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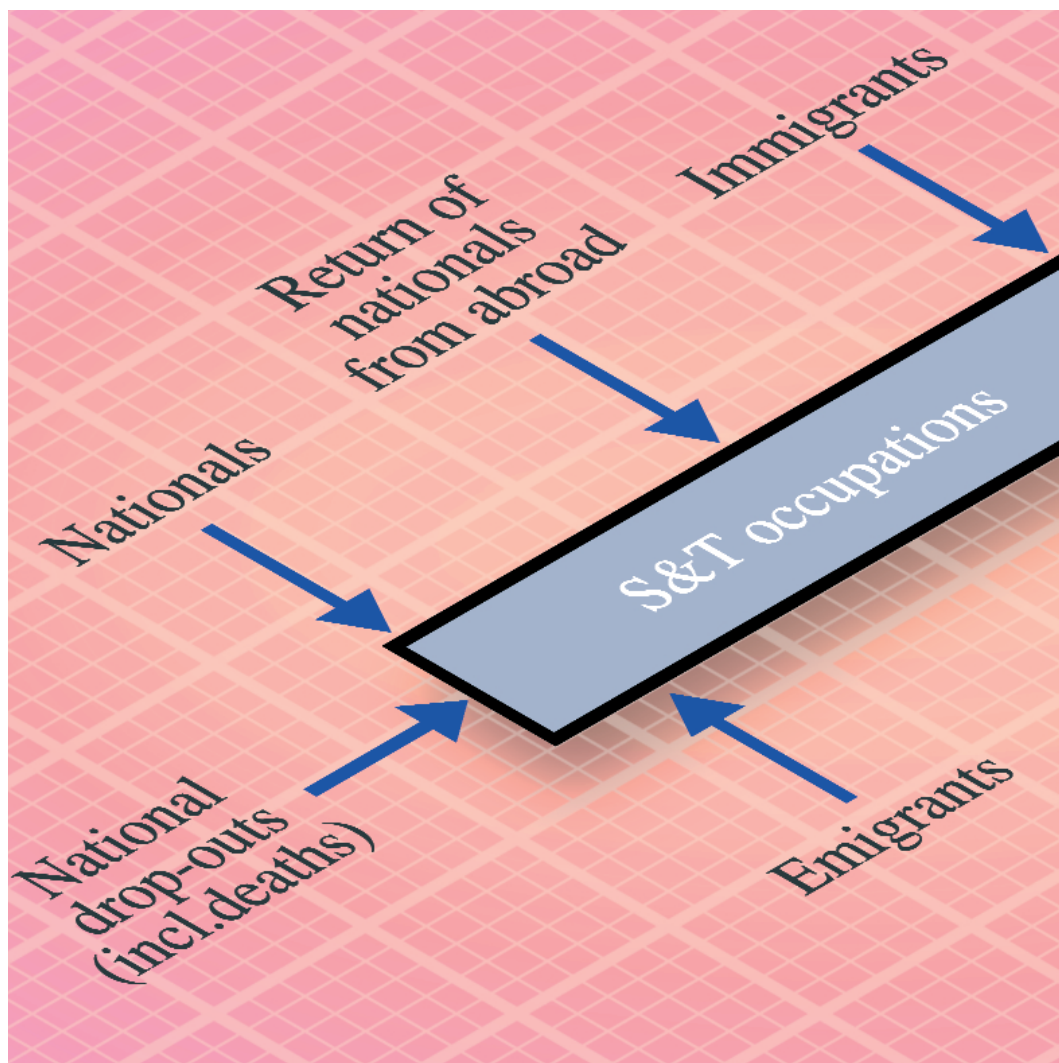# Research training and national innovation systems

Finland compared to Australia and the USA

Sandra Haukka

TEKES

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Tekes – Your contact for Finnish Technology

Tekes, the National Technology Agency of Finland, is the main funding organisation for applied and industrial R&D in Finland. Funding is granted from the state budget.

Tekes' primary objective is to promote the competitiveness of Finnish industry and the service sector by technological means. Activities aim to diversify production structures, increase production and exports and create a foundation for employment and social well-being. Tekes finances applied and industrial R&D in Finland to the extent of about 400 million euros annually. The Tekes network in Finland and overseas offers excellent channels for cooperation with Finnish companies, universities and research institutes.

Technology programmes – part of the innovation chain

Tekes' technology programmes are an essential part of the Finnish innovation system. These programmes have proved to be an effective form of cooperation and networking for companies, universities and research institutes for developing innovative products, processes and services. Technology programmes boost development in specific sectors of technology or industry, and the results of the research work are passed on to business systematically. The programmes also serve as excellent frameworks for international R&D cooperation. In 2005, 24 extensive technology programmes are under way.

Foreword

Research training has strong links to national innovation environments and innovation policies practised 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.

This report is based on key findings from the PhD study by Sandra Haukka from the RMIT University, Melbourne, Australia. The introductory chapter of this report summarises the PhD topic, research design, and key findings for Finland (compared to Australia and the USA). The second chapter defines and clarifies the key concepts for this study and includes an overview of the nature and performance of national innovation and research training systems in each country. The remaining chapters each represent an element of the conceptual framework, starting with a theoretical background to the particular element and followed by an analysis of findings for each country against key assumptions that have been drawn. The final PhD thesis containing all findings and recommendations, together with a description of a *research training culture of innovation* will be available in late 2005.

The data collection stage was undertaken in the three countries – Australia (from February to June 2003), Finland (from July to December 2003), and USA (from January to May 2004). Whilst overseas, the author of this report was a Visiting Scholar at the University of Oulu and University of Illinois at Urbana-Champaign. Document analysis, interviews with innovation and research training experts, and statistical analysis were the main methods used as part of the historical research component. Case study methodology (which used the methods of semi-structured interviews, short observations and document analysis) produced 30 case studies of research students in the science and technology fields of geospatial science, wireless communication, biosciences, and materials science and engineering. The quantitative research component involved collecting data from the OECD and country sources in relation to innovation investment and performance, size and outputs of research training systems, international mobility and migration, and human capital stocks, investments, returns and impacts (economic and non-economic).

Tekes wishes to thank the author for an informative, analytical and, policywise, a most timely study.

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Tekes

Acknowledgement

Summary: Key findings for Finland compared to Australia and USA

Nature and performance of national innovation systems and research training systems

Efforts to create a coherent and efficient national innovation system have transformed Finland into a leading innovating nation. Finland invests significantly more than Australia and the United States in terms of gross and business expenditure on R&D (as a proportion of GDP) and the number of researchers as a proportion of total employment. Patenting and S&E publishing activities (on a population basis) remain above that for Australia and the United States. Finland's share of world citations continues to rise. Rankings from the latest *Global Competitiveness Report* indicate that Finland remains a world leader 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. Chapter 2 presents key strengths and weaknesses as well as strategies to strengthen Finland's national innovation system. The key challenge is internationalising the national innovation system to ensure it can better manage the impact of globalisation and rapid international change on industrial structures, business models and competencies.

The Graduate School system and other research funding arrangements have succeeded in expanding the number of research (doctorate) graduates within Finland's national innovation system. Finland's commitment to the Bologna process is expected to increase mobility of research students within Europe (including Finland) and further reduce the time taken to complete doctorates. It is still too early to determine whether the *Knowledge and Innovation* reforms to research training in Australia have succeeded in addressing specific deficiencies and creating better connections between universities and the national innovation system. The steady increase in the number of research completions is a positive sign. The research training system in the United States has also aimed 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 were also concerns about the rapidly increasing supply of foreign research students who remain in the United States after graduating.

Element 1: International mobility and migration of research students and graduates

This element of the conceptual framework assumes that research students are likely to contribute to a national innovation system in Australia, Finland or the USA if, after graduating, they continue their research career AND remain in their own country (they are *immobile*); migrate to Australia, Finland or the USA 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*).

Finland, along with Australia and the United States, has a range of programs in place which aim 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 research students and graduates. The issue for Australia is the *brain drain* of domestic research graduates. The United States has relied heavily on a supply of foreign students and researchers for some time and events of recent years are suggesting that it is no longer the primary destination for these people.

Foreign research students and graduates in Finland are attracted to the high level research environment and as a

whole are satisfied with the quality of information and guidance provided. As a result, nearly half of those people surveyed in 2004 intend 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. Therefore, Finland should continue its efforts to encourage more student exchanges but with a greater focus on attracting research students. This includes more innovative approaches (including funding opportunities) to attract foreign research students and graduates to Finland. More effort is also needed to encourage Finnish research students and graduates to work abroad where they can establish international networks. Although most of the Finnish research students who were case studied participate in international conferences, workshops and/or courses, this study recommends mobility initiatives that are longer in duration in order to establish strong and ongoing networks.

Finland, Australia and the United States are proud of its ability to employ researchers at rates that are consistently above the OECD average and for its efforts in expanding the number of research jobs (particularly in industry for Finland and the United States). However, those with doctoral degrees 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 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 their programs have not prepared them to work in other sectors and demand for research graduates in industry is not sufficient. More effort is needed in the three countries to address these issues whilst considering the demand and supply for research graduates in science and technology fields.

Element 2: Knowledge production and distribution by research students
(case studies)

Element 2 assumes that the contribution of the 30 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; research results are effectively disseminated to all stakeholders through 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 and the capabilities to work in knowledge-based economies. These activities are further enhanced when they occur in countries with cultural characteristics that are conducive to innovation.

All 30 research students were undertaking research that to varying degrees was context related i.e. useful to industry, government or society. The usefulness of their research is indicated in many cases by funding support by potential benefactors. The students are expected to disseminate their results through the traditional Mode 1 methods of reporting in journals or at conferences – three to four international (and refereed) publications 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 were interacting with and disseminating 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) in Oulu regularly report 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. Students could interact with people from other disciplines through seminar series and the sharing of facilities. The three students from the Beckman Institute were the only students who appeared to be directly involved in transdisciplinary research.

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 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 international conferences were usually held in the United States, UIUC students could easily access these international networks. Students from the University of Oulu mainly attended international conferences and meetings held in Europe with some students (particularly those from the CWC) travelling beyond Europe. Most of the Australian students were unable to attend 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.

All three countries have cultural traits that support innovation. However, Australian culture does not appear to have embraced innovation and the importance of R&D to the extent that the other two countries have. This study recommends that research is undertaken to examine the impact of national culture on the production and distribution of new knowledge in research and research training environments.

Element 3: Research training, human capital and economic growth in Finland

This element of the conceptual framework assumes that 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 a country in order to build a highly qualified workforce. 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 than Australia and the USA, a higher proportion of the population go on to complete a research degree. Finland produces a higher share of graduates in S&E fields than Australia, the United States and the OECD mean mainly due to the very high share of engineering graduates. However, Finland has experienced lower average growth in HRST contributing to recent declines in HRST stocks, HRST core and the number of scientists and engineers in Finland (after peaking in 2001).

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. High earnings combined with the low cost of education have led to private rates of return for university educated people in Finland that are well above that for Australia and the United States Higher taxation rates in Finland may have offset the high public cost of education, leading to above average social rates of return for university educated people. For all three countries, earnings data suggests that private and social rates of returns for those people with research degrees are above rates given for the combined category of tertiary type A and advanced research degrees.

The relatively high level of human capital investment and stocks in Finland appears to have had a positive impact on GDP per capita, life expectancy, infant mortality, relative poverty and life satisfaction and feelings of happiness. However, human capital investment appears to have negatively impacted on Finland's homicide conviction/committal rate which is 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. This study recommends a more thorough analysis of the relationship between research training and economic growth in each country.

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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).

Reforms were largely in response to the Government's concern that **research in universities is often disconnected from the national innovation system**. Reforms aim to extend higher education research to the national innovation system through closer links with industry, thereby contributing to stronger local and international connections between the producers and users of research. Universities are expected to conduct research and research training in an entrepreneurial environment. This involves universities collaborating with partners across the world and with other actors in the national innovation system. There would be a stronger movement of staff and researchers across various research settings through collaborative projects and student exchanges. Research students would acquire 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: 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. However, there has been little research on the impact of research and research training initiatives 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 study is to investigate if and how **research training contributes to a national innovation system** in order to determine ways that Australia can improve this contribution. Australia currently 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. However, 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 of American (USA) – two contrasting countries which are regarded as world leaders in innovation.

Findings should provide stakeholders in each country (such as policy makers, funding bodies, universities and innovation researchers) with greater insight into the contribution of research training to the national innovation systems of Australia, Finland and the United States. The key outcome of the study is the identification of the features of a **research training culture of innovation** that could enhance this contribution. This is achieved through an analysis of research training and innovation policy and systems in these three countries since the early 1990s together with case studies of 30 research students in the science and technology fields of geospatial science, wireless communication, biosciences, and materials science and engineering.

1.2 Research design

The study aims to address the key research question of whether research training (particularly in science and technology fields) contributes to national innovation systems in Australia, Finland and the USA. This involves answering eight secondary research questions within a conceptual framework consisting of three elements (Figure 1):

- International mobility and migration of research students and graduates, particularly in science and technology fields.
- 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).
- The relationship between research training, human capital and economic growth.

The study uses a mixed methodology strategy based on a complementary relationship between qualitative and quantitative research methodologies. The strategy consists of three components that were undertaken for Australia, Finland and the USA:

- Historical research to source and analyse key documents that explain the nature, development and performance of the national innovation system and research training system in each country. The key focus of the historical research component was to determine if policies and systems encourage research students to contribute to a national innovation system.
- Case study research to produce 30 case studies of research students in science and technology fields from RMIT University (Australia), University of Oulu (Finland) and University of Illinois at Urbana-Champaign (USA).
- Quantitative research whereby statistical data is an important part of the historical research methodology and two elements of the conceptual framework.

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

Elements of the conseptual 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 rational innovation system, research training and research students?*

❷ What is the role of research training (particulary in science and technology fields) 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 United States?

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

❺ How has each country perfomed on terms of *brain drain, brain gain* and *brain circulation?*

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

❼ Does research training as human capital formation contribute to economic growth in Australia, Finland and the United States?

❽ What is *a reseach training culture of innovation?*

Constructivism/Interpretivism

Country

Methodology: Historical research, late 1980s to present

Methods: Documents, statistical records and oral statements

Methodology: Quantitative

Methods: OECD and country statistical records

University level

Research training program level

Research student level

Methodology: Case study research

Methods: Interviewing, observing and filming to form 30 intrinsic case studies of research students in science and technology fields

Number of people interviewed/case studied

Figure 1. Research design

2 Key concepts

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

This chapter aims to present internationally agreed and/or recognised definitions and explanations for these concepts rather than to debate their meanings (as addressing the key research question is the focus of this study). By doing so, this chapter aims to explain what is meant by "innovation", a "national innovation system", "research training" and "research students" (research question 1). The discussion in this chapter also aims to identify the role of research training (particularly in science and technology fields) in a national innovation system (research question 2). This chapter also provides an overview of the nature and performance of national innovation systems and research training systems in Finland, Australia and the United States.

