebuild in his Masters research the missing parts of the PEX5's TPR-domain and docked that with SCP-2L in a manner correlating with experimental results. The purpose of this research is to continue the binding studies began in his Masters project by studying the disruption of the binding and possible dissociation by the means of biocomputing. This will involve studying the nature of binding between PEX5 and SCP-2L and the dissociation of PEX5 and SCP-2L in order to remove ligand from SCP-2L and see if that causes disruption or dissociation in the system. Previously no one has looked into this level of detail into this interaction of these two proteins. In the longer term, findings should contribute to other research the aims to find solutions to the numerous genetic disorders associated with defects in the peroxisome such as the Zellweger syndrome that is lethal for small babies.

University of Illinois at Urbana-Champaign: Department of Materials Science and Engineering

Student 1: Fundamental studies of dislocation-particle interactions at elevated temperature in aluminium alloys

Highly alloyed aluminium has been one of the most successful and broadly applicable materials developed for engineering structures in the last century. The packaging, automotive and aerospace industries have benefited significantly from the development of these alloys.

Fabrication of aluminium products begins with direct chill casting followed by heat treatment for homogenization. The slabs are then taken from the furnace and hot rolled through several passes until the desired final thickness is achieved. The rolled material is then quenched and stretched. In the final step, the plate is aged to precipitate the strengthening phases. As a key step in the production of aluminium products, hot rolling contributes significantly to the development of final product properties and property anisotropy. In order to meet the desired material specifications, enough deformation energy must be generated to maintain a temperature above that promoting significant recrystallization. At the same time, hot rolling must not be so fast as to induce melting of second phases, and deformation zone geometry not so aggressive as to induce marked shear.

During hot rolling of aluminium alloys, failures due to hot shortness slow production and lead to costly reprocessing. Recent rolling simulations indicate that the failure plane experiences higher shear stresses, due to friction between the plate and the rollers, which leads to significant temperature excursions. Additionally, mechanical property tests show a change in deformation mechanism at high temperatures and intermediate strain rates that can be correlated to changes in the microstructure. In combination, higher temperatures and shear rates could lead to the unfavourable initiation of damage, and thus give rise to hot shortness.

Development of material models and simulations capable of defining a thermomechanical processing window to avoid such failures requires detailed knowledge of the interrelationship between microstructural processes and mechanical behaviour. However, in order to construct physically-based continuum models it is necessary to understand the details of the micro-structural interactions occurring during deformation at elevated temperature, which is the primary emphasis of this PhD research.

In order to fully characterise dislocation-particle interactions in aluminium alloys, to the extent that new physically-based models can be developed, the student intends to undertake further experimentation in areas of: In situ TEM deformation experiments of Al-4Mg-0.3Sc at room temperature in order to ascertain the influence of temperature on the interactions; use of stereo-pairs, weak-beam dark-field, dislocation characterization, and image simulation to determine mechanistic details of the interactions; observation of any changes in future interactions due to the presence of a complex particle-matrix interface as a result of a previous interaction; characterisation of the particle-matrix interface via high resolution imaging; and study of another aluminium alloy to see the effect of varying particle coherency on mechanical behaviour and dislocation-particle interactions.

From the experimental work and the simulations, key elements of the dislocation-particle interactions will be used to develop a continuum model capable of robustly describing the behaviour of particle-strengthened aluminium alloys over a range of temperatures and particle coherencies. The Department of Energy and Alcoa, which is the one of the largest aluminium companies in the world, are funding this research. The student works closely with specialists from the Alcoa Technical Center in Pittsburgh.

Student 2: ***Fluctuation electron microscopy investigation of photo induced changes in the medium-ranged order of a-Si:H***

Hydrogenated amorphous silicon (a-Si:H) is a technologically important material for large area electronic and opto-electronic devices, such as solar cells and flat panel displays. It has a higher optical absorption coefficient than crystalline silicon (c-Si) in the visible range of the spectrum and can be easily deposited over large areas at an economical cost. Solar cells made with a-Si:H as the active layer have shown operating efficiencies of up to 15 percent.

Hydrogen is incorporated into a-Si during growth to passivate the dangling bonds (three fold coordinated Si atoms) that would otherwise give rise to mid-gap electronic states which act as efficient recombination centers, decreasing devise efficiencies. A typical a-Si:H film has native defect concentration after growth and this defect concentration increases upon prolonged exposure to light. This light induced degradation is called the Staebler-Wronski effect (SWE). However, since most devices are operated near room temperature, the SWE remains a significant limitation in the use of a-Si:H for photovoltaic (solar cell) applications.

The microscopic mechanism involved in the light induced degradation is still unresolved, although it has been shown to result from the recombination of electron-hole pairs. In addition to an increased defect density, recent experimental results have shown the occurrence of larger structural changes in the a-Si network upon light exposure. The nature of these structural changes, whether they are reversible upon thermal annealing, and their possible relation with the creation of Si dangling bonds remain unanswered questions.

This PhD research is studying the changes in Medium Range Order (MRO) using fluctuation microscopy to develop better insights into the mechanism involved in the Staebler-Wronski effect. Fluctuation Electron Microscopy (FEM) is a new and critical tool for investigating the structure in amorphous network solids. He is analysing the structural changes accompanying light induced degradation in state-of-the-art a-Si:H materials grown by a variety of deposition techniques and checking for reversibility in MRO modulations. Based on the information gathered, the student will optimise growth methods to produce the desired MRO that is least susceptible to Staebler-Wronski effect.

When asked who will benefit from his research the student responded as follows: “My research is pretty basic. It is more scientific than technology oriented. The science is still being established. I think that in a few years this research will develop some facts, which the industry can try to make use of. The solar cell industry for example can use it for tailoring their material so that it absorbs more sunlight and gives more electricity. Solar cells absorb the sunlight falling on them and converted it into electricity. Amorphous silicon based solar cells are very economical compared to solar cells made with other materials which are costly but more efficient”. The National Science Foundation is funding this research.

University of Illinois at Urbana-Champaign: Beckman Institute of Advanced Science and Technology

Student 3: ***Quantifying and directing molecular diffusion on surfaces and through grafted polymer layers***

This PhD research is studying the lateral diffusion of small fluorescent molecules diffusing on and in organic-based monolayers and on silica. The organic layers studied, commonly known as self-assembling monolayers (SAMs), are comprised of molecules grafted to silica substrates. The first part of the research involved making a variety of surfaces and layers of grafted oligomers/polymers with commercially available molecules as well as molecules synthesized specifically for the project. The eventual goal is to assemble polymer molecules into amorphous layers with high mobility and a specific “pore size” and chemistry. The chemistry, shape and weight of the assembled molecules and the thickness of the polymer layers were varied to explore their effect of diffusion.