2.1 Innovation

Definition of innovation

The OECD Oslo Manual (1997) contains guidelines for collecting and interpreting science and technological data related to innovation. The 1997 version 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 main type of innovation in the manual 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 is defined as a "product whose technological characteristics or intended uses 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 in the manual 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 defined as "an existing product whose performance has been significantly enhanced or upgraded. A simple product may be improved (in terms of better performance or lower cost) through use of higher-performance components or materials, or a complex product which consists of a number of integrated technical sub-systems may be improved by partial changes to one of the sub-systems" (p. 32). Examples provided include 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. Technological **process innovation** is defined 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).

The manual distinguishes between **worldwide TPP innovation**, "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). The manual presents these terms as *New to the world* and *New to the firm* in Figure 2, which also includes 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** or "the introduction of significantly changed organisational structures; the im-

			INNOVATION			Not innovation
			Maximum	Intermediate	Minimum	
			New in the world	(a)	New in the firm	Already in firm
TPP	Technologically new	Product				
		Production process				
		Delivery process				
INNOVATION	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

Figure 2. Types of innovation. Source: OECD (1997) p. 36

plementation 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 category of **not innovation** refers to changes in products and processes that "are insignificant, minor, or do not involve a sufficient degree of novelty; or "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 most well known theories, models or approaches to innovation. Rothwell (1994) identified **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 func-

tions. 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).

Linear models (post World War II)

In the period following World War II, the linear model of innovation in which the market reacted to R&D outputs in a simple sequential process was generally accepted. 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 in-

ventor 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).

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 process, 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.
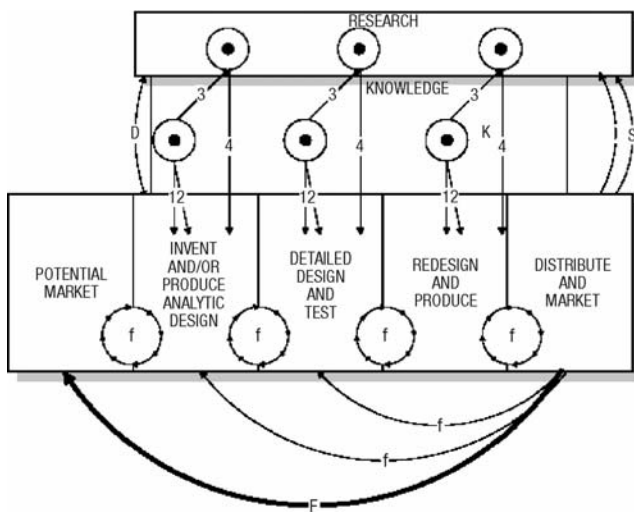
Figure 3. Chain-link model of innovation.
Kline & Rosenberg (1986) p. 289

Kline & Rosenberg (1986) proposed a **chain-link model** (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).

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 represent 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, 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 are often formalised in R&D laboratories, undertaken by large firms and lead to product innovations that are 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.

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 achieve international success in particular industries. He identified four broad and interrelated factors (and presented these as a "diamond" in 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 (such as policies for capital markets and education), standards and regulations, and as a major buyer of many of the nation's products. *Chance* events (such as surges in world or regional demand, changes in financial markets and exchange rates, war, pure invention etc) are included in the diamond as they cause shifts in competitive advantage.

Porter (1990) divided factor conditions into *basic* factors (e.g. natural resources, climate, location, unskilled and semi-skilled labour, and debt capital) and *advanced* factors (e.g. modern digital data communications infrastructure, highly educated personnel such as graduate engineers and computer scientists, 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, 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, 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 are 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 to do not occur evenly throughout an economy, Porter (1999) proposed that industries are connected through **clusters** which draw on "common inputs, skills, and infrastructure and also stimulates government bodies, educational institutions, firms, and individuals to invest in relevant factor creation or factor-creating mechanisms" (p. 135).
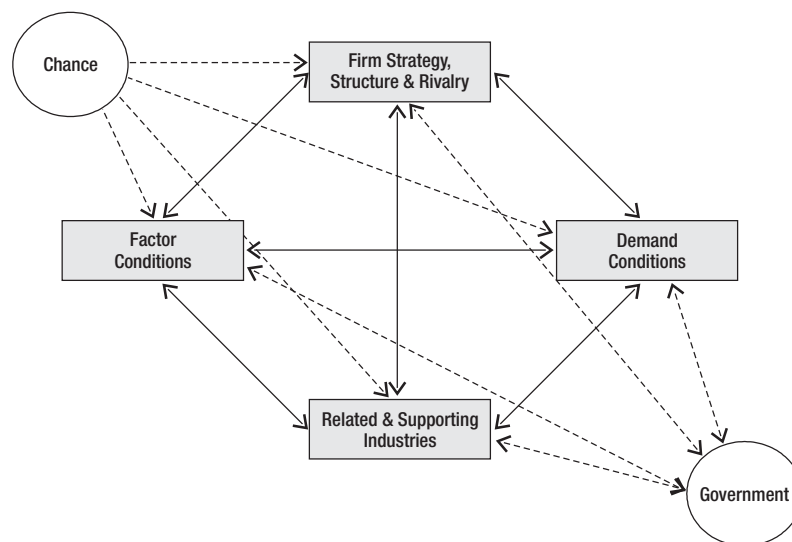
Figure 4. Determinants of national competitive advantage. Source: Porter (1990) p. 127

The impact of industry clusters on factor creation (and up-grading) is strongest when there is vigorous domestic rivalry and rivals are located in the same city or region.

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[1], sectoral[2] and technological[3], and their development have 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. The basic premise of the evolutionary theory of technical change first proposed by Nelson and Winter (1982) is 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). 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.
- 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 (such as the unspecific boundaries of systems) 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.

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, forthcoming). 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 US 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

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1   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.
2   Malerba (2002) defines 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).
3   Carlsson (1997) refers 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).

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, such as 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 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.

2.2 National innovation systems

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 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 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 Dosi et al (1988). The book included a four chapter-section on national systems of innovation by Lundvall, Freeman and Nelson. Lundvall (1992) and Nelson (1993) developed different but somewhat com-

plementary 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 "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). This 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) believes it is still important to understand how institutional and economic structures impact on the promotion of innovation at a national level. Lundvall (1992) 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 three interconnected phenomena[4] in the post-Fordist era (i.e. ICT, flexible specialisation and changes in the innovation process)

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4   The three interconnected phenomena included "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).

created new constellations of knowledge and learning in the economy. This 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).

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* (knowledge about "facts" or "information"); *know-why* (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* (the ability to do different kinds of things on a practical level i.e. skills); and *know-who* (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 government's role in the learning economy is to support learning processes by:

- 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 programmes for projects of cooperation to support network formation
- encouraging learning to forget through for example, a system of redistribution to compensate victims of change such as different social security arrangements, active labour market and retraining policies.

By 2002, Lundvall et al (2002) were advising that national innovation systems should be considered from the dimensions of structure (what is produced in the system and what competencies are most developed) and the institutional set up (how production, innovation and learning takes places). 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) examines 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), Nelson and Rosenberg (1993) stated 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 are becoming increasingly transnational, they questioned the relevance of the *national* innovation systems concept, and clarified each word rather than the concept itself. They focused on identifying the factors that influence national technological capabilities rather than understanding the behaviour of firms and institutions to explain the word 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, as it gives rise to new technology on the one hand yet is undertaken to understand and improve new technologies on the other. They found that technology advances in many fields are being made by people who are 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" (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 the observe *national* innovation systems however internationalisation is making it difficult for national governments to support national industry and requires people, governments and the public re-

search system to work with firms with overseas head-quarters.

- 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.
- Highly competent firms in their line of business, an education and training system that provides firms with a flow of people with the rights 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 are features common to effective innovation performance.
- 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.

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), but 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 (enterprises, research institutes and universities) but states that these interactions 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 such as country size, level of development, industrial specialisation, specific in-stitutional 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 (the users) and non-market institutions[5] (knowledge-producers) to achieve collective goals "influences the direction and speed of innovation and technology diffusion" (OECD, 1999, p. 23).

A national innovation system aims to **generate, diffuse and use knowledge**, which is crucial for economic performance, competitiveness, increased productivity and improved living standards in a knowledge economy (Figure 5). 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, such as 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 through macro-clustering (where the economy is a network of interlinked sectoral clusters) and functional analysis (where the economy, as networks of institutions, maps knowledge interactions among and between institutions). The OECD (1999) identified five types of knowledge flows within the functional analysis approach that can be measured. 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 element in a national innovation system, 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 programmes to the needs of the changing world.

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*) together with the ability of organisations to ap-

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5   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.
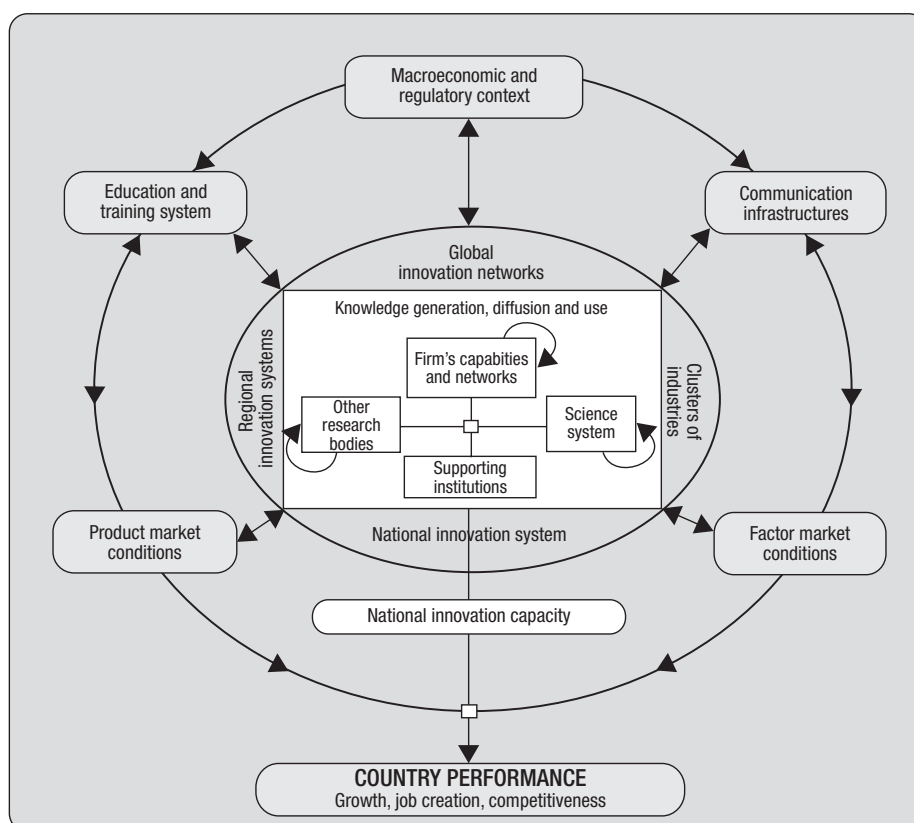
Figure 5. Actors and linkages in a national innovation system.
Source: OECD (1999) p. 23

ply new knowledge (their *absorptive capacity*). Creating new and disseminating existing knowledge also requires individual learning, which leads to *human capital*. New knowledge created by a PhD student is an example of individual learning in table 1. The OECD (2002a) 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).

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

Table 1. 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 student; 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

address blocks[6] in the innovation system and to secure framework conditions[7] that are conducive to innovation. In a report from the National Innovation Systems project, *Dynamising National Innovation System*, the OECD (2002b) 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, such as 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 providing institutions with incentive mechanisms and coordination arrangements, including intellectual property rights that encourage the disclosure and pooling of knowledge (which is discussed further in Chapter 4). 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 etc) 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, 2002c, p. 16). The OECD (2002c) identified a number of areas for policy action that would support and encourage industry-science relationships in a national innovation system. These include giving priority to basic and long-term mission oriented research in government S&T programmes; 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).

Assessing national innovation system performance

To assess the performance of a national innovation system, Lundvall (1992) recommends 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. In 2000 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 for candidate countries 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 third Community Innovation Survey (CIS).

Another useful approach for measuring innovation is included in the European Commission's *Third European Report on Science and Technology Indicators* produced in 2003. This report divides indicators into two categories: investment in knowledge production, dissemination and absorption; and performance in knowledge production, exploitation and commercialisation. Many of these indicators as well as other indicators are provided in the OECD's

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6   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.

7   Framework conditions include a stable macroeconomic environment, a supportive tax and regulatory environment, and appropriate infrastructure and education and training policies.

Table 2. 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)

Main Science and Technology Indicators and *Science, Technology and Industry Scoreboard*. Key innovation investment and performance indicators from these two publications are contained in Table 2. Finland's performance in most of these indicators is assessed against that for Australia, the USA and the OECD in this chapter.

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 GCI 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 shown in Figure 6 below.

Porter and Stern regard the number of international **patents** granted by the US Patent and Trademark Office (USPTO) as the best measure of national innovative performance
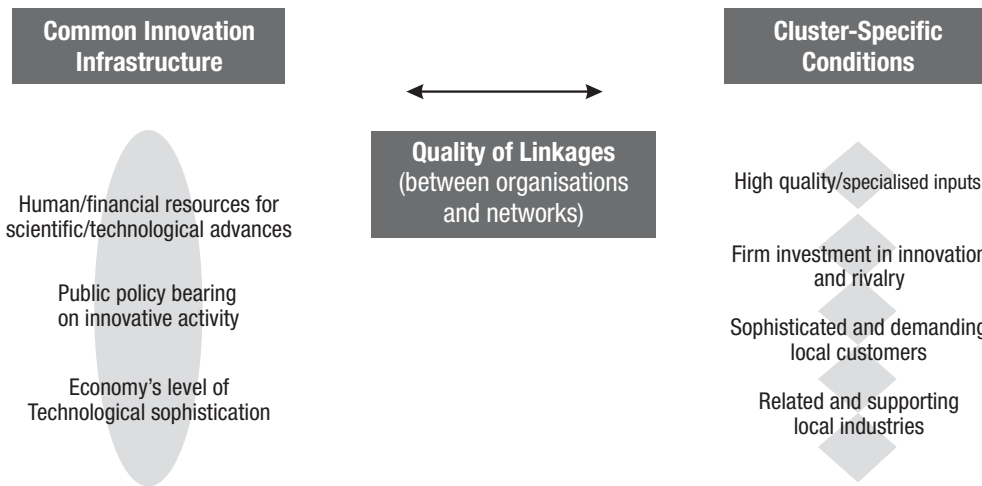
Figure 6. Elements of national innovative capacity.
Source: World Economic Forum (2003) p. 105

(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, the 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, UK 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 & Pereira (2003) found that most mapping exercises have concentrated on the actors and linkages that connect a national innovation system. They argue 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 use 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 *resource supply* dimension and PhDs in science and engineering per 1000 in the age group 25 and 34 years is a variable in the *actors and their behaviours* dimension.