Scanning tunneling microscopy and other high vacuum surface science techniques are commonly used in inorganic studies. In biological systems, where many of the high vacuum tools of the surface science community can not operate, entirely different classes of tools, primarily centred around fluorescence imaging, have been developed. The student is using the technique of fluorescence recovery after photobleaching (FRAP) to measure the diffusion of dye molecules that are easily bleached and not sufficiently bright for single molecule detection. Dye is deposited uniformly over the sample. A defined volume of the sample is illuminated with photons of an appropriate energy to excite the dye and at a sufficient power to bleach a measurable fraction of the dye molecules. Subsequent to bleaching, images are collected as a function of time. The fluorescence recovery in the bleached region is due to diffusion of “live” dye molecules in the bleached area, and thus a diffusion rate is calculated from the recovery rate.

This research about the transport of molecular species through patterned structures could contribute to a new paradigm for defined molecular transport, and be of use for the interfacing of traditional microelectronic devices with chemical and biological structures. Successful design of two-dimensional chemical pathways (called “molecular conduits”) on a surface requires a thorough understanding of the dynamics of diffusion of small molecules on surfaces and the development of surfaces in which rapid diffusion exists and surfaces in which slow, near zero diffusion exists. These surfaces will serve as the transporting and insulating regions respectively. Self-assembled monolayers and other thin films of functionalized (small or polymer) molecules chemically attached to the substrate may be ideal structures for both the molecular conduits and the insulating layers. In the long run, the student’s research is likely to be used in a wide variety of applications, such as sensor design and in electronics products, as well as being important to further biological and nanotechnology studies. It is supported in part by the Beckman Foundation’s Young Investigator award, the Nanoscale Interdisciplinary Research Teams (NIRT) initiative of the National Science Foundation and the U.S. Department of Energy’s Division of Materials Science.

Student 4: *Atomistic and continuum simulations of electroosmotic transport in nanometer channels*

Fluid and ion transport through nanometer scale pores, or nanofluidics, plays an important role in determining the function of many engineering systems, e.g., chemical analysis system and fuel cell system. It is also of great importance to many biological systems. For example, many types of ion channels, whose size range from a few angstroms to a few nanometers, are found to be embedded in the cell membrane. These channels control the ion and water transport through the membrane, and if something goes wrong with the ions channels, the functionality of the cell will be damaged.

Advances in fabrication technology now allow one to produce nanopores as small as 1 nanometer. Because the nanofluidics based devices consume only minuscule amount of reagent and can produce rapid results with molecular-level precision, there is now a surge to develop these devices. However, the mechanism of the fluid and ion transport in such small pores and channels is still largely unknown. One of the major reasons is that, the continuum theories, which guided the design of macroscopic system successfully in the past, may simply become invalid in such small channels. For example, it would be difficult to believe the water flow in a 1 nanometer wide channel, which can barely accommodates 5 water molecule side by side, can be described by the classical Navier-Stokes equations.

This PhD research is aiming to understand how fluids and ions are transported through nanochannels, particularly the flow rate when certain forces are applied and how to control the flow rate. The first part of his research involves simulations of fluid transport in microchannels, and the second part involves simulations of fluid and ion transport in nanochannels. According to the student "what I am trying to do is to develop a simulation method and use this method to analyse what is really going on at this very small scale. Behaviour of fluid transport is fundamentally different from that in a microscopic system which has been well understood. What I am trying to do right now is trying to find out what is the different behaviour, why is it different and can we capture that. That would be the research".

Although there are some theories for simple fluids, there is no theory for more complicated scenarios such as those being undertaken by the student. Therefore, he also hopes to develop some general theory for the simulation observations. In term of who could benefit from the student stated: "I think it is pretty useful for many industry applications. I don't know if you are aware of the lab-on-a-chip companies. Traditionally you go to a hospital and they get some blood from you. They have a lab with three persons working there. Now what people do is bring this lab into a single chip in the order of 3 by 3 cm. That is very small, and they use the unique characteristic of the nano and microfluidics. These companies are going to be the first generation of companies that may benefit from my research".

DARPA, the Department of Defence's Defense Advanced Research Projects Agency, and the National Science Foundation have supported this research.

Student 5: *Optical image enhancement for the diagnosis of breast cancer*

Cancer is one of the leading causes of death in the developed world. Currently, most forms of cancer are only recognized when a tumour mass develops, but early detection of cancer may lead to more effective therapy and significantly reduced morbidity and mortality. Direct tomographic techniques are increasingly becoming widely accepted as methods of non-invasive cancer detection.

The resolution limit in optical coherence tomography (OCT) imaging systems has recently undergone significant advancements that allow for sub-cellular resolution. This progress, along with the development of portable needle-based optical biopsy systems, suggests that OCT will successfully advance beyond the research environment into widespread clinical use for targeted biopsies and identification of malignancies in breast tissue. Significant issues remain, however, that may limit effectiveness in a clinical environment. Critical improvements include: a means of distortion free imaging, the development of new contrast sources, and an increase in the knowledge of scattering properties of tissues. These issues establish the need for increased knowledge of contrast sources within cancerous tissues.

This PhD research involves experimental characterization of the optical properties of individual organelles in cancerous and non-cancerous breast tissues as well as techniques that exploit index of refraction contrast sources. He is currently working to construct an experimental apparatus for the characterization of refractive index, absorption, and scattering of a variety of materials.

In addition to the characterization of contrast agents, sub-cellular samples from existing breast cancer models being used in the Biophotonics Imaging Lab are also being analyzed. The local hospital in Champaign is providing Adam with samples of tumours. He intends to break apart the cellular structures in this tissue using widely accepted protocols. These separated organelles from both cancerous and normal tissues can then be fully characterized. When combined with data from collaborative contrast agent work, this data offers the ability to compare the effectiveness of exogenous and endogenous contrast sources in cancerous tissues.

The resulting knowledge of refractive index, scattering, absorption, and polarization of cellular materials could potentially be instrumental in the enhancement of cancer detection. This new understanding of endogenous optical contrast sources, combined with the introduction of distortion-free optical imaging techniques, holds significant promise for the improvement of optical breast cancer diagnostics. The Whitaker Foundation and National Science Foundation are supporting this research. The student will spend two months as a visiting researcher at the University of Western Australia where he will work with a professor who is using a similar technique. He was awarded an East Asia and Pacific Summer Institutes for U.S. Graduate Students (Australia) Fellowship from the National Science Foundation to undertake this research visit in 2004.

University of Illinois at Urbana-Champaign: Department of Crop Sciences

Student 6: *Herbicide resistance in tall waterhemp*

Tall waterhemp (*Amaranthus tuberculatus*) is a dynamic plant species and primary weed concern for crop producers in Illinois. A major problem associated with tall waterhemp control is its ability to develop resistance to herbicides, most notably the family of *acetolactate synthase* (ALS) inhibitors. Resistance to ALS inhibiting herbicides rapidly spread among Illinois tall waterhemp populations in the 1990's. Consequently, this class of herbicides are no longer a viable option for use in controlling tall waterhemp throughout the state. However, ALS herbicides are routinely used for the control of other species within the *Amaranthus* family, such as smooth and redroot pigweed.