2.3 National innovation systems in Finland, Australia and the USA

Finland

Finland was the first country to adopt the national innovation system approach in its science and technology policy during the depression of the early 1990s. This 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, 2004). Finland describes its 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" (Finnish Science and Technology Service, 2005). Finland currently assesses the success of its national innovation system in five areas: the capability for constantly generating new high-standard and relevant knowledge; efficient and unimpeded diffusion of knowledge and know-how; advanced capability for exploiting knowledge produced abroad; effective horizontal partnerships in the domain of knowledge which permeates society; and as a result of which network-building across sectoral boundaries comes naturally.

Key organisations or "players" in **Finland's national innovation system** (Figure 7) 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 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.
- The network of higher education institutions, technology centres, centres of expertise and other operational players within regional innovation systems.
- Large (and increasingly internationalised) industrial enterprises particularly in forestry, engineering, manufacturing and electronics.
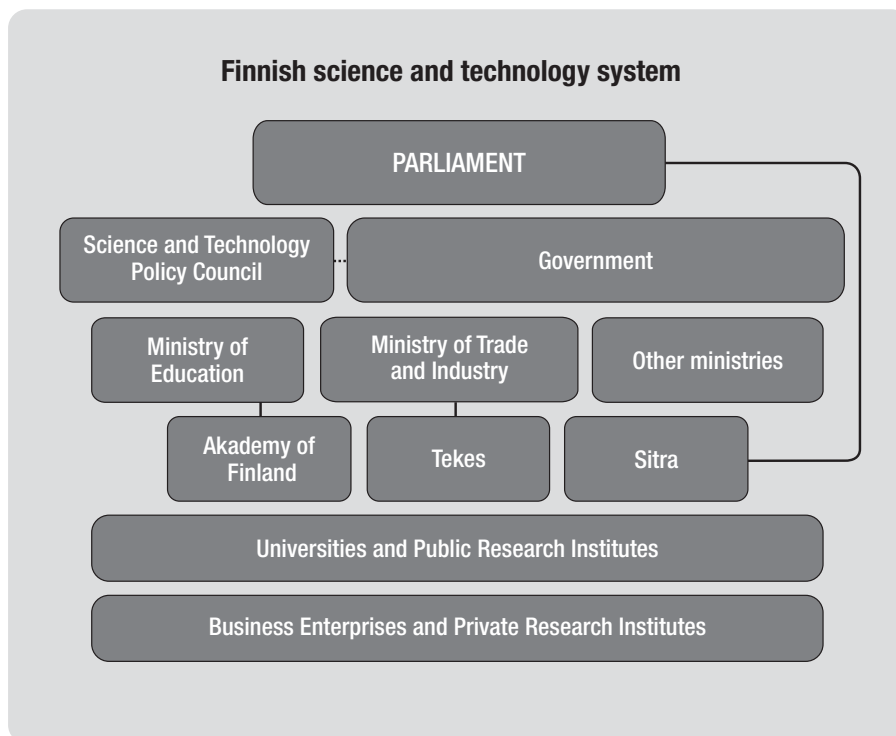
Figure 7. Finland's national innovation system.
Source: Finnish Science and Technology Service (2005)

In 2002, the total R&D workforce in Finland national innovation system consisted of 55,044 personnel 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. In addition, there were 22,105 students enrolled in postgraduate courses in 2004 of which around 70% were undertaking doctoral research.

Finland reports on its innovation performance as part of the European Innovation Scoreboard (European Commission, 2004). The SWOT analysis of Finland's national innovation system included in the latest report for the period covering September 2003 to August 2004 is included in Table A1 in the appendix. Key strengths identified in the report and SWOT analysis included 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, 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 are key challenges for Finland. This study included interviews with representatives from key players in Finland's national innovation system. Table 3 contains strengths and issues about the Finnish innovation system that were largely identified from these interviews.

Table 3. 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 that are 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 pressures 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" (ProAct, 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, *Knowledge, Innovation and Internationalisation*, 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.	Also stated in the above report and reiterated by the representative from the Science and Technology Policy Council of Finland (2002), 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 Master degree.	
Greater efforts are now being placed on social innovations to ensure complementarity of societal and social development with economic and technological development.	

The current policy framework for science, technology and innovation was released in December 2002 in the sixth triennial review of the Science and Policy Council of Finland, *Knowledge, Innovation and Internationalisation*. Table A2 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. In summary, the national strategy includes a focus on 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.

Three major reports that were recently released support this national strategy by aiming 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 include 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 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 aims to strengthen knowledge, competence, education, research, and innovation through extensive international cooperation. One of the strategy's objectives is 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 aims to continually develop 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, 2005a).

Australia

The diagram of **Australia's national innovation system** (Figure 8) 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. More recently, five main groups of *players* across the public and private sectors were identified as part of Australia's major mapping exercise of science and innovation that was completed in November 2003 (Nelson, 2003a):

- Thousands of large and small firms in the business sector in all industries, including firms that are part of multinational corporations.
- 39 higher education institutions (universities) which undertake research to generate new knowledge and train the future research workforce, as well as other organisations including Cooperative Research Centres and Centres of Excellence.
- A variety of Australian Government and state and territory government research and science agencies (e.g. CSIRO, 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.
- 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.

There were 95,710 personnel in Australia's R&D workforce in 2000 of which 66,099 personnel (or 69.1%) were 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. In 2004, there were 47,309 research students enrolled in higher education institutions in Australia and 15,231 of these students (or 32.2%) were undertaking research in the S&T fields of natural and physical sciences, information technology, and engineering and related technologies.

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* (see Table A3 in the appendix) – a five year $2.9 billion strategy announced by Prime Minister John Howard in January 2001. The Government estimated that their strategy would be underpinned by $6 billion from the private sector and educational and research institutions that will work in partnership with it to enhance Australia's capacity for innovation. In May 2004, Prime Minister John Howard announced that the 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.

FEDERAL PARLIAMENT

Cabinet

Prime Minister

Ministers

Industry

Advisory bodies
PMSEIC
Chief Scientist

Policy and Programme
Development Departments
(ISR, DETYA, AFFA, etc.)
Co-ordination: CCST

Legal and regulatory framework | IP Australia

Promoting and supporting organisations

Australian Research Council

National Health and Medical Research Council

Ausindustry and R&D Board

R&D Start | R&D tax concession

Rural R&D corps.

Industry associations

Business networks

Public research organisations

Universities

Federal government research bodies – CSIRO, etc.

State government research bodies

R&D performing firms

Private non-profit research organisations

Private research

Linkages and technology diffusion

University consultancy and contracting services

External earning targets for public research orgs.

Technology Diffusion Programme

Science and technology parks

Co-operative Research Centres

Venture capital programmes

KEY	public	Private
Initiated		
funded		

Innovation Investment Fund

Australian Technology Group

Pooled Development Funds

Figure 8. Australia's national innovation system.
Source: DISR (1999) p. 37

The Minister for Education, Science and Technology, Dr Brendan Nelson, released *Mapping Australian Science and Innovation* in November 2003. The purpose of the mapping exercise was to inform future policy development by identifying strengths that should be maintained and developed; weaknesses and gaps in science and innovation performance; and complementarities and areas of possible greater cooperation between the national Government and state and territory Governments. Many of the strengths, weaknesses and complementarities in Australia's national innovation system from this report (in Table A4 in the appendix) have existed for some time and 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 include patenting levels, business expenditure on R&D, and breadth of international science and engineering collaboration.

United States

The European Trend Chart on Innovation includes annual policy trend reports on the North American countries of Brazil, Canada, Mexico and the United States. The latest report for the period from September 2003 to August 2004 described the US national innovation system as a combined centralised and regionalised system consisting of many Federal agencies with R&D and commercialisation programmes and State and local government agencies with science and technology initiatives. There is no central body coordinating these activities.

Mowery and Rosenberg (1993) referred to the gargantuan task in describing the **US 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 US national innovation system:

- National R&D investment that was more than that of all other OECD nations combined during most of the post war era. However, US national output devoted to R&D has been flat or declining since the early 1990s. This 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).

- 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 technology industries).

- The significant increase in Federal Government support for university research during and after World War II (particularly in basic research and in defence-related technologies) transformed major US 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 importance of new firms in the commercialisation of new technologies within the US economy such as in microelectronics, computer hardware and software, biotechnology and robotics.

- The decentralised structure and funding of the US 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 scale of the US education system allowed for a broad based system of training 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 US 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 US national innovation system. The *Bayh-Dole University and Small Business Patent Act (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 (1986)* allowed Federal laboratories to conduct cooperative research and development agreements with private firms (Mowery and Rosenberg, 1998). However, there is concern that inappropriate and poor quality patents have imposed hidden economic costs and inhibited growth, leading to a call for open, global standards that can enhance interoperability, encourage collaboration and speed process transformation (Council on Competitiveness, 2004a).

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. However, there are a number of issues that are narrowing the gap between the United States and some European Union and Asian countries. These include a lack of US students entering S&E graduate programmes, 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 US 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*
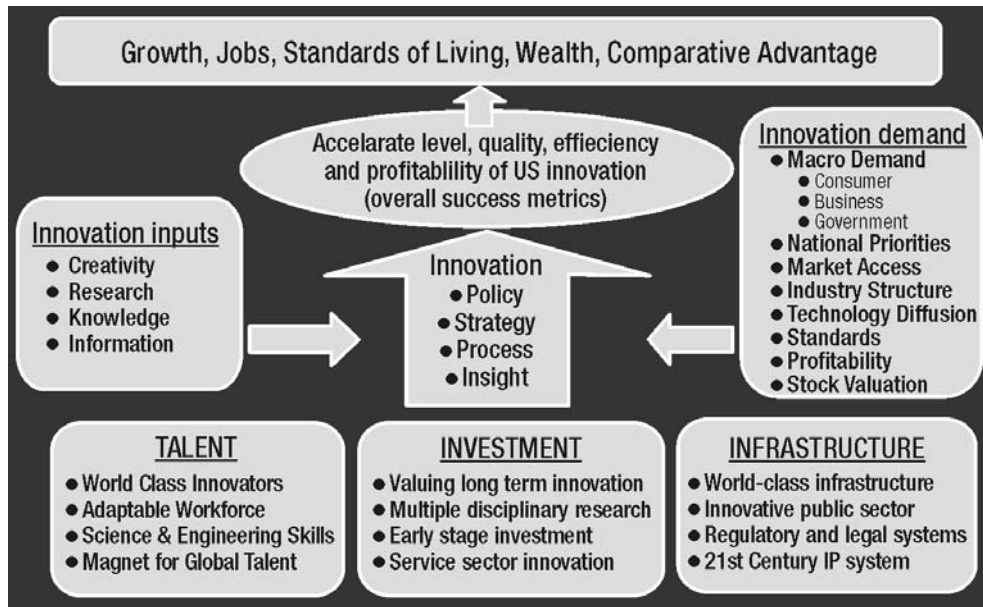
Figure 9. US National Innovation Ecosystem.
Source: Council on Competitiveness (2004b) p. 22

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 is also concern about the changing nature of innovation. Prior to the National Innovation Summit of December 2004, the Council on Competitiveness released the *National Innovation Initiative Interim Report in July 2004* which found 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 market but the way people in society live, work and engage with each other (pp. 5-6). The working group's final report *21st Century Innovation* 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 A5 in the appendix contains policy recommendations in relation to these themes. The working group proposed that policy initiatives occur within a *National Innovation Ecosystem* (Figure 9) in which innovation is considered primarily in terms of customer value creation, leading ultimately to broader economic and social benefits.

Finland's national innovation system performance

The performance of Finland's national innovation system presented in this section is based on key innovation **investment** indicators i.e. 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; and key innovation **output** indicators i.e. triadic patents, publications and citations. This data is supported by Finland's rankings in the World Economic Forum's *Global Competitiveness Report*. The following analysis shows that Finland invests significantly more than Australia and the United States in terms of gross and business expenditure on R&D (as a proportion of GDP) and the number of researchers as a proportion of total employment. Patenting and S&E publishing activities as a proportion of the population remain above that for Australia and the United States. Finland's share of world citations continues to rise. Finland remains a world leader in terms of its potential to attain sustained economic growth over the medium and long term (as indicated by the Global Competitiveness Index), ability of its firms to create value good and services using efficient methods (as indicated by the Business Competitiveness Index); and potential to innovate for competitiveness (as indicated by the National Innovative Capacity Index).