Recently, several tall waterhemp populations have been identified with resistance to not only ALS inhibitors, but also herbicides that inhibit photosystem II (PSII) and protoporphyrinogen oxidase (PPO). During the summer of 2003, four separate populations of tall waterhemp were positively identified with resistance to inhibitors of ALS, PSII, and PPO in Illinois. The identification of a tall waterhemp population with multiple resistances to PPO, ALS, and PSII inhibitors severely reduces the number of chemical options to control emerged tall waterhemp. In soybean production, for example, the only remaining chemical option to control emerged tall waterhemp is glyphosate, but its use requires the planting of glyphosate-resistant soybean varieties.

This PhD research is studying the characteristics of herbicide resistance in tall waterhemp to recommend ways that would contribute to the efficient, long-term management of this weed species. His research has mainly involved examining a specific tall waterhemp biotype with resistance inhibitors of ALS, PSII, and PPO. These studies include characterizing the molecular biology, physiology, and genetics of herbicide resistance in this multiple herbicide-resistant tall waterhemp biotype.

This research is funded by the Illinois Soybean Program Operating Board. In 2001 and 2002 the student was awarded a University Fellowship and the Frerichs Graduate Fellowship, respectively. For his research efforts, he was awarded the Graduate Student Research Award from the College of Agricultural, Consumer, and Environmental Sciences in 2002.

As well as undertaking PhD research related to herbicide resistance in tall waterhemp, the student is currently undertaking two other related projects. One of the projects is investigating the likelihood that tall waterhemp will develop resistance to glyphosate, which is claimed to be the world's leading herbicide, and is currently funded by Monsanto. If tall waterhemp does become resistant to glyphosate "they say this is the biggest event as far as herbicide resistance in this country as far as widespread problems and loss of income potentially to farmers". The second side project, funded by the Illinois Soybean Program Operating Board, involves global gene expression in conventional and transgenic (or Roundup Ready™) soybeans using microarray technology. The main objective of this research is to determine the effect of glyphosate on glyphosate-resistant soybeans varieties.

Student 7: *Investigation into the genetic basis of resistance to brown stem rot in soybean*

Brown stem rot (BSR) is an important soybean disease in North American and is one of the more frequently occurring soybean diseases in Illinois. The soilborne fungus, *Phialophora gregata* f. sp. *sojae* has been identified as the causal agent of this disease. In early summer, *P. gregata* f. sp. *sojae* invades root tissue of young soybean plants and then slowly spreads upwards in vascular and pith tissues via mycelial and conidial growth. Yield losses of 11 to 38 percent have been reported from BSR infection in years when environmental conditions were conducive for disease development. For example, earlier planting dates can lead to more severe disease development. The genetic resistance level of the soybean cultivar planted has an effect on fungal infection and progression. Increased space between soybean rows has been shown to favour a higher degree of disease development.

Three dominant, independently segregating loci that confer BSR resistance in soybean have been identified through classical genetics studies. Newer studies, however, propose more complex models of BSR resistance. Although the inheritance of BSR resistance may not be totally understood, it has been incorporated into commercial cultivars and has been successfully used to control the disease. It has been determined that resistance genes, or quantitative trait locus (QTL), act in the root tissues to give the soybean plant resistance.

This PhD research consists of five projects to achieve the following objectives: screening exotic germplasm to find accessions with strong genetic resistance to brown stem rot; fine mapping BSR resistance genes/QTL; studying the interaction between soybean cyst nematodes and BSR; developing a co-inoculation screen using both BSR and soybean cyst nematodes; and investigating the four gene model of BSR resistance as proposed by Bachman and Nickell (2000).

When asked who will benefit from her research the student stated: "From a practical standpoint, farmers and other soybean breeders as I am looking at a specific disease problem and trying to improve upon it. If I find a new gene we will immediately start breeding that into our breeding materials to be put into new cultivars for the farmers. From more of an intellectual standpoint, geneticists at large can benefit from my research". This research has been funded by the Illinois Soybean Program Operating Board and the Pioneer Seed Company.

Student 8: *Gene flow among weedy Amaranthus species*

This PhD research is examining gene flow and gene transfer in the weed species *Amaranthus*. This weed has become increasingly problematic in the mid-west, mainly due to its ability to develop resistance to herbicides. As a result, the United States Department of Agriculture is funding his project. The student is using molecular and cytogenetic tools to assess the rate at which different species may hybridize in field conditions. His research originates in the evolutionary biology field that argues that hybridization is a major component for evolution. The research is developing a way to positively identify the progeny between the two species, that is the outcome of the mating and not that comes from self pollination or pollination by other individuals from the same species.

The first part of his research involved a field study during the summers of 2002 and 2003. Hybridisation plots with two species were set out. Seeds obtained from the plots were screened in the greenhouse for hybrids. This stage of the research found that hybrids occur at very high frequencies. The next stage of the research involved examining how genes are transferred from the hybrid to a more genetically stable background by backcrossing the hybrids to the original parent species, looking at chromosomal segregation and assessing the different chromosomal combinations with restoration of fertility. Because hybrids are very sterile, Federico is investigating how to restore fertility, how genes from one species are moving to another, and whether allopolyploidy is the only form of hybrid speciation.

Past research about hybridization, in particular the fitness of the hybrid progeny and how introgression occurs, averaged every single generation. Averaging over generations misses the variability of that generation. Because the student is looking at every individual progeny and trying to match their fitness with genomic constitutions, his approach is going to lead to a more accurate picture of how genes are passed from one species to another. When asked how his results could be used, the student said: "By having a profound understanding of how species share their genes in nature could potentially help us to design better ways of interbreeding species and improving crops or just knowing how different traits may be acquired in nature and model the likelihood of development of adaptation of let's say herbicide resistance".

Student 9: *Effects of soybean cyst nematode population densities on Fusarium solani f. sp. glycines colonization of soybean roots in the field and a potential application of Q-PCR for quantification of fungal colonization in roots*

Two of the most important diseases of soybean in the Midwest are soybean cyst nematode (microscopic worms) and sudden death syndrome. The soybean cyst nematode (SCN), *Heterodera glycines* Ichinohe, causes the most economically devastating disease of soybean in the United States and is estimated to cause yield losses in excess of five million metric tonnes a year. Soybean cyst nematode occurs in approximately 83 percent of Illinois soybean fields which makes Illinois the most heavily infested state in the north central region of the United States.

Yield losses due to sudden death syndrome were estimated at over 900,000 metric tons in 1998. Sudden death syndrome was not a serious threat to soybean production in Illinois until an epidemic in 1993 when the disease was observed in approximately 46 percent of soybean fields and caused estimated yield losses of between 20 to 46 percent in the east-central part of the state. Previous research has shown that the nematode can dramatically hasten development of sudden death syndrome and significantly increase yield losses when both pathogens are present. However, this interaction is not well understood and new management strategies are needed to reduce yield losses as both become increasingly prevalent.