GERD as a proportion of GDP in Finland has grown significantly, from 1.17% in 1981 to 3.46% in 2002. Finland's investment in R&D as a proportion of GDP compares to 1.54% for Australia (in 2000), 2.6% for the USA (in 2003) and 2.26% for the OECD (in 2002) (Figure 10). Following a period of falling growth in the late 1980s and early 1990s,
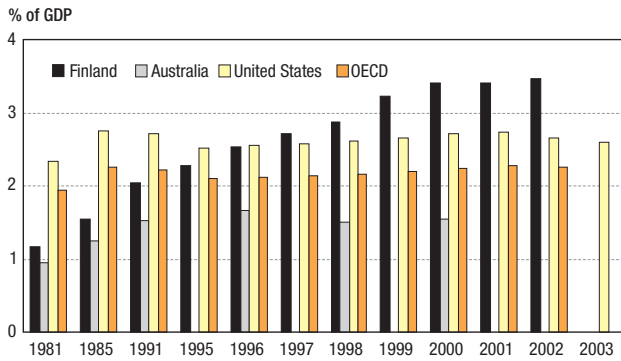
Figure 10. GERD as a percentage of GDP.
Source: OECD (2005a)

Note: 1998 data for the USA is 1999 data
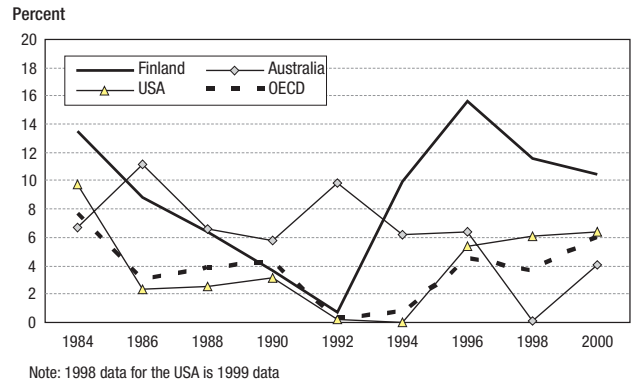
Figure 11. Compound annual growth rate of GERD.
Source: OECD (2005a)
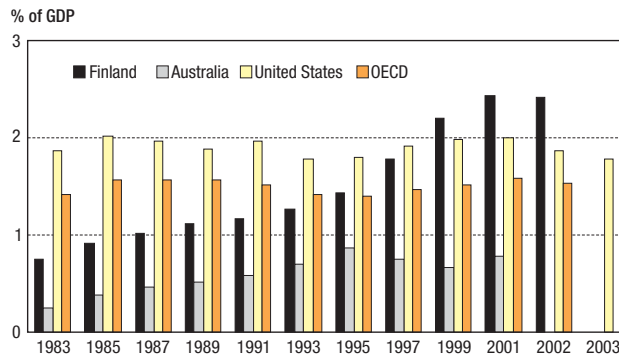
Figure 12. BERD as a percentage of GDP.
Source: OECD (2005a)
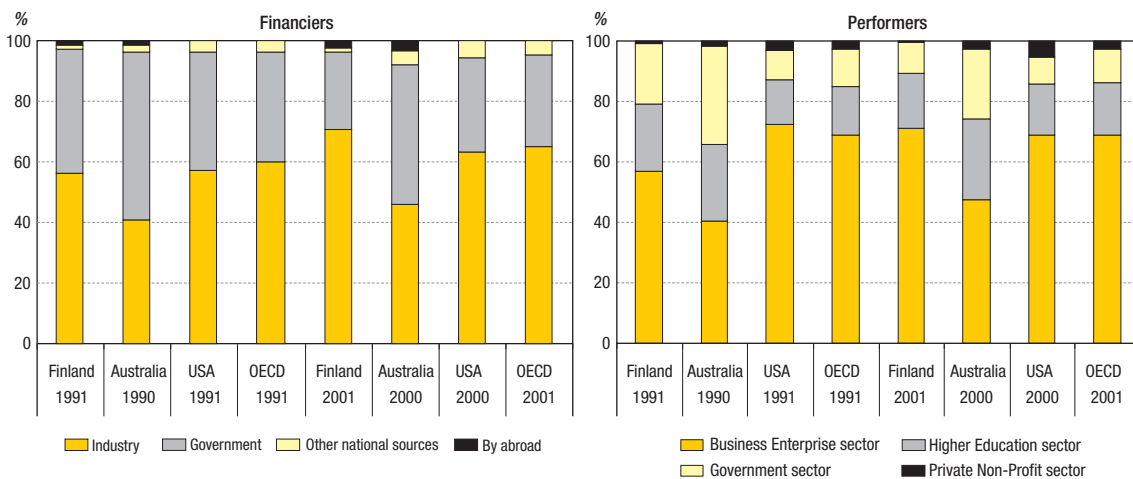
Figure 13. Financiers and performers of R&D. Source: OECD (2005a)

Finland's compound growth rate (in constant prices) for GERD has been consistently above that for Australia, the USA and the OECD (Figure 11). During the 1990s, Finland recorded average annual growth of 8.7% compared to 5.4% for Australia, 3.5% for the USA and 3.3% for the OECD. Finland's **BERD** as a proportion of GDP rose consistently throughout the 1980s and 1990s and since 1999 it has been above has that for the USA and the OECD. In 2002, Finland's BERD as a proportion of GDP was 2.41% compared

to 0.78% for Australia (in 2001), 1.79% for the USA (in 2003) and 1.53% for the OECD (in 2002) (Figure 12).

The proportion of R&D financed and performed by the four difference sectors (business enterprise, higher education, government and private non-profit) has varied in Finland, due largely to the increased role of the business enterprise sector (Figure 13). The proportion of R&D **financed** by industry in Finland rose from 56.3% in 1991 to 70.8% in

2001 (compared to an increase for the OECD from 58.8% to 63.2% over this period). Similarly, the proportion of R&D **performed** by business enterprises in Finland has increased (from 57% in 1991 to 71.1% in 2001) compared to 69% for the OECD in 2001.

The number of **researchers** in Finland has increased from 6 out of every 1000 people employed in 1991 to 16.4 people in 2002. This is well above that recorded of 7.2 researchers for Australia (in 2000), 8.6 researchers for the USA (in 1999) and 6.5 researchers for the OECD (in 2000) (Figure 14). The proportion of researchers employed in the Finland's business sector has increased from 36.8% in 1991 to 55.1% in 2002, with both the Government and higher education sectors accounting for a smaller proportion of researchers. Despite this increase, the business sector in Finland accounted for a lower proportion of researchers than the OECD (63.8% in 2000). The size and nature of the research workforce in the three countries is discussed as part of researcher careers in the next chapter.

Finland's **investment in knowledge** (R&D expenditure + higher education expenditure + investment in software) as a proportion of GDP has increased from 4.3% in 1992 to 6.2% in 2000 (Figure 15). During this period, Finland has consistently recorded a rate above that for the OECD (which was 4.3% in 2000) and narrowed the gap between

Figure 16. Number of triadic patent families per million inhabitants. Source: OECD (2005a)
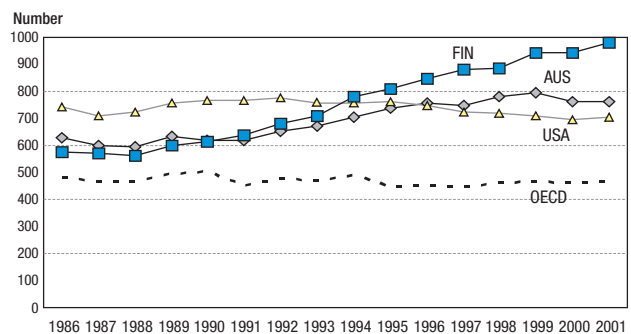
Figure 17. S&E publications per million inhabitants. Source: OECD (2005a)

itself and the United States (which invested 6.8% of GDP in knowledge in 2000).

Patent data indicates that Finland continues to diffuse and/or commercialise innovations at a rate well above that for Australia, the USA and the OECD (Figure 16). The number of triadic patents from Finland that were filed at the European and Japanese Patent Offices and granted by the US Patent & Trademark Office (USPTO) has increased from 32.1 patents per million inhabitants in 1991 to 83.1 patents per million inhabitants in 2001. This compares to 16.3 patents in Australia, 52.6 patents for the United States and 37.6 patents for the OECD in 2001 (per million inhabitants). In terms of patents in high technology industries, Finland performs strongly in the ICT sector but below the OECD in the biotechnology sector. In 1999, the USPTO granted Finland 60 patents per million inhabitants in the ICT sector (compared to 51.7 patents for the OECD) and 2.1 patents per million inhabitants in the biotechnology sector (compared to 4 patents for the OECD). However, patents in high tech industries in Finland are falling with ICT patents peaking at 78.4 patents per million inhabitants in 1998 and biotechnology patents peaking at 5.9 patents per million inhabitants in 1994.

Since 1994, Finland has produced more **science and engineering (S&E) publications** as a proportion of its population than Australia, the USA and the OECD (Figure 17).

Figure 14. Total researchers per thousand. Source: OECD (2005a)

Figure 15. Investment in knowledge of total employment. Source: OECD (2005a)

Table 4. 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)

The number of publications per million inhabitants produced in Finland rose from 576 publications in 1986 to 983 publications in 2001. This compares to 760 publications for Australia, 705 publications for the USA and 468 publications for the OECD in 2001 (per million inhabitants).

Finland's share of world publications has also increased, rising from 0.63% in 1992 to 0.78% in 2001 (Table 4). The fields of clinical medicine (37.8%), biomedical research (14.1%) and biology (10.1%) accounted for a large share of Finland's S&E publications in 2001. There has also been an improvement in Finland's share of world citations from 0.55% in 1992 to 0.79% in 2001, with the fields of health (a world ranking of 1), clinical medicine, biology and biomedical research achieving the highest citation rates for Fin-

land. Because the citation of Finland's S&E publications was above its publication rate, its relative citation index (i.e. share of cited literature adjusted for its share of published literature) was 1.02 in 1999, which represented a world country ranking of 7. This compares to a citation index for Australia of 0.87 (and a world ranking of 14) and a citation index for the USA of 1.35 (and a world ranking of 2).

Finland's retained its world ranking of 1 for the GCI in 2004 although it fell to second place in the BCI ranking (Table 5). Between 2001 and 2004, Finland improved its macroeconomic index ranking from 10 to 3 but its company operations and strategy ranking fell from 2 to 7. The NICI represents a country's potential to innovate for competitiveness based on innovation output (mainly patenting)

Table 5. 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 Engineer 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), (2004) and (2005)

and innovation drivers (such as infrastructure, clusters and linkages). Finland retained its world ranking of 2 in the NICI in 2003 and improved its performance in the proportion of scientists and engineering index, innovation policy index and innovation linkages index. However, Finland was ranked 8th in the operations and strategy index.

2.4 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 (2002d) regards 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 belong to the Frascati family of methodological manuals and 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 are the only activities that are regarded as automatically TPP innovation activities with the remainder included if required.

The Frascati manual refers 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, 2004d, p. 30). The manual identified three types of R&D activities and examples of the three types in the fields of natural sciences and engineering are provided in Table 6:

- **Basic research** is defined as "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable factors, without any particular application or use in view" (p. 77). The manual distinguishes between *pure basic research* which is "carried out for the advancement of knowledge, without seeking long-term economic or social benefits or making any effort to apply the results to practical problems or to transfer the results to sectors responsible for their application" (p. 78); and *oriented basic research* which is "carried out with the expectation that it will produce a broad base of knowledge likely to form the basis of the solution to recognised or expected, current future problems or possibilities" (p. 78).

- **Applied research** is defined as "also original investigation undertaken in order to acquire knowledge. It is, however, directed primarily towards a specific practical aim or objective" (p. 78). The manual acknowledges that new projects for applied research are often based on promising results from basic research.

- **Experimental development** is defined as "systematic work, drawing on knowledge gained from research and practical experience, that is directed to producing new materials, products and devices; to installing new processes, systems and services; or to improving substantially those already produced or installed" (p. 79).

Table 6. Examples of three types of R&D in natural sciences and engineering

Basic research	Applied research	*Experimental development*
Study of a given class of polymerisation reactions under various conditions, of the yield of products and of their chemical and physical properties.	Attempt to optimise one of these reactions with respect to the production of polymers with given physical or mechanical properties, making it of particular utility.	*Scaling up the optimised process at laboratory level and investigating and evaluating possible methods of producing the polymer and articles to be made from it.*
Study of a crystal's absorption of electromagnetic radiation to obtain information on its electron band structure.	Study of absorption of electromagnetic radiation by this material under varying conditions (temperature, impurities, concentrations) to obtain given properties of radiation detection (sensitivity, rapidity).	*Preparation of a devise using this material to obtain better detectors of radiation than those already existing in the spectral range considered.*
Determination of amino acid sequence of an antibody molecule.	*Investigations to distinguish between antibodies for various diseases.*	*Devising a method for synthesising the antibody for a particular disease on the basis of knowledge of its structure and clinically testing the effectiveness of the synthesised antibody on agreeable patients.*

Source: OECD (2002d) pp. 79-80

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[8]. 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). R&D activities are classified by *institutional classification* (i.e. the organisations performing and funding R&D) and by *functional distribution* (i.e. the nature of the R&D programmes). The five sectors within the institutional classification of national R&D effort are: 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.

The Frascati Manual uses R&D expenditure and R&D personnel as key measures of R&D inputs or "effort devoted to R&D" (OECD, 2004d,p. 20), both of which allow for international comparisons. The manual refers to two types of R&D expenditure: *intramural expenditure* defined as "all expenditures for R&D performed within a statistical unit or sector of the economy" (p. 21) and *extramural expenditure* which are "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 - presented as a percentage of gross domestic product i.e. GERD/GDP ratio.

2.5 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 acknowledges the importance of highly skilled human resources to the innovation process, particularly in terms of the development and diffusion of knowledge. It makes reference 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).

The manual broadly and cautiously defines *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 excluding 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 18 com-
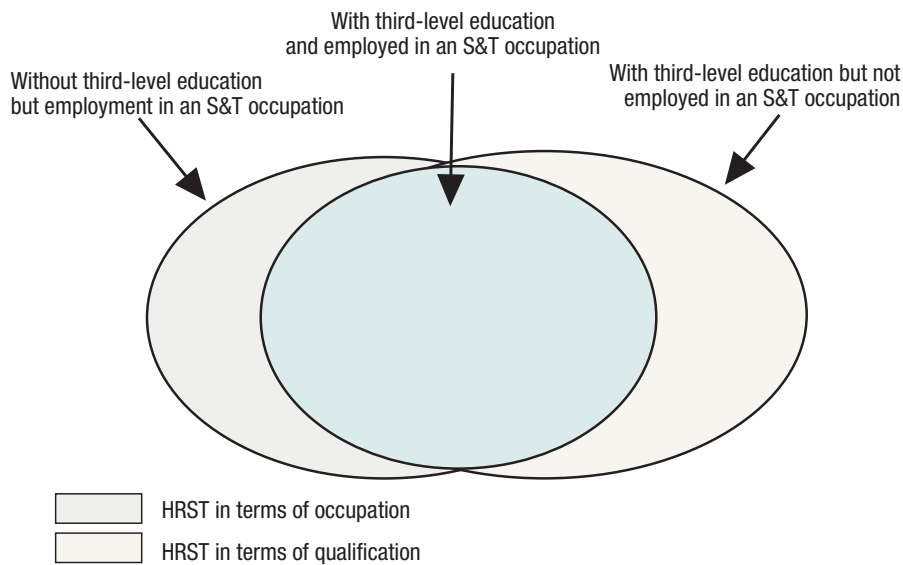
Figure 18. Categories of HRST. Source: OECD/Eurostat (1995) p. 17

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8   "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, 2002d).

Table 7. 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

Table 8. 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 (1995)

bines 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** is 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.

Given the wide definition of HRST, the manual recommends 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 7 indicates **coverage by field and level of education** based on three categories: core (e.g. a person with a university degree in engineering), extended (e.g. a person with a PhD in English literature) and complete (e.g. a person with non-university, level 5 qualification in graphic art). Categories of **coverage by occupation type** in Table 8 are based on the International Standard Classification of Occupations (ISCO) and 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).

The Canberra Manual defines professionals as including "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" (OECD/Eurostat, 1995, p. 93). People 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 8 (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).

2.6 Research students and training in Finland, Australia and the USA

Definitions of "research students" and "research 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 9 shows that a PhD is classified in the International Standard Classification of Education (ISCED) as level 6. At this level, tertiary programmes "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, 2004d, 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 programmes should prepare graduates for faculty and research posts. The manual acknowledges the difficulty of the borderline between R&D and education and training at ISCED level 6. The manual treats any level 6 curricula (such as set courses, study schemes, compulsory laboratory work) as education and training when it is highly structured and "the teacher transmits knowledge and trains in research methods" (p. 36). However, independent study undertaken by students as part of their thesis or dissertation is treated as 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 states 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 manual recommends 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 Frascati Manual refers to researchers as "professionals", the Canberra Manual states 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 level 6 programmes is to provide students with the necessary knowledge and experience to work as HRST professionals.

Table 9. 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 programmes to qualify for entry to advanced research programmes		Holders of basic university degrees below the PhD level
	5B. Practically oriented or occupation-specific programmes		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 (2002d)

Finland

Research training in Finland occurs within an education system that consists of pre-school education, comprehensive school, post-comprehensive general and vocational education, higher education and adult education (Figure 19). 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, such as 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.

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, 2005).

Postgraduate degrees include the *licentiate (lisensiaatti)* and the *doctorate (tohtori)*. Students can commence a post doctoral degree after obtaining the Master's degree. The licentiate is an optional pre-doctoral postgraduate degree, which can be completed in two years of full-time study after the Master's degree. Full-time studies for a doctorate take approximately four years following the Master's 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.
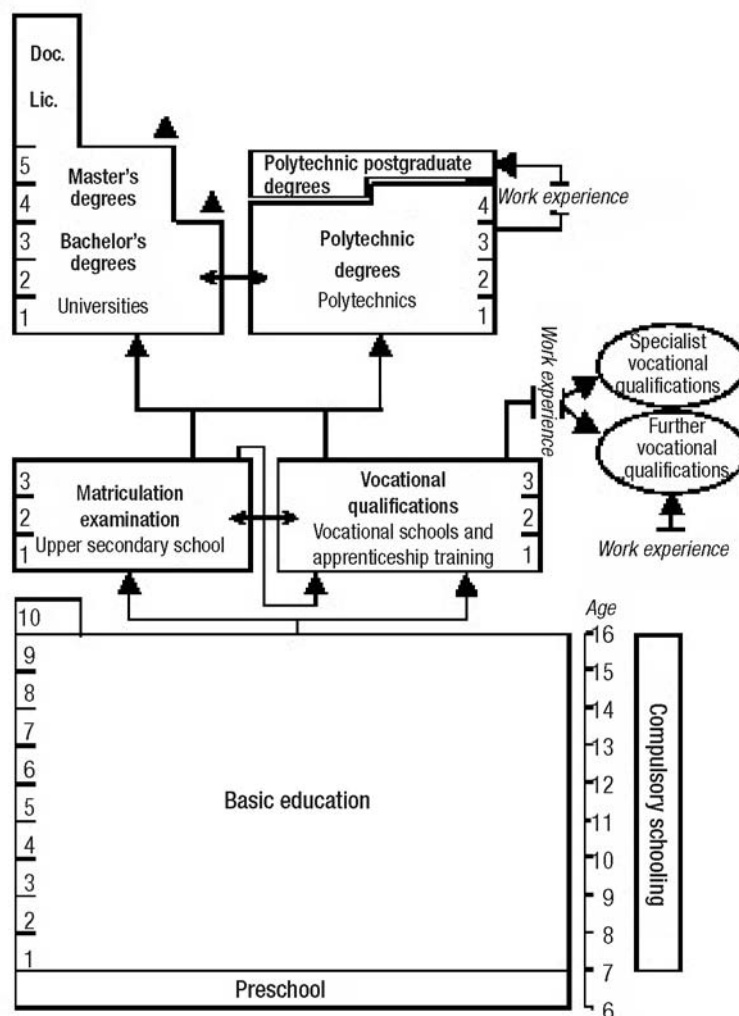
Figure 19. Finland's education system. Source: Ministry of Finland (2005)

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 on preparing 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). Particular concerns included small universities not offering enough research training, too few international contacts, too few researchers seeking training abroad, excessive length of research training, age of doctorate recipients, 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 are 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 are encouraged to complete their dissertation in four years.

Research training in Finland is also supported through 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 has supported 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.

Enrolments in postgraduate degrees (licentiates and doctorates) in Finland increased from 10,442 in 1990 to 22,105 in 2004 (Figure 20), 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 900 in 1990 to 1,957 in 2004, which represents average annual growth of 5.5%. Most of this growth in research degrees in Finland is due to the significantly larger number of doctoral degrees that have been awarded (Figure 21), which have increased from 490 in 1990 to 1,399 in 2004 (and represents average annual growth of 8.9% over this period). Females accounted for 45.2% of all doctoral completions in Finland in 2004 compared to 31.6% in 1990. Over the three year pe-
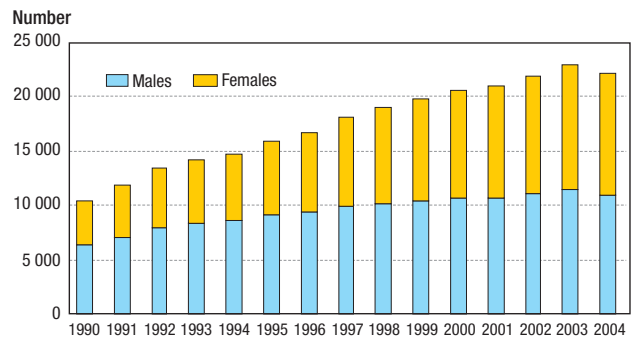
Figure 20. Postgraduate enrolments by gender, Finland 1990 to 2004. Source: KOTA Online (2005)
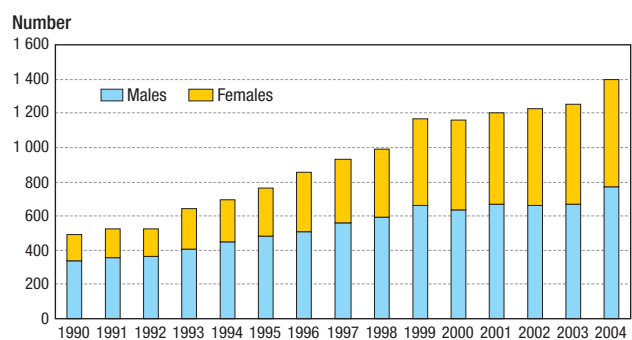
Figure 21. Doctoral completions by gender, Finland 1990 to 2004. Source: KOTA Online (2005)

riod 2001 to 2003, the S&T fields of natural sciences and technology accounted for 37.8% of all doctorates awarded in Finland.

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. The involves having a uniform degree structures (based on two main cycles: 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. As a result of its commitment to

the Bologna process, Finnish universities will adopt a 3+2+4 degree structure (3 years Bachelor degree + 2 years Master degree + 4 years Doctorate) and a national credit unit system that is compatible with the ECTS system in August 2005. A national strategy for the internationalisation of higher education released by the Ministry of Education (2001) aims to increase the annual volume of student exchanges to 28,000 of which 15% are to 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 are 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 includes increasing studies that involve 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.
- Revisions by the Academy of Finland to the criteria and conditions for funding doctoral studies of employed persons so that research grants are made available not only for the completion of doctoral theses but also for earlier stages of thesis research. This involves greater integration of employed doctoral students into graduate schools or university research teams, including those people undertaking their thesis in industry.

Australia

In Australia, research students are defined as those people enrolled in a theoretically-based advanced research degree i.e. a Doctorate by Research or a Masters 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 22). Qualifications awarded in these sectors are within a national structure called the Australian Qualifications Framework (AQF)[9]. There are currently 44 universities that are eligible for Commonwealth Government operating grants, and 39 of these 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, 2002, p.6). Over the past decade, revenue from Commonwealth Government grants has decreased from 60% to less than 50%, increasingly replaced with revenue from fees and charges, especially from international students.

Enrolments in research degrees (Masters and Doctorates) in Australia increased from 16,539 in 1990 to 47,309 in 2004 (Figure 23), which represents average annual growth of 7.8%[10], 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 have also increased significantly, from 2,212 completions in 1990 to 6,321 completions in 2003, which represents average annual growth of 8.4%. Those complet-

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9   The Australian Qualifications Framework (AQF) 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).

10   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 22 diagram

Age

Third level (tertiary education)

—18
—17 | 2nd stage year 11–12
—16
—15[a]
—14 | 1st stage year 7/8–10
—13
—12

Second level

—13
—12
—11
—10
—9
—8
—7 | First level K/1 – 6/7
—6
—5
—4
—3

Schools

Vocational Education and Training

Advanced Diploma[d]
Diploma[d]
Certificate IV
Certificate III
Certificate II[c]
Certificate I[c]

Higher Education (Universities)

Doctoral Degree
Master Degree
Graduate Diploma
Graduate Certificate

Bachelor Degree
Advanced Diploma
Diploma

Senior Secondary Education
Year 12 11 10 9 8 7 6 5 4 3 2 1 Kinder

Senior Secondary Certificate of Education

Secondary Education

Primary Education[b]

Pre-school Education

(a) End of compulsory schooling in some States
(b) In some states, year 7 is part of primary education, while on others it is part of secondary education
(c) Certificates I and II (perhaps higher in some States) are offered in the schools sector as part of VET in schools
(d) Some Diplomas and Advanced Diplomas are offered in the higher education sector.

Figure 22. Australia's education system. Source: Nelson (2003b) p. 30

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ing doctorates accounted for 74.8% of all research degrees (Figure 24) and females accounted for 46.8% of research degree completions in 2003. Almost 36% of research degree completions were in S&T fields.

The current structure of Australia's research training system is largely based on reforms announced by Minister for Education, Training and Youth Affairs, Dr David Kemp in the higher education White Paper *Knowledge and Innovation: A policy statement on research and research training* in December 1999. 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 re-
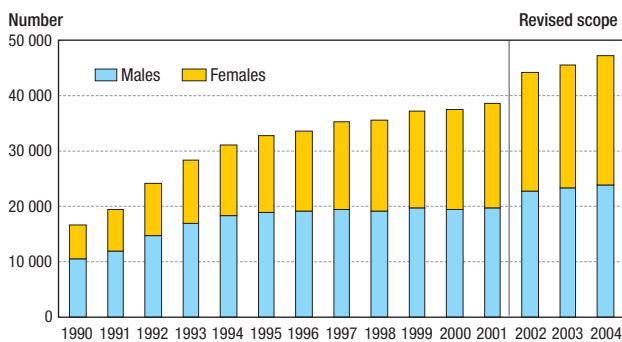
Figure 23. Research degree enrolments by gender, Australia 1990 to 2004. Source: Department of Education, Science and Training (2005a)
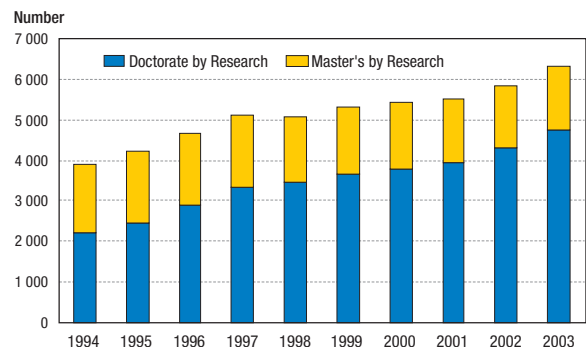
Figure 24. Research degree completions, Australia 1994 to 2003. Source: Department of Education, Science and Training (2005a)

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search 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 Masters by Research. The Government funded around 22,000 students at a cost of $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 $18,837 per annum for APAs and $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 and Masters students receive an award for a maximum of two years. There were 1,550 APA awards worth $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 $17.7 million in 2004.

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 leading to research training in high quality environments. 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 in 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. These centres also provide high quality postgraduate training environments. Other Commonwealth schemes that support research training in universities are as follows:

- The Institutional Grants Scheme (IGS) allocates funds based on research income (60%), publications (10%) and research student places (30%) at a cost of $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 (RIBG) Scheme meets project-related infrastructure costs at a rate of 20 cents for each competitive research dollar obtained by universities, at a cost of $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 $27.8 million in 2004.

Universities receiving funding from the Research Training Scheme and Institutional Grants Scheme are required to submit Research and Research Training Management Reports as part of their profiles. These plans "describe an institution's approach to the planning and management of its research and research training activity and its assessment of its research and research training performance" (Kemp, 1999a, p. 41). From 2002, the Government required universities to include information covering intellectual property management and processes for commercialising research (that was consistent with the National Principles for Intellectual Property released in September 2001) in their Research and Research Training Management Reports.

The **Cooperative Research Centres (CRC) Program** was 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, information and communications technology, mining, medical science and technology and manufacturing. 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 $25,000 and top up scholarships of $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 1991/92 to 2001/2002, 1,426 Doctorates by Research and 1,022 Masters 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).

Reforms to research and research training are part of the Commonwealth Government's commitment to building a highly skilled research workforce as part of an effective national innovation system. This includes research training initiatives that encourage enrolments in research degrees (particularly those that involve industry), improve the quality of research training, and ensure research students have the necessary capabilities to work in different settings. Some of the reforms also sought to address deficiencies in research training that were perceived by students, research institutions and employers (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.

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

- Research training environments were associated with poor supervision, inadequate levels of departmental support and limited access to quality infrastructure.
- High attrition rates[11] and slow rates of completion (over four years for a Masters by research degree and nearly six years for a PhD) for research students wasted private and public resources.