The first objective of this PhD research was to investigate the effects of varying levels of soybean cyst nematode on root infection by the fungus that causes sudden death syndrome, *F. solani* f. sp. *glycines*, and the subsequent development of disease. This research was conducted with near-isogenic soybean germplasm varying in resistance to both organisms in field sites naturally infested with both pathogens. Greenhouse experiments have also been conducted that examined the effects of varying levels of both pathogens in artificially-infested soil.

The best strategy for management of sudden death syndrome is the use of resistant cultivars, although many current methods for screening varieties for resistance are inefficient and time-consuming. The second objective of the student's research has focussed on the use of Q-PCR to quantify fungal colonization in roots of samples taken during the field experiments. Results were compared with cfu/g of *F. solani* f. sp. *glycines* estimations made by direction isolation of the fungus on a semi-selective medium. The effectiveness of Q-PCR as an alternative to the traditional methods used to estimate fungal colonization is currently under investigation. Preliminary results indicate that the Q-PCR procedure may be a promising alternative because of its increased sensitivity and precision.

This research is funded by the Illinois Soybean Program Operating Board. The student also received funding from Syngenta in 2004 to evaluate an experimental nematicide on corn and soybean.

Student 10: *Improving the fertiliser value of swine manure*

Illinois is one of the largest pork meat producers in the country. Pork farms have increased in size in the last decades and manure disposal has become a problem to producers. Yet hog manure is a very important fertiliser for corn because it is composed of organic and inorganic nitrogen. Inorganic nitrogen is present in the form of ammonium (NH4+), and several factors can cause ammonium to be lost when it loses a proton and is transformed into volatile ammonia (NH3). Significant inorganic nitrogen losses through ammonia volatilization can occur during manure storage and field application, and lowering the pH through acidification can decrease these losses.

The student is undertaking two field studies as part of her PhD research which is aiming to improve the fertiliser value of swine manure. Her research is funded by the United States Department of Agriculture. After the field studies, she will undertake another project that will produce six types of manure from six different diets.

The first field study is being conducted at the UIUC's Swine Research Farm. Pigs (42) will be either fed 15N labelled corn or the conventional corn. The manure collected is acidified or non acidified. This field study will result in four different manures (faeces and urine) products: Acidified 15N labelled manure, non-acidified 15N labelled manure, acidified non-labelled manure, and non-acidified non-labelled manure. The second field study involves studying nitrogen transformations in the soil following manure application. The experiment will take place in the South Farms in Urbana. Eight experimental units will include a 15N labelled hand applied manure area, a non-labelled hand applied manure area, and an injected manure area, all with either acidified or non-acidified manure. Corn yields will be calculated from the injected areas, and 15N enrichment will be analysed in the plants sampled from the labelled areas.

When asked who will benefit from her research, the student responded as follows: "I think scientists are definitely going to if I do conduct all the nitrogen transformation studies. Also anyone who wants to produce N15 labelled manure from hogs. This will be the first paper that uses actually 16 hogs instead of one. This is a big scale study. Given that we are sampling every day how the N15 changes as they eat. That is going to be very interesting for people who want to produce labelled manure. I think this is going to be useful for farmers because they will know how much manure is available to the crop. It is going to help them with the manure issues that they don't know how to handle. Farmers are over applying manure in the fields. One type of manure that we will be producing has low phosphorus and low nitrogen. That is going to be good for them. The six diet experiment will help producers choose the diet for the pigs knowing beforehand what type of manure they will deal with and its quality in terms of nutrient availability and phosphorous contamination potential".

Bibliography

Åberblom, M. (2001). Constructing Internally Comparable Indicators on the Mobility of Highly Qualified Workers: A Feasibility Study. In *STI Review 27 Special Issue on New Science and Technology Indicators*. Paris: OECD.

Academy of Finland. (2002a). *Finnish Programme for Centres of Excellence in Research*. Helsinki: Academy of Finland.

Academy of Finland. (2002b). *How about a career in research?* Helsinki: Academy of Finland.

Academy of Finland. (2003a). *PhDs in Finland: Employment, Placement and Demand*. Helsinki: Academy of Finland.

Academy of Finland. (2003b). *Scientific Research in Finland. A Review of Its Quality and Impact in the Early 2000s*. Helsinki: Academy of Finland.

Academy of Finland. (2004). *Annual Report 2004*. Helsinki: Academy of Finland.

Academy of Finland. (2005a). *Sustainable and dynamic partnership. Research cooperation and researcher training between universities, research institutes and business and industry*. Helsinki: Academy of Finland.

Academy of Finland. (2005b). *International Cooperation*. Retrieved June 1, 2005, from http://www.aka.fi/index.asp?id=2EFBE56F851A4E0D9CB242E2DEE73F5A

American Electronics Association. (2005). *Losing the Competitive Advantage? The Challenge for Science and Technology in the United States*. Washington: American Electronics Association.

Auriol, L., & Sexton, J. (2002). Human Resources in Science and Technology: Measurement Issues and International Mobility. In *International Mobility of the Highly Skilled*. Paris: OECD.

Australian Bureau of Statistics. (1999). *Human Resources in Science and Technology (HRST)* (Catalogue number 8149.0 ed.). Canberra: ABS.

Australian Bureau of Statistics. (2003). *Human Resources by Selected Qualifications and Occupations* (Catalogue number 8149.0 ed.). Canberra: ABS.

Australian Research Council. (2001). *Annual Report 2000/2001*. Canberra: ARC.

Australian Research Council. (2003). *Annual Report 2001/2002*. Canberra: ARC.

Australian Research Council. (2005a). *Annual Report 2003/2004*. Canberra: ARC.

Australia Research Council. (2005b). *Grant Programs*. Retrieved June 1, 2005, from http://www.arc.gov.au/grant_programs/default.htm

Australian Government. (2006). About Australia. Retrieved July 15, 2006, from http://www.australia.gov.au/about-australia

Avveduto, S. (2001). International Mobility of PhDs. In *Innovative People. Mobility of Skilled Personnel in National Innovation Systems*. Paris: OECD.

Barro, R. J. (1997). *The Determinants of Economic Growth: A Cross Country Empirical Study*. Cambridge MA: MIT Press.

Barro, R. J., & Lee, J. (1996). International Measures of Schooling Years and Schooling Quality. *American Economic Review, 86*(2), 218-223.

Barro, R. J., & Sala-I-Martin, X. (1995). *Economic Growth*. Cambridge, MA: MIT Press.

Batterham, R. (2000). *The Chance to Change: final report by the Chief Scientist*. Canberra: Department of Industry, Sciences and Resources.

Becker, G. S. (1964). *Human Capital: A theoretical and empirical analysis, with special reference to education*. New York: National Bureau of Economic Research.

Benhabib, J., & Spiegel, M. (1994). The Role of Human Capital in Economic Development: The Role of Policies and Institutions. *Journal of Monetary Economics, 34*, 143-173.

Biocenter Oulu. (2003). *Biocenter Oulu 2002*. Oulu: University of Oulu.

Birrell, B., Rapson, V., Dobson, I. R., & Smith, T. F. (2004). *Skilled Movement in the New Century: Outcomes for Australia*. Melbourne: Centre for Population and Research, Monash University.

Blöndall, S., Field, S., & Girouard, N. (2002). Investment in Human Capital through Upper-Secondary and Tertiary Education. *OECD Economic Studies, 34*(1), 41-89.

Borthwick, J., & Wissler, R. (2003). *Postgraduate Research Students and Generic Capabilities: Online directions*. Canberra: DEST.

Brown, H., & Syverson, P. (2004). *Findings from U.S .Graduate Schools on International Graduate Student Admission Trends*. Washington D.C.: Council of Graduate Schools.

Carlsson, B. (Ed.). (1997). *Technological Systems and Industrial Dynamics*. Massachusetts: Kluwer Academic Publishers.

Centre for International Mobility. (2004). *CIMO 2003*. Helsinki: CIMO.

Centre for Wireless Communication. (2003). *CWC Biennial Report 1.1.2001-31.12.2002*. Oulu: University of Oulu.

Cervantes, M. (2004). Attracting, retaining and mobilising high skilled labour. In *Global Knowledge Flows and Economic Development* (pp. 51-71). Paris: OECD.

Cohen, L., & Manion, L. (1989). *Research Methods in Education* (Third ed.). London: Routledge.

Cooke, P. (2001). Regional Innovation Systems, Clusters, and the Knowledge Economy. *Industry and Corporate Change, 10*(4), 945-974.

Council on Competitiveness. (1999). *The New Challenge to America's Prosperity: Findings from the Innovation Index*. Washington D.C.: Council on Competitiveness.

Council on Competitiveness. (2004a). *Innovate America. Thriving in a World of Challenge and Change. National Innovative Initiative Interim Report*. Washington D.C.: Council on Competitiveness

Council on Competitiveness. (2004b). *21st Century Innovation Working Group Final Report for the National Innovation Initiative*. Washington D.C.: Council on Competitiveness.

Criminal Intelligence Agency. (2006). *World Fact Book. United States*. Retrieved on July 15, 2006, from https://www.cia.gov/cia/publications/factbook/geos/us.html#Intro

Crotty, M. (1998). *The Foundations of Social Research*. Crows Nest, New South Wales: Allen & Unwin.

David, P. A., & Foray, D. (1995). Accessing and Expanding the Science and Technology Knowledge Base. *STI Review 16*, 13-62.

Dawkins, J. (1989). *Research for Australia: Higher Education's Contribution*. Canberra: Australian Government Publishing Service.

Denecke, D. (2004, October 5). The Ph.D. Attrition Challenge in U.S. Graduate Programs. *Bridges - The Office of Science & Technology Publication on Science & Technology Policy, 3*.

Denison, E. F. (1962). *The Sources of Economic Growth in the United States and the Alternatives Before Us*. New York: Committee for Economic Development.

Denzin, N. K., & Lincoln, Y. S. (1998). Introduction: Entering the Field of Qualitative Research. In N. K. Denzin & Y. S. Lincoln (Eds.), *The Landscape of Qualitative Research* (pp. 1-34). Thousand Oaks, California: Sage Publications.

Department of Education, Science and Training. (2005a). *Higher Education Statistics Collections*. Canberra: DEST.

Department of Industry, Science and Resources. (1999). *Shaping Australia's Future. Innovation Framework Paper*. Canberra.

Dosi, G. (1988). The nature of the innovative process. In G. Dosi, C. Freeman, R. Nelson, G. Silverberg & L. Soete (Eds.), *Technical Change and Economic Theory* (pp. 221-238). London: Pinter Publishers Limited.

Dyal, J. A. (1975). *Investment in Graduate Education*. University of Illinois at Urbana-Champaign, Champaign, Illinois.

Edquist, C. (1997). System of Innovation Approaches - Their Emergence and Characteristics. In C. Edquist (Ed.), *Systems of Innovation. Technologies, Institutions and Organizations* (pp. 1-35). London: Pinter.

Education USA. (2005). *If You Want to Study in the United States. Book 2 Graduate and Professional Study and Research*. Washington D.C.: U.S. Department of State.

Etzkowitz, H. (1998). The Triple-Helix of Academia-Industry-Government: The U.S. National Innovation System. In R. Anderson, T. Cohn, C. Day, M. Howlett & C. Murray (Eds.), *Innovation Systems in a Global Context* (pp.127-147). Quebec: McGill-Queen's University Press.

Etzkowitz, H. (2001). The Second Academic Revolution and the Rise of Entrepreneurial Science. *IEEE Technology and Society Magazine, Summer 2001*.

European Commission. (1995). *Green Paper on Innovation*. Brussels: European Commission.

European Commission. (2000). *Towards a European Research Area*. Brussels: European Commission.

European Commission. (2003). *Third European Report on Science and Technology Indicators*. Brussels: European Commission.

European Commission. (2004a). *Annual Innovation Policy Report for Finland*. Brussels: Enterprise Directorate-General.

European Commission. (2004b). *Annual Innovation Policy Trends Report for Brazil, Canada, Mexico, U.S.* Brussels: Enterprise Directorate-General.

Eurostat. (2005). *Science and Technology in Europe: Statistical Pocketbook - Data 1993-2003*. Brussels: European Commission.

Evans-Pritchard, E. (1951). *Social Anthropology*. London: Cohen and West.

Fell, C. (2004). *Evaluation of Knowledge and Innovation Reforms Consultation Report*. Canberra.

Finnish Science and Technology Service. (2005). *Information on Finnish Science and Technology*. Retrieved May 12, 2005, from www.research.fi

Foray, D. (1997). Generation and Distribution of Technological Knowledge: Incentives, Norms, and Institutions. In C. Edquist (Ed.), *Systems of Innovation. Technologies, Institutions and Organizations* (pp. 41-63). London: Pinter.

Forrest, D. (2002, May). *Historical Research Module handout. OTED1085 Research Methods.* Melbourne: RMIT.

Freeman, C. (1987). *Technology Policy and Economic Performance: Lessons from Japan*. London: Pinter.

Freeman, C. (1995). The 'National System of Innovation' in historical perspective. *Cambridge Journal of Economics, 19*(1), 5-24.

Freeman, R. (2004, May 7). Stimulating Careers in Science and Engineering. *Next Wave, 5*(7).

Gaughan, M., & Robin, S. (2004). National science training policy and early scientific careers in France and the United States. *Research Policy 33*, 569-581.