United States

There is no comprehensive system of education in the United States as the 50 states have freedom in shaping their own educational systems. Figure 25 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 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. Students commence a Master's degree and progress to a Doctorate program after they have completed an undergraduate degree. A Master's degree takes at least one year following the completion of an undergraduate degree and a PhD takes a minimum of three or four years to complete. Graduates from Professional Schools (such as medicine and law) can also enrol in doctorate and post-doctorate programs.
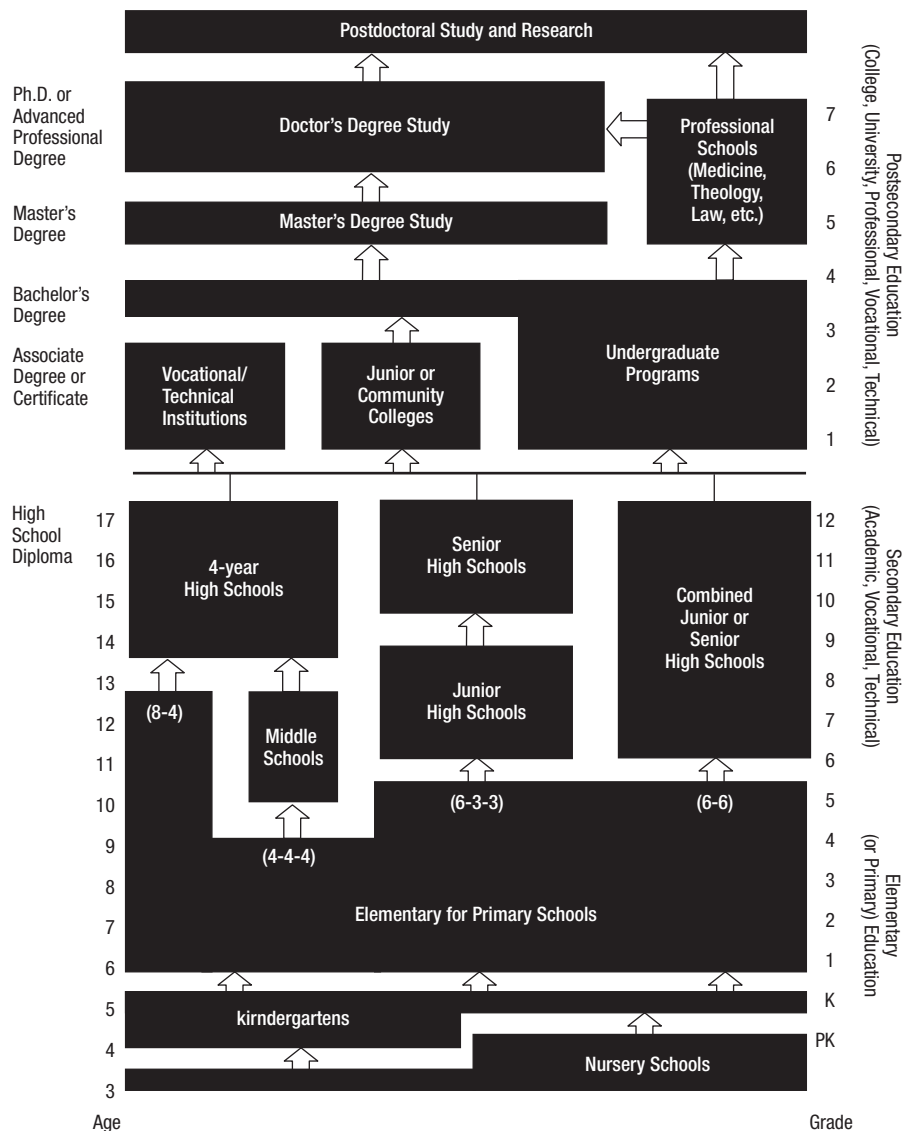
Figure 25. United States education system.
Source: National Center for Education Statistics (2002)

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

The National Science Foundation (NSF) estimates that in the year 2000 there was around 3,700 degree-granting colleges and universities serving 15.6 million students in the US higher education system. 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- 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, Master's 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 in preparing workers to meet the evolving demands for skilled workers is the key challenge for the higher education system in the United States.

Students enrolled in doctoral programs are 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 Defense, 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 or family contributions. In 2001, one in five graduate students received Federal financial support mostly in the form of research assistantships.

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, which represents average annual growth of 1.6% during 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 26), of which 47.3% percent were awarded to females (compared to 36.4% of doctorates awarded to females 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.

In 1995, the US Committee on Science, Engineering and Public Policy released the report *Reshaping the Graduate Education of Scientists and Engineers*. The Committee found that the three areas of primary employment for graduates (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. However, employers were concerned that PhD grad-
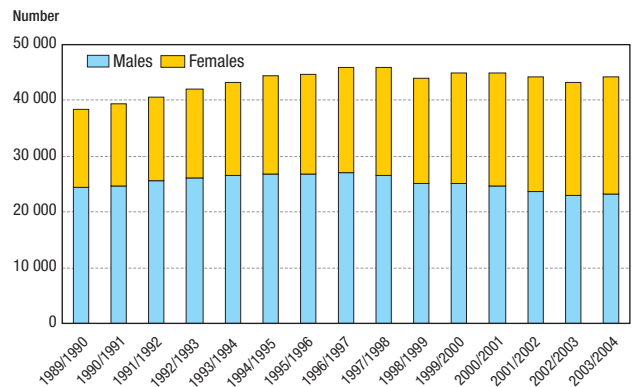
Figure 26. Doctoral completions by gender, United States 1989/1990 to 2003/2004.
Source: National Center for Education Statistics (2004)

uates 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 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 report included the relationship between the supply of and demand for PhDs in science and technology (in particular, an apparent oversupply) and concerns raised about the rapidly increasing numbers of students who are foreign citizens and work in the United States after they graduate. The committee recommended against across-the-board limits on enrolments in PhDs or limiting the number of foreign students.

In a workshop attended by stakeholders in 2000 on re-envisioning the PhD to meet the needs of the 21st century, six themes for doctoral reforms were identified: 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, concerns have been raised about doctoral attrition which was estimated at 50%. A study by the Council of Graduate Schools found that completion rates are higher in science in technologies fields (at around 75% for those in life sciences) but are much lower in humanities (between 30 to 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 providing funded 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 on these projects on rates of doctoral completions and attrition patterns" (Denecke, 2004).

2.7 Summary

A key purpose of this chapter is to determine 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. This study is not aiming to debate these concepts but draws on the work of well known innovation researchers and accepted international definitions and classifications contained in 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 technological product and process (new and significantly improved) innovation that have been implemented or organisational innovations that led to measurable changes 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** provides research students with a high level of knowledge and skills necessary to work as HRST professionals (and independent researchers) after graduating.
- **Research students** are "researchers" who undertake independent and novel research to form a thesis or dissertation. When educated in key science and technology fields, they are a core part of the HRST stock and a critical component of a national innovation system.

This chapter also aims to identify the role of research training (particularly in science and technology fields) in a national innovation system (research question 2). Innovation theories show the changing nature of the innovation process, which in turn has impacted on the features and functions of a national innovation system. One of these changes has been the increasing reliance on scientific knowledge for major new technologies, particularly in the areas of biotechnology, new materials and information technology. This has led to greater university-industry cooperation in many countries where producers 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. As shown in the some of the case studies presented in Chapter 4, unexpected innovations are occurring as a by-product of the students' research suggesting that research training can also be regarded as *learning-by-producing*. This study assumes that the role of research training in a national innovation system is to build the competence of research students to produce scientific knowledge by developing their ability to learn about and create economically relevant knowledge and to interact with research users.

This chapter also provides an overview of the major developments in, and performance of innovation and research training policies/systems in Australia, Finland and the USA (research question 3). The three national systems of innovation and research training presented in this chapter face similar challenges in their endeavours to be leading countries in the generation, diffusion and use of new knowledge. However, the structure, performance and priorities of these systems differ due to factors such as national history, culture, population size and investments made by government and industry. Large and highly developed countries like the United States have markets with 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. Innovators in small high income countries like Finland can more easily capture and benefit from technology inflows but need 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. Efforts by the Commonwealth Government have improved the performance of Australia's national innovation system and significantly increased the number of research graduates working in it. However, below average R&D investment (particularly by industry), low patenting levels, insufficient employment opportunities for researchers in industry, and a lack of scientific recognition by the world (as indicated by citation data) are serious and persistent issues for Australia.

3 International mobility and migration of research students and graduates

The following literature review aims to explain common terms (i.e. transnational/international mobility, brain drain, brain gain, brain circulation), reasons why countries are concerned about improving their performance (i.e. the positive and negative effects of mobility), why people work/study abroad (drivers), the obstacles people face or prevent them from working/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 mobility experiences of the 30 research students participating in this study.

This element of the conceptual framework assumes that research students are likely to contribute to a national innovation system in Australia, Finland or the USA 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 USA from another country i.e. *brain gain*
- return (home) to Australia, Finland or the USA from another country i.e. *brain circulation*
- leave Australia, Finland or the USA 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 Finland, Australia and 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 by "pushing" graduates out of their home country to other countries with better opportunities.

3.1 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[12]. 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** (movement between countries) and is also known as "international mobility"; and **intersectorial mobility** (movement 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 are 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. When researchers return to their home country they also bring back knowledge and capacities acquired from abroad (known as **brain circulation**) 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. These concepts are presented in Figure 27 as flows in and out of S&T occupations or the HRST stock.

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12 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 percent by 2010 (Communication adopted on 18 January 2000 called *Towards a European Research Area.)*
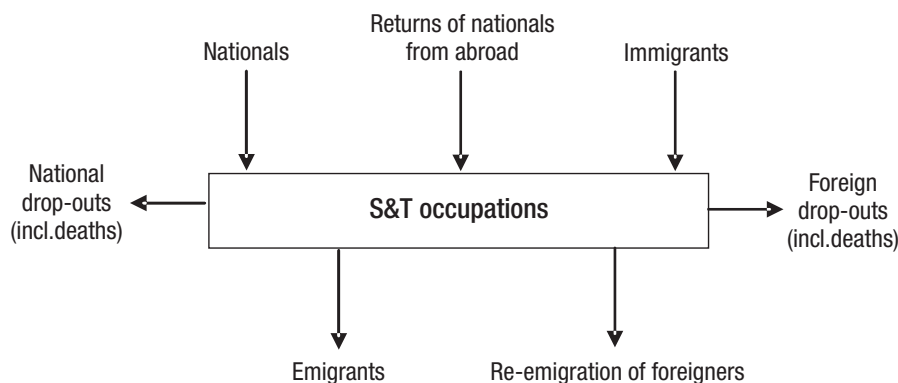
Figure 27. Main flows in and out of S&T occupations.
Source: Auriol and Sexton (2002) p. 25

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 (undertaking 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).

3.2 The importance of international mobility and migration

The STRATA-ETAN Expert Working Group[13] 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[14], representing knowledge transfer and a common knowledge base between two NIS institutions. Therefore, the higher education sector and R&D sector are very important NIS institutions. 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, 2002a). 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 (as shown in Table 10).

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 (i.e. education). Foreign students who do not return to their home country after their studies also represent *brain drain*. The European Union believes that such losses would impact on its competitiveness in the knowledge-based economy. However, returning migrants and networks that facilitate skilled worker circulation between sending and receiving countries can offset any loss of human capital (OECD, 2002a). 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.

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13   The European Commission established the group in 2001 to examine human resources in research and technical development.
14   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).

Table 10. 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 programmes/keeping smaller programmes 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 *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)	**Receiving countries: possible negative effects** *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 (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

3.3 Drivers and obstacles

Countries with internationalised higher education and research systems and environments conducive to entrepreneurship, innovation and financial opportunity (such as the USA) 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 (e.g. 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 and promote 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, **push factors** (such as lack of opportunities and poor working conditions for researchers and lack of capital for entrepreneurs) can lead to people leaving their home country. 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 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 11). 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.

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,

Table 11. 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, 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)

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 (through a dissertation) in another country.

With over 80% of international students based in five countries[15], the STRATA-ETAN Expert Working Group sought to identify factors that influence **student mobility**. These factors include larger country populations with greater diversity of educational systems and therefore 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 organisations they enrol with 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 doctoral students were the United States (33.5%), United Kingdom (22.6%), France (18.5%) and Germany (11%).

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, as well as 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 doctoral 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).

3.4 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 for science and technology (as discussed in the previous chapter). At the OECD International Conference on New Science and Technology Indicators for the Knowledge-based Economy held in June 1996 there was concern about 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,

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15   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%).

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) believes 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 12 contains examples of proxy indicators of international mobility and migration for Australia, Finland and the United States.

3.5 Mobility programs and performance in Finland, Australia and the USA

Finland

Key researcher mobility programs that are funded by the Academy of Finland and other Finnish and international organisations are summarised in Table A6 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 provided by the **Centre for International Mobility (CIMO)** in Finland. 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 which is a joint initiative with the European Union. The site is linked to the European portal and provides information to researchers 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 stu-

Table 12. 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)
Permanents visa issued to immigrant in S&T occupations, 2001			33,900
Temporary entry of foreign students (F-1), scholars (J-1) and skilled workers (H-1B)			606,514
Stay rates of foreign PhD graduates in S&T, 1998-2001			54.1%
Stay rates of foreign PhD students and researchers, 2004 (sample only)		47.6%	
Foreign-born US residents with S&E doctorates, 1999			192,000

Source: OECD (2004a), (2004b) and National Science Board (2004)
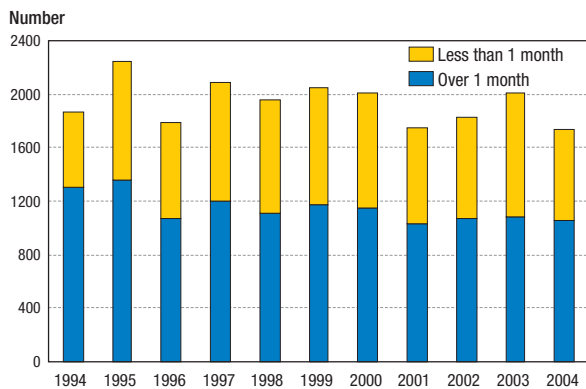
Figure 28. Visits to Finland by foreign researchers, 1994 to 2004. Source: KOTA Online (2005)
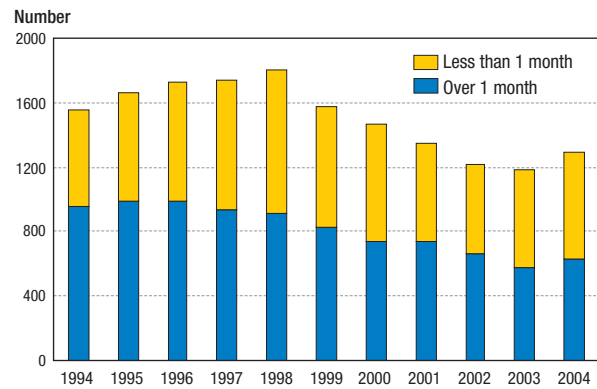
Figure 29. Overseas visits by Finnish university teachers and researchers, 1994 to 2004.
Source: KOTA Online (2005)

dents 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 28) exceeds the number of overseas visits by **Finnish teachers and researchers** (Figure 29). For example, 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). Data on the length of stays for 2004 indicate that 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 28 and Figure 29 show a declining trend in inward and outward movements, particularly in the case of overseas visits by Finnish university teachers and researchers.