Graduate Careers Council of Australia. (2004). *A National Survey of Activities of 2002 University Graduates. Postgraduate Research Experience Questionnaire*. Parkville, Victoria: Graduate Careers Council of Australia.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., & Trow, M. (1994). *The New Production of Knowledge*. Stockholm: Sage.

Godinho, M., Mendonca, S., & Pereira, T. (2003). *Mapping Innovation Systems: A Framework Based on Innovation Data and Indicators.* Paper presented at the International Workshop on Empirical Studies on Innovation in Europe, Faculty of Economics, University of Urbino.

Gottschalk, L. (1969). *Understanding History: A Primer of Historical Method* (2nd ed.). New York: Alfred A. Knopf.

Green, P. (2002). Naturalistic Inquiry: A Method of Transforming Curiosity into Active Enquiry. In P. Green (Ed.), *Slice of Life. Qualitative research snapshots* (pp. 3-17). Melbourne: RMIT University Press.

Griliches, Z. (2000). *R&D, Education and Productivity. A Retrospective*. Cambridge: Harvard University Press.

Guellec, D., & Cervantes, M. (2002). International Mobility of Highly Skilled Workers: From Statistical Analysis to Policy Formulation. In *International Mobility of the Highly Skilled* (pp. 71-98). Paris: OECD.

Hammersley, M., & Atkinson, P. (1995). What is ethnography? In M. Hammersley & P. Atkinson (Eds.), *Ethnography: Principles in Practice* (2nd ed.) (pp. 1-22). London and New York: Routledge.

Haukka, S. (2003, 25-27 July 2003). *How is research training linked to innovation in Australia.* Paper presented at the Third Conference on Researching Work and Learning, Tampere, Finland.

Haukka, S. (2005). *Research training and national innovation systems. Finland compared to Australia and the United States*. Helsinki: Tekes.

High-Level Expert Group on Improving Mobility of Researchers. (2001). *Final Report*. Brussels: European Commission. Directorate of General Research.

Higher Education Council of the National Board of Employment, Education and Training. (1990). *Higher Education: The Challenges Ahead*. Canberra: Australian Government Publishing Service.

Horsley, M., & Woodburne, G. (2003). *Australian Academic Salaries Time Series Project 1977-2002*. Sydney: The Centre for Organisational, Vocational and Adult Learning.

Howard, J. (1997). *Investing for Growth*. Canberra: Australian Government Publishing Service.

Howard, J. (2001). *Backing Australia's Ability. An innovation action plan for the future*. Canberra: Australian Government Publishing Service.

Howard, J. (2005). *Backing Australia's Ability. The Australian Government's Innovation Report 2004-2005*. Canberra: Australian Government Publishing Service.

Howard Partners. (2003). *Evaluation of the Cooperative Research Centres Programme*. Manuka, ACT: Department of Education, Science and Training.

Hugo, G., Rudd, D., & Harris, K. (2003). *Australia's Diaspora. Its Size, Nature and Policy Implications*. Melbourne: Committee for Economic Development Australia (CEDA).

IDP Education Australia. (2005). *Scholarships*. Retrieved June 1, 2005, from http://www.idp.com/development/scholarships/default.asp

Industry Commission. (1995). *Research Development*. Canberra: Australian Government Printing Service.

Innovation Summit Implementation Group. (2000). *Innovation. Unlocking the Future. Final report of the Innovation Summit Implementation Group*. Canberra.

Jortikka, M., & Zirra, P. (2004). *International Mobility in Higher Education 2004*. Helsinki: CIMO.

Kemp, D. (1999a). *Knowledge and Innovation. A policy statement on research and research training*. Canberra: AusInfo.

Kemp, D. (1999b). *New Knowledge, New Opportunities. A Discussion Paper on Higher Education Research and Research Training*. Canberra: AusInfo.

Kline, S. J., & Rosenberg, N. (1986). An Overview of Innovation. In R. Landau & N. Rosenberg (Eds.), *The Positive Sum Strategy* (pp. 275-306). Washington D.C.: National Academy Press.

Knack, S., & Keefer, P. (1997). Does social capital have an economic payoff? *Quarterly Journal of Economics, 112*(4), 1251-1288.

KOTA Online. (2005). *Postgraduate students*. Helsinki: Ministry of Education.

Lam, A. (2002). *Changing R&D Organisation and Innovation: Developing the New Generation of R&D Knowledge Workers.* Paper presented at the Loc Nis Workshop, Rebild, Denmark.

Lancy, D. F. (1993). *Qualitative Research in Education. An Introduction to the Major Traditions*. New York: Longman.

Legal and Constitutional Committee. (2005). *They still call Australia home: Inquiry into Australian expatriates*. Canberra: Australian Senate.

Leydesdorff, L. (2006). "While a Storm is Raging on the Open Sea": Regional Development in a Knowledge-based Economy. *Journal of Technology Transfer*, *31*(1), 189-203.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic Inquiry*. Newbury Park, California: Sage Publications.

Lucas, R. (1988). On the Mechanics of Economic Development. *Journal of Monetary Economics, 22*(1), 3-42.

Lundvall, B.-Å. (1992). *National Systems of Innovation*. London: Pinter.

Lundvall, B.-Å. (2000). *Europe and the Learning Economy - on the need for reintegrating the strategies of firms, social partners and policy makers.* Paper presented at the Lisboa Seminar, Lisbon.

Lundvall, B.-Å., & Johnson, B. (1994). The Learning Economy. *Journal of Industry Studies, 1*(2), 23-42.

Lundvall, B.-Å., Johnson, B., Andersen, E., & Dalum, B. (2002). National systems of production, innovation and competence building. *Research Policy 31*, 213-231.

Mahroum, S. (1999). *Highly Skilled Globetrotters: The International Migration of Human Capital.* Paper presented at the OECD Workshop on Science and Technology Labour Markets, Paris.

Mahroum, S. (2001). Foreign Scientific Researchers in Selected OECD EU Countries. In *Innovative People. Mobility of Skilled Personnel in National Innovation Systems* (pp. 219-228). Paris: OECD.

Malerba, F. (2002). Sectoral systems of innovation and production. *Research Policy 31*, 247-264.

McKeon, R., & Lee, L. (2001). Australia's Challenge: The Knowledge-based Economy. *Committee for Economic Development of Australia (CEDA) Bulletin, March*.

McMahon, W. M. (1999). *Education and Development. Measuring the Social Benefits*. New York: Oxford University Press.

Ministry of Education. (2001). *An International Strategy for Higher Education*. Helsinki: Ministry of Education.

Ministry of Education. (2002). *Finnish Universities 2002*. Helsinki: Ministry of Education.

Ministry of Trade and Industry. (2003). *Research Programme for Advanced Technology Policy*. Retrieved October 10, 2003 from http://www.ktm.fi/index.phtml?l=en&s=552

Ministry of Trade and Industry. (2004). *Final Report: Innovation Policy to Yield More Returns*. Helsinki: Ministry of Trade and Industry.