The number of **foreign students** studying in Finland has increased significantly and in 2004 there were more foreign students in Finland than Finnish students abroad (Figure 30). Although foreign students continue to account for a small share of all tertiary students in Finland, data from Eurostat shows this share has increased from 1.73% in 1998 to 2.38% in 2002. In 2004, 4,279 Finnish students were studying overseas (and stayed for an average of 5.9 months) and 4,341 foreign students were studying in Finland (and stayed 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 shows that foreign PhD students also account for a

Figure 30. International movements of students, Finland 1997 to 2004. Source: KOTA Online (2005)

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).

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 an average share of between 3% and 3.5% for 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 31, 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 & Stevens (2004) attributed low migration to language and integration difficulties, and blamed high marginal tax rates (of around 56%) 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.
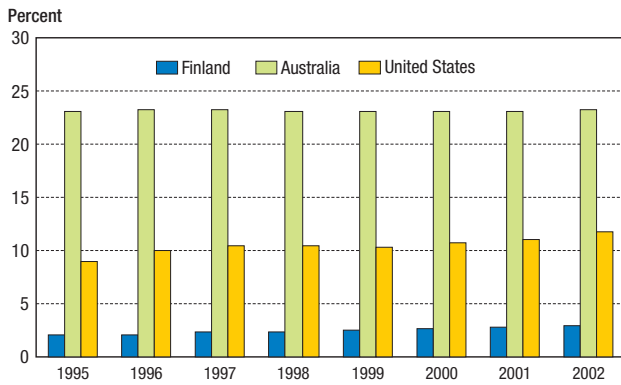
Figure 31. Foreign-born people in the population, Finland, Australia and USA 1995 to 2002.
Source: OECD (2005b)

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. It also sought to increase the annual volume of student exchanges to around 28,000 students, with foreign students accounting for 15% of graduate school students. Despite increases in student exchanges, data on overseas researcher visits, foreign postgraduate students, foreign HRST and 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 (2002) called for greater investment in all levels of education, particularly research training, and increased researcher mobility. This 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 A7 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 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 believes 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 are more permanent and "not just on researcher exchange" (Puustinen-Hopper, 2005, p. 14). Table 13 shows that 47.6% of respondents intended to stay in Finland, with senior researchers more likely to stay due largely to nature of their contract i.e. permanent versus temporary.

Puustinen-Hopper (2005) found that the most important 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 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). Other "pull" factors that were identified as supporting mobility to Finland included free university

Table 13. Intended residence of foreign PhD students and researchers by career stage

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

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 foreigner 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. Researchers in senior roles are often invited as visiting lecturers to foreign universities" (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. However, 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 programmes. 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.

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 programmes are currently funded by Commonwealth Government through the Australian Research Council (as part of Linkage-International) and the Department of Education, Science and Training (as part of the Endeavour Programme), and in partnership with other organisations.

The final report from the National Innovation System, *Innovation: Unlocking the Future,* produced by the Innovation Summit Implementation Group (August 2000) recommended that Australia builds its competitiveness through knowledge of and access to overseas science and technologies. This recommendation include ensuring that technology developed in Australia and overseas is accessible to those who need it, including 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)[16]. The program funded two grant types from 2002: 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. Linkage-International awards in 2005 include a new cooperative program between the ARC and the US 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 14).

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16 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.

Table 14. Number and value of international fellowships and awards, 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, 2003c). 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 A8 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 are targeted at overseas research students and graduates to Australia, the Commonwealth Government also contributes funding to other major awards that enable Australians to undertake research overseas. For example, the 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 Australian Fullbright Scholarship to undertake research in the United States. In addition, 20 Americans received a US 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 in-

formation 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 includes providing information about postgraduate research scholarship opportunities. It states on its website 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 of overseas students compiled by the Department of Employment, Science and Training (DEST) as part of its higher education statistics collection; and 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 et al (2004). However, 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 32). 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 are from Asian countries, such as 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 33), which represents 16.6% of all completions in 2003. However, overseas research students are accounting for a lower share of enrolments and completions than previously. 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 34). This indicates that 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
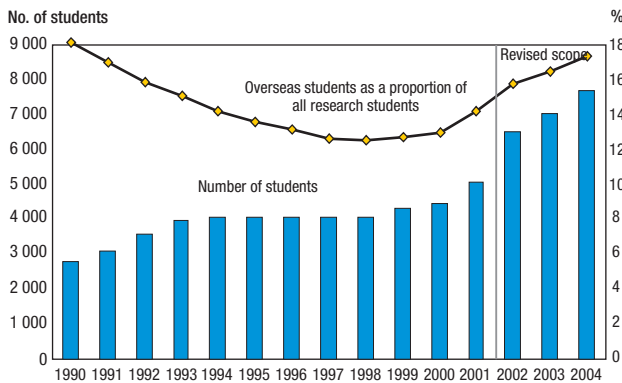
Figure 32. Enrolments of overseas research students, Australia 1988 to 2004. Source: Department of Education, Science and Training (2005a)
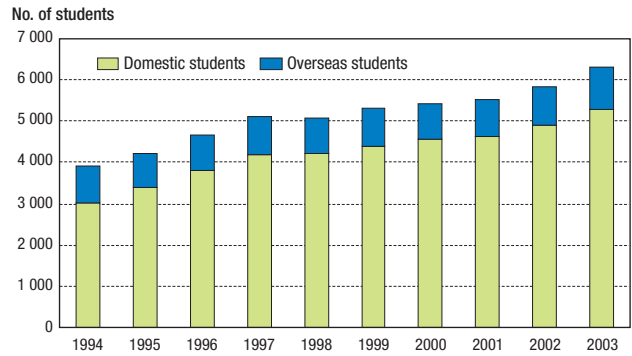
Figure 33. Completions of overseas and domestic research students, Australia 1994 to 2004. Source: Department of Education, Science and Training (2005a)
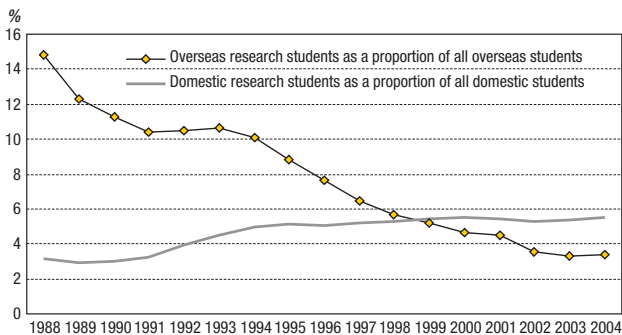
Figure 34. Overseas and domestic students as a proportion of research students, Australia 1988 to 2004. Source: Department of Education, Science and Training (2005a)

students, overseas students are more likely to enrol in a Doctorate by Research (83.6% compared to 78.9% for domestic students) and 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).

Table 15 (on the next page) 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 oc-

cupations until recently. Over this eight period 35,368 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 spend on average two years overseas.

Any net losses in Australian residents in S&T occupations were 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) believes this overall net gain is understated as it does not include the onshore factor i.e. people who applied for permanent residence while on some other visa category in Australia. For example, temporary workers and working holiday makers who successfully applied for permanent residence under the Employment Nomination Scheme. Even more so, is the impact of 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[17] 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 PhD qualifications). 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

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17   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 by Research were regarded as detailed levels within the narrow levels of Doctoral degree level and Master degree level, respectively (ABS, 2001).

Table 15. 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	1386	1521	1529	1757	1685	1447	10806
Engineers	796	875	1421	712	512	489	369	291	5465
Computing professionals	1488	1940	2369	2814	2193	2446	3040	2707	18997
Total S&T departing	*2996*	*3584*	*5176*	*5047*	*4234*	*4692*	*5094*	*4445*	*35268*
S&T residents returning									
Scientists	523	543	892	752	872	979	901	975	6437
Engineers	660	638	999	358	344	295	328	391	4013
Computing professionals	1195	1360	1676	1250	1377	1284	2009	2515	12666
Total S&T returning	*2378*	*2541*	*3567*	*2360*	*2593*	*2558*	*3238*	*3881*	*23116*
Net S&T residents									
Scientists	-189	-226	-494	-769	-657	-778	-784	-472	-4369
Engineers	-136	-237	-422	-354	-168	-194	-41	100	-1452
Computing professionals	-293	-580	-693	-1564	-816	-1162	-1031	-192	-6331
Total S&T net residents	*-618*	*-1043*	*-1609*	*-2687*	*-1641*	*-2134*	*-1856*	*-564*	*-12152*
S&T settler arrivals									
Scientists	908	809	705	779	937	808	583	629	6158
Engineers	1333	1144	1190	1221	1327	1365	1055	1079	9714
Computing professionals	1183	1288	1248	1430	1778	3705	4661	3338	18631
Total S&T settler arrivals	*3424*	*3241*	*3143*	*3430*	*4042*	*5878*	*6299*	*5046*	*34503*
Net S&T visitors									
Scientists	144	263	206	635	454	519	495	486	3202
Engineers	237	270	620	611	525	582	574	530	3949
Computing professionals	362	337	570	1533	1325	1514	1433	1543	8617
Total S&T net visitors	*743*	*870*	*1396*	*2779*	*2304*	*2615*	*2502*	*2559*	*15768*
Net S&T movement									
Scientists	863	846	417	645	734	549	294	643	4991
Engineers	1434	1177	1388	1478	1684	1753	1588	1709	12211
Computing professionals	1252	1045	1125	1399	2287	4057	5063	4689	20917
Total S&T net movement	*3549*	*3068*	*2930*	*3522*	*4705*	*6359*	*6945*	*7041*	*38119*

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

awarded a PhD in Australia between 1996 and 2001. However, this loss was offset by the inflow of 1,710 PhD qualified migrants and 480 PhD qualified Australians returning from overseas, also with PhDs awarded between 1996 and 2001. As a result, they estimated a gain of 1,730 PhD qualified people over this period (Table 16). Birrell et al (2004) believes that the substantial expansion in the number of research positions in Australian universities over the 1990s contributed to this gain. However, analysis by field shows overall net losses in the fields of education (260 people),

management & commerce (240 people) and IT & engineering (220 people). Overall gains occurred in the fields of science & health (1,420 people) and arts & design (1,060 people).

Birrell et al (2004) attributes the movement of Australian residents abroad largely to the long-standing keenness of young Australians to see the world. They also believe 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

Table 16. International movement of PhDs attained between 1996 and 2001

		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

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 Bail bombing in October 2002.

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 brain drain of Australia's best and bright 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 et al (2003) which identified "pull factors" of better employment opportunities, professional development and higher income as the prime motivations for emigration (Table A9 in the appendix). Of the 2,072 people who responded to the survey, 50% stated that they intended to return to Australia and one third of the remainder was undecided. Hugo et al (2003) found that older respondents and those from the USA 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 they were offered a better job and 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.

United States

The United States 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, US government assistance, private US sources and international organisations, US universities and loans. These sources are further explained in Table A10 in the appendix. Just over 78% of foreign doctoral students in 2001 were supported by US universities through research assistantships (44.7%), teaching assistantships (17%) and fellowships (16.4%) (Table 17). Only 6.1% of foreign students who were temporary residents used personal savings to undertake their doctorate compared to 24.5% for US citizens. Table A10 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 US and international organisations that are funding research students and graduates from the United States to undertake research abroad.

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 US S&E doctorate between 1998 and 2001 were from East and South Asian countries particularly China, India, South Korea and Taiwan. Data on the number of US students undertaking doctorates abroad is difficult to obtain. However, OECD data on the net balance of international student exchange shows that the number of total foreign students in the United States exceeded the number of US students going abroad by 544,000 in 2002 (OECD, 2004b). This suggests that the number of foreign doctoral

Table 17. Funding sources for S&E doctorate recipients, United States 2001

	Research assistantships		Teaching assistantships		Fellowships (1)		Traineeships (2)		Other (3)		Personal (4)		All students
US 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-US 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.
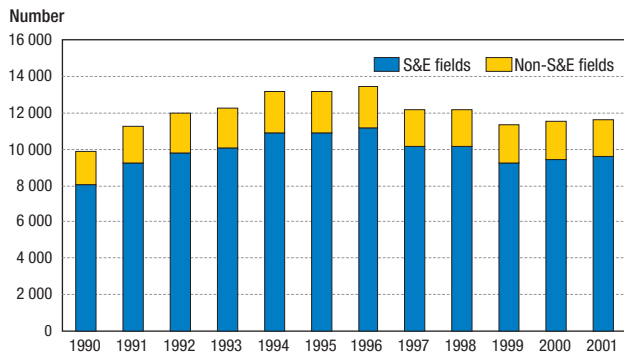
Figure 35. Doctoral completions by foreign students, United States 1990 to 2001.
Source: National Science Foundation (2004)
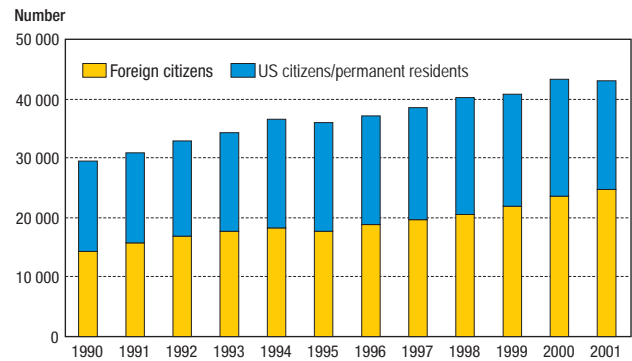
Figure 36. S&E postdocs at universities in the United States 1990 to 2001.
Source: National Science Foundation (2004)

students in the United States was well above the number of US students undertaking a doctorate or participating in a student exchange abroad.

Between 1990 to 2001, an increasing share of **foreign recipients of S&E doctorates** from US universities were planning to stay or had firm plans to stay in the United States. 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 18). 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.

Increasing stay rates have contributed to the steady rise in the number of foreign citizens working as **S&E postdoctoral researchers** at US universities (Figure 36). In 2001, 24,601 foreign citizens were in S&E postdoctoral positions, which represented 57.2% of all postdoctoral positions. The US 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 US residents with S&E doctorates in 1999.