Ministry of Education (2005a). *The Finnish Education System*, 1 July 2005, from http://www.minedu.fi/minedu/education/education_system.html

Ministry of Education (2005b). *University Education*, 1 July 2005, from http://www.minedu.fi/minedu/education/university_edu.html

Ministry of Education. (2005c). Government Resolution on the Structural Development of the Public Research System. *Composite News Bulletin January 2005*.

Ministry for Foreign Affairs of Finland. (2006). *Virtual Finland. Your Window on Finland*. Retrieved July 15, 2006, http://virtual.finland.fi/

Mowery, D. C., & Rosenberg, N. (1993). The U.S. national innovation system. In R. R. Nelson (Ed.), *National Innovation Systems: A Comparative Analysis* (pp. 29-75). New York: Oxford University Press.

Mowery, D. C., & Rosenberg, N. (1998). *Paths of Innovation. Technology change in 20th-Century America*. Cambridge: Cambridge University Press.

Nås, S. V., Ekeland, A., Iversen, E. J., Åkerblom, M., Virtaharju, M., Svanfeldt, C., & Ullström, J. (1998). *Formal Competencies in the Innovation Systems of the Nordic Countries: An analysis based on register data*. Oslo: STEP Group.

National Unions of Students in Europe (ESIB). (2003). Bologna Student Surveys. Retrieved July 5, 2006, from http://www.esib.org/frankfurt/survey/ESIB%20B%7f%7cogna%20Student%20Surveys.pdf

National Center for Education Statistics. (2002). *The Condition of Education*. Washington D.C.: National Center for Education Statistics.

National Center for Education Statistics. (2004). *Digest of Economic Statistics 2003*. Washington D.C.: National Center for Education Statistics.

National Research Council. (1998). *Trends in the Early Careers of Life Scientists*. Washington D.C.: National Academy Press.

National Science Board (2004). *Science and Engineering Indicators 2004*. Washington D.C.: National Science Foundation.

Nelson, B. (2002a). *Striving for Quality: learning, teaching and scholarship*. Canberra: Department of Education, Science and Training.

Nelson, B. (2002b). *Higher Education Report for the 2002 to 2004 Triennium*. Canberra: Department of Education, Science & Training.

Nelson, B. (2002c). *Higher Education at the Crossroads*. Canberra: Department of Education, Science and Training.

Nelson, B. (2003a). *Mapping Australian Science and Innovation*. Canberra: Department of Education, Science and Training.

Nelson, B. (2003b). *Higher Education Report for the 2003 to 2005 Triennium*. Canberra: Department of Education, Science and Training.

Nelson, B. (2003c). *Our Universities: Backing Australia's Future*. Canberra: Department of Education, Science and Training.

Nelson, B. (2003d). *$113 million to strengthen international education*. Canberra: Department of Education, Science and Training

Nelson, B. (2005). *Research Quality Framework. Assessing the quality and impact of research in Australia. The Preferred Model*. Canberra: Department of Education, Science and Training.

Nelson, R. (Ed.). (1993). *National Innovation Systems. A Comparative Analysis*. New York: Oxford University Press.

Nelson, R., & Rosenberg, N. (1993). Technical Innovation and National Systems. In R. Nelson (Ed.), *National Innovation Systems. A Comparative Analysis* (pp. 3-21). New York: Oxford University Press.

Nelson, R., & Phelps, E. S. (1971). Investments in Humans, Technological Diffusion and Economic Growth. In R. A. Wykstra (Ed.), *Human Capital Formation and Manpower Development*. New York: The Free Press. (Reprinted from *American Economic Review: Papers and Proceedings, 56,* 69-75).

Neuman, W. L. (1997). *Social Research Methods* (3rd ed.). Boston: Allyn and Bacon.

Neumann, R. (2003). *The Doctoral Education Experience: Diversity and Complexity*. Canberra: DEST.

Numminen, S. (1996). *National Innovation Systems: Pilot Case Study of the Knowledge Distribution Power of Finland*. Helsinki: VTT Group for Technology Studies.

OECD. (1997). *Oslo Manual*. Paris: OECD.

OECD. (1998a). *Human Capital Investment. An International Comparison*. Paris: OECD.

OECD. (1998b). *Education at a Glance*. Paris: OECD.

OECD. (1999). *Managing National Innovation Systems*. Paris: OECD.

OECD. (2000). *Knowledge Management in the Learning Society: Education and Skills*. Paris: OECD.

OECD. (2001a). *Cities and Regions in the Learning Economy*. Paris: OECD.

OECD. (2001b). *The Well-being of Nations. The Role of Human and Social Capital*. Paris: OECD.

OECD. (2002a). *Frascati Manual*. Paris: OECD.

OECD. (2002b). *International Mobility of the Highly Skilled*. Paris: OECD.

OECD. (2002c). *Dynamising National Innovation Systems*. Paris: OECD.

OECD. (2002d). *Benchmarking Industry-Science Relationships*. Paris: OECD.

OECD. (2002e). International Mobility of Science and Technology Personnel. In *Science, Technology and Industry Outlook 2002*. Paris: OECD.

OECD. (2003). *Science, Technology and Industry Scoreboard 2003*. Paris: OECD.

OECD. (2004a). *Main Science and Technology Indicators* (Vol. 2). Paris: OECD.

OECD. (2004b). *Education at a Glance, OECD Indicators 2004*. Paris: OECD.

OECD. (2004c). *Innovation in the Knowledge Economy: Implications for Education and Learning*. Paris: OECD.

OECD. (2004d). *Science, Technology and Industry Outlook 2004*. Paris: OECD.

OECD. (2005a). Main Science and Technology Indicators database. Paris: OECD.

OECD. (2005b). *Factbook 2005*. Paris: OECD.

OECD/Eurostat. (1995). *Canberra Manual*. Paris: OECD.

Office of Technology Management. (2005). *OTM brochure*. Champaign: University of Illinois at Urbana-Champaign.

Oxford Encyclopedia of Economic History. (2003). *Human Capital* (Vol. 3). New York: Oxford University Press.

Porter, M. (1990). *The Competitive Advantage of Nations*. New York: The Free Press.

Puustinen-Hopper, K. (2005). *Mobile Minds, Survey of foreign PhD students and researchers in Finland*. Helsinki: Academy of Finland.

Rastas, T., & Stevens, C. (2004). *Developing Highly Skilled Workers: Review of Finland*. Paris: OECD.

Re-envisioning the PhD a working conference. (2000). *Coming together to re-envision the PhD to meet the societal needs of the 21st century*. Seattle, WA.

RMIT University. (2002). *RMIT Guidelines to Examiners of Thesis*. Melbourne: RMIT.

RMIT University. (2004). *Intellectual Property Policy, August 2004*. Melbourne: RMIT.

Roberts, R. (2002). SET for success: The supply of people with science, technology, engineering and mathematic skills. Retrieved July 15, 2006 from http://www.hm-treasury.gov.uk/documents/enterprise_and_productivity/research_and_enterprise/ent_res_roberts.cfm

Romer, P. (1990). Human Capital and Growth: Theory and Evidence. *Carnegie-Rochester Conference Series of Public Policy, 32*, 251-286.

Romer, P. (2000). *Should the Government Subsidize Supply or Demand in the Market for Scientists and Engineers*. Cambridge, M.A.: National Bureau of Economic Research.

Rosengren, M. (1998). *An Inventory of National Priorities and Availability of Data in OECD Countries to Quantify Science and Technology Personnel Mobility Patterns*. Paper presented at the Joint NESTI/TIP/GSS Workshop, Paris.

Rothwell, R. (1994). Industrial innovation: success, strategy, trends. In M. Dodgson & R. Rothwell (Eds.), *Handbook of industrial innovation* (pp. 33-53). Cheltenham: Elgar Edward.

Salt, J. (1997). *International Movements of the Highly Skilled. Occasional Papers No. 3*. Paris: International Migration Unit, OECD.

Sarantakos, S. (1995). *Social Research*. South Melbourne: Macmillan Education Australia.

Schmookler, J. (1966). *Invention and Economic Growth*. Cambridge, Massachusetts: Harvard University Press.

Schuetze, H. G. (2000). Industrial Innovation and the Creation and Dissemination of Knowledge: Implications for University-Industry Relationships. In *Knowledge Management in the Learning Society* (pp. 161-174). Paris: OECD.

Schultz, T. W. (1963). *The Economic Value of Education*. New York: Columbia University Press.

Schultz, T. W. (1971). *Investment in Human Capital: The Role of Education and Research*. New York: The Free Press.

Science and Technology Policy Council of Finland. (2002). *Knowledge, Innovation and Internationalisation*. Helsinki: Science and Technology Policy Council.

Science and Technology Policy Council of Finland. (2004). *Internationalisation of Finnish Science and Technology*. Helsinki: Science and Technology Policy Council.

Sheehan, J. (1973). *The Economics of Education* (Vol. 9). London: Oxford University Press.

Sinclair, M. (2004). *The Pedagogy of 'Good' PhD Supervision: A National Cross-Disciplinary Investigation of PhD Supervision*. Canberra: DEST.

Smith, R. (1988). *Review of Higher Education Research Policy*. Canberra: Department of Employment, Education and Training.

Stake, R. E. (1995). *The Art of Case Study Research*. Thousand Oaks, California: Sage Publications.

Statistics Finland. (2005). *Wage and salary statistics*. Helsinki.

STRATA-ETAN Expert Working Group. (2002). *Human Resources in RTD (including attractiveness of S&T professions)*. Brussels: European Union.

Stewart, D. W. (2005, May 8). U.S. colleges losing foreign students. *The Boston Globe*. Retrieved June 10, 2005, from http://www.boston.com/news/education/higher/articles/2005/05/08/the_brain_drain/

Stocker, J. (1997). *Priority Matters. A report to the Minister for Science and Technology, on Arrangements for Commonwealth Science and Technology, by the Chief Scientist*. Retrieved February 29, 2004, from http://www.dest.gov.au/Archive/Science/chiefscientist/reports/Priority_Matters/

Sturman, A. (1997). Case Study Methods. In J. P. Keeves (Ed.), *Educational Research, Methodology and Measurement: An international handbook (Second ed.)* (pp.49-53). Oxford: Elsevier Science.

Sweetland, S. R. (1996). Human Capital Theory: Foundations of a Field of Inquiry. *Review of Educational Research, 66*(3), 341-359.

Tekes. (2004). *Tekes Annual Review 2004*. Helsinki: National Technology Agency of Finland.

The Taskforce on the Future of American Innovation (2005). *The Knowledge Economy: Is the United States Losing its Competitive Edge?* Retrieved August 21, 2005, from http://www.futureofinnovation.org/

Tomei, P. (2005). *Study Outside of the United States of America (USA)*. Retrieved June 1, 2005, from http://scholarships.fatomei.com/study.html

Tremblay, K. (2002). Student Mobility Between and Towards OECD Countries: A Comparative Analysis. In *Innovative People. Mobility of Skilled Personnel in National Innovation Systems* (pp. 39-67). Paris: OECD.

United Nations. (2005). *Eighth United Nations Survey of Crime Trends and Operations of Criminal Justice Systems, covering the period 2001 - 2002*.

University of Oulu. (2005). *Principles for the Distribution of Benefits in the University of Oulu*. Retrieved June 1, 2005, from http://www.oulu.fi/tupa/english/html/principles.html

U.S. Committee on Science, Engineering and Public Policy. (1995). *Reshaping the Graduate Education of Scientists and Engineers*. Washington D.C.: The National Academies Press.

Vann Maanen, J. (1988). *Tales of the Field. On Writing Ethnography*. Chicago: University of Chicago.

Varis, M. (2004). The Reforms in Finland: A Student's Perspective. *Next Wave, 5*(7).

Villaschi, A. (2002). *An Analytical Framework for Understanding the Finnish National System of Innovation*. Helsinki: The Research Institute of the Finnish Economy (ELTA).

Walshok, M. L. (1995). *Knowledge without Boundaries: What American Research Universities can do for the Economy, the Workplace and the Community*. San Francisco: Jossey-Bass.

Wiersma, W. (2000). *Research Methods in Education* (Seventh ed.). Boston: Allyn and Bacon.

Wikipedia. (2006). *Australia*. Retrieved July 15, 2006, from http://en.wikipedia.org/wiki/Australia

Wikipedia. (2006). *Finland*. Retrieved July 15, 2006, from http://en.wikipedia.org/wiki/Finland

Wikipedia. (2006). *United States*. Retrieved July 15, 2006, from http://en.wikipedia.org/wiki/United_States

Wills, P. (1999). *The Virtuous Cycle. Working together for health and medical research. Executive Summary*. Canberra: National Health and Medical Research Council.

Wood, F., & Boardman, K. (1999). *International Networks and the Competitiveness of Australia's Science and Technology*. Canberra: Australian Academy of Science.

World Economic Forum. (2002). *Global Competitiveness Report 2001/2002*. Geneva: World Economic Forum.

World Economic Forum. (2003). *Global Competitiveness Report 2002/2003*. Geneva: World Economic Forum.

World Economic Forum. (2004). *Global Competitiveness Report 2004/2005*. Geneva: World Economic Forum.

World Economic Forum. (2005). *Nordic countries and East Asian tigers top the rankings in the World Economic Forum's 2005 competitiveness rankings*. Geneva: World Economic Forum.

Wykstra. (1971). *Human Capital Formation and Manpower Development*. New York: The Free Press.

Yin, R. K. (1989). *Case Study Research. Design and Methods*. Newbury Park, California: Sage Publications.