Table 18. Plans of foreign recipients of US 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-US citizens	**63.4%**	**69.3%**	**76.3%**	**40.9%**	**43.3%**	**54.1%**
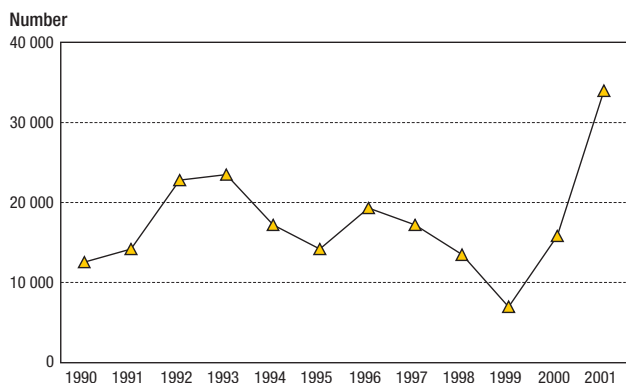
Figure 37. Permanent visas to immigrants
in S&E occupations, 1990 to 2001.
Source: National Science Foundation (2004)

Figure 38. Non-immigrant (temporary) F-1, J-1
and H-1 visas, United States 1998 to 2002.
Source: National Science Foundation (2004)

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). These falls in permanent and temporary visas are likely to contribute to a decline in the number of S&E postdoctoral researchers employed by US universities from 2002.

The National Science Board (2004) attributed the slow-down 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. As a result, the National Science Board (2004) believes 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). With the European Union now producing more PhDs in science and technology than the USA (as well as harmonising their systems of education) and the Governments of China, India and Korea investing heavily in graduate education, Stewart (2005) argues that the United States must *redouble* its efforts to develop the domestic talent pool.
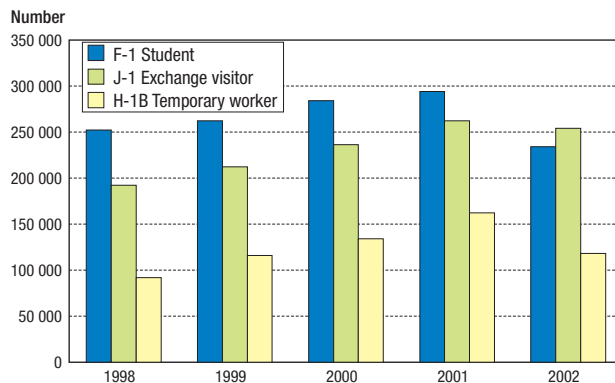
In the summer of 2004, Heather Brown and Peter Syverson from the Council of Graduate Schools surveyed US Graduate Schools on international student admissions trends. They also attributed the decline in foreign students to global competition in graduate education, changing visa processes and the diminished perception of the US as a destination for advanced graduate study. Brown & Syverson (2004) found that many institutions are developing specific practices to improve the administration process for international graduate students such as 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 US science and engineering would have been in crisis without the influx of the 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 US 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 US citizens from investing in science and engineering careers, and thereby increases our dependence on the foreign-born.

3.6 Research careers in Finland, Australia and the USA

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 graduate schools, it also has schemes to support postdoctoral researchers, research fellows and professors (Table 19). 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 programmes and centre of excellence programmes. 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 20). Lower success rates combined with a decline in the number of applications (from 257 in 2000 to 219 in 2004) has 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).

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 21). 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 19. 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, 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. Academy 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)

Table 20. 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

Table 21. R&D project 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[18] (27 projects), COST[19] (26 projects) and ERA-Nets (with Tekes involved in 14 projects aimed at enhancing national and regional research and technology programmes).

Data in the previous chapter shows that Finland continues to employ significantly more people as researchers (as a proportion of total employment) than the OECD average – 16.4 people out of 1000 people employed (in 2002) compared to 6.5 people out of 1000 people employed (in 2000). Finland's **research workforce** has grown from 14,030 in 1991 to 38,632 researchers, with all sectors employing more researchers (Figure 39). The business sector recorded the highest growth in the employment of researchers between 1991 and 2002, and as a result it accounts for a significantly larger share of researchers (from 36.8% in 1991 to 55.1% in 2002). Growth in doctoral degree completions and the research workforce has slowed in recent years fol-

lowed a decade of relatively high and consistent growth (Figure 40). Growth in business researchers in 2002 was the lowest recorded in almost 10 years. HRST data from Eurostat presented in Chapter 5 shows HRST stocks, HRST core and the number of scientists and engineers have fallen after peaking in 2001.

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 referred to factors that suggest 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). However, 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
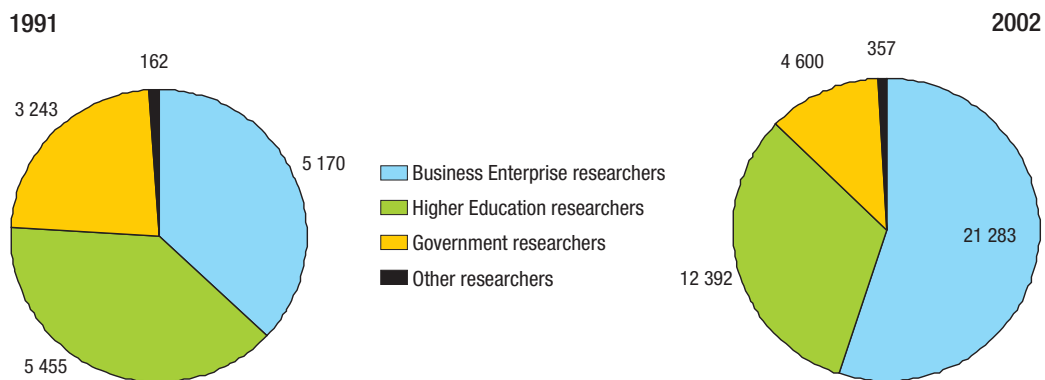
Figure 39. Researchers by sector, Finland 1991 and 2002. Source: OECD (2005a)

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18 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.

19 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
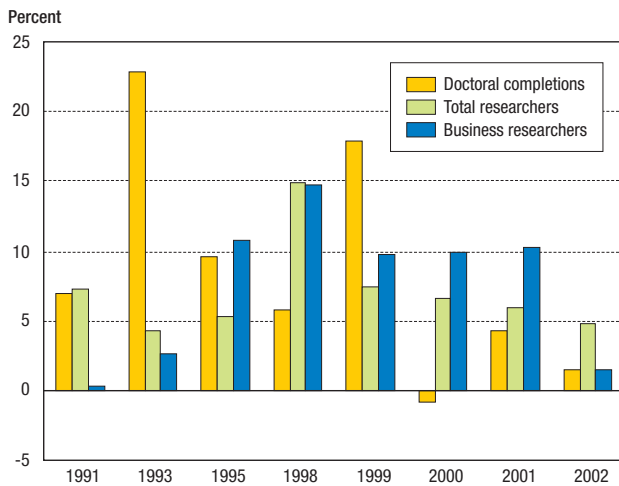
Figure 40. Growth in doctoral completions and research workforce, Finland 1991 to 2002.
Source: OECD (2005a)

competencies for careers outside of basic research: "It is necessary to look into how the contents of different options within PhD programmes could be developed and how a multidisciplinary approach could be more broadly and firmly integrated into PhD programmes" (p. 44). The Academy also highlighted the importance of competitive, high quality education and research environments with an ability to act in an internationally networked environment and to 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 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".

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* that followed, 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. This led to an increase in the value and number of grants available in this scheme and 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 (see Table 23): 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.

Table 22. Researcher pay scales, Australia (NHMRC) and USA (NIH), 1998 ($AUD)

	Australia	USA
Research Assistant/Postdoc	$38,000-$51,000	$30000-$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 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 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).

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 has led many researchers to pursue careers outside Australia that provide more attractive research environments, such as the USA. 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). Comments about postdoctoral fellowships by the Group of Eight universities that were included in Nelson (2003a) identified issues about research careers in universities. These issues included a lack of a well-defined career paths, reduced employment opportunities, contract and short term nature of postdoctoral employment, and uncompetitive salaries. As a result, many postdoctoral fellows are more attracted to industry and other research agencies than universities, and there is an increasing tendency for best doctoral graduates to go overseas.

Table A11 in the appendix explains the current Australian postdoctoral fellowship and award schemes that are funded by the **Australian Research Council**. The number of fellowships funded by the ARC 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[20] 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.

As well as the Australian Research Council, there are other agencies that 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 be-

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20   **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 around 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, 2005).

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/Queen Elizabeth II Fellowships	30	30	30	31	33
Success rate	n/a	n/a	13.9%	12.2%	14.6%
Discovery Australian Professorial Fellowships	15	15	23	25	24
Success rate	n/a	n/a	13.9%	14.5%	15.4%
Total Discovery project fellowships **Success rate (%)**	**100** **14.6%**	**100** **14.3%**	**163** **19.6%**	**166** **16.5%**	**169** **19.4%**
Federation Fellowships			25	22	25
Success rate (%)			9.3%	24.7%	17.5%
Linkage Australian Postdoctoral Fellowships CSIRO				10	
Success rate (%)				14.3%	
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 (2005)

cause of the lack of suitable opportunities). Eight industry fellowships (where researchers 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 post-doctoral 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 also employs more people as researchers (as a proportion of total employment) than the OECD average. Following strong growth in the first half of the 1990s, growth in the employment of researchers in all sectors has slowed (Figure 41). Growth in research degree comple-
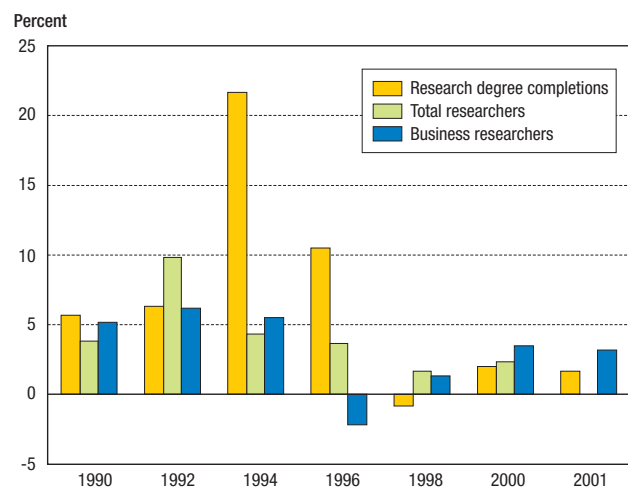
Figure 41. Growth in research degree enrolments and research workforce, Australia 1990 to 2000.
Source: OECD (2005a)
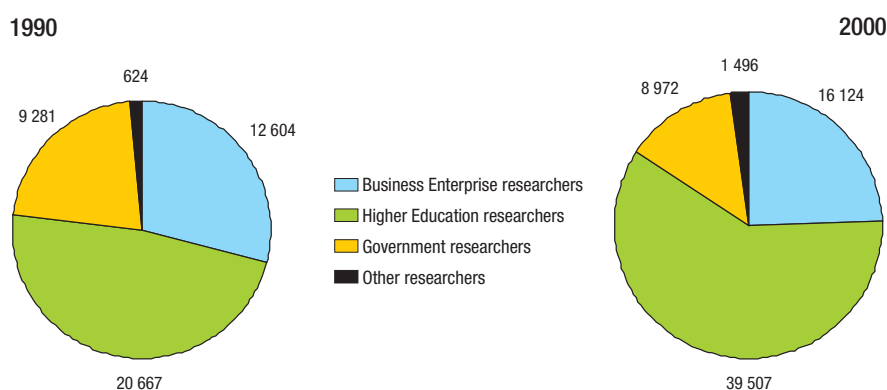
Figure 42. Researchers by sector, Australia 1990 and 2000. Source: OECD (2005a)

tions in the mid 1990s was significantly above growth in the **research workforce** suggesting an oversupply of research graduates at the time. 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 42). Despite the increase in the number of 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) combined with increases in researchers employed in other sectors led to a fall in the Government share of researchers from 21.5% to 13.6%.

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.

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.

As stated in Chapter 2, the United States employs more researchers than the OECD average – 8.6 researchers out of every 1000 people employed (1999) compared to 6.5 researchers for the OECD (2000). 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. However, people with a doctorate accounted for only 13.7% of people in the HRST core in 1999 i.e. employed in S&E occupations and with S&E qualifications (which totalled 3.54 million). Most people working in S&E occupations have a Bachelor's degree (56.3%) or a Master's degree (29.1%).

Data from the National Science Foundation (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 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[21] 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"
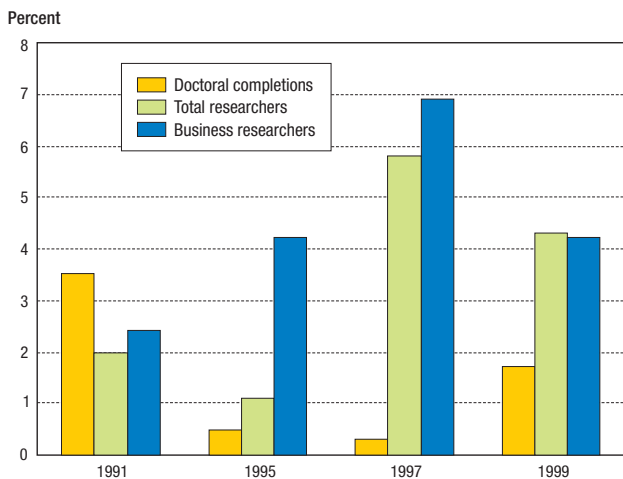
Figure 43. Growth in doctoral completions and research workforce, USA 1991 to 1999.

Source: OECD (2005a)

search assistantships which have grown from 79,100 in 1989 to 99,700 in 2001. The number of postdoctoral researchers at US universities has also increased, 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 (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, as discussed below.

Figure 44. Researchers by sector, USA 1991 and 1999. Source: OECD (2005a)

(or "instructor"). It normally takes as 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 American, 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 research (doctoral) students in the United States are financed through re-

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 (as discussed in this section) 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 en-

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21 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).
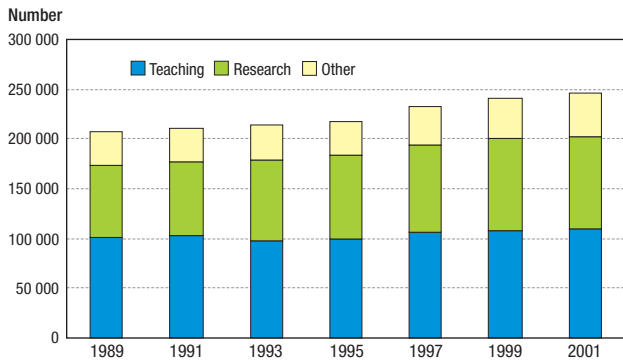
Figure 45. S&E doctorate holders employed in US universities & colleges by activity, 1989 to 2001.
Source: National Science Foundation (2004)

courage universities to introduce innovative PhD programs that would train people primarily for work in the private sector without affecting existing programs.

Romer (2000) referred to a National Research Council (1998) report that found the attractiveness to young people of careers in life science research is declining. 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 research grants to support PhD education

• Enhance opportunities for 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.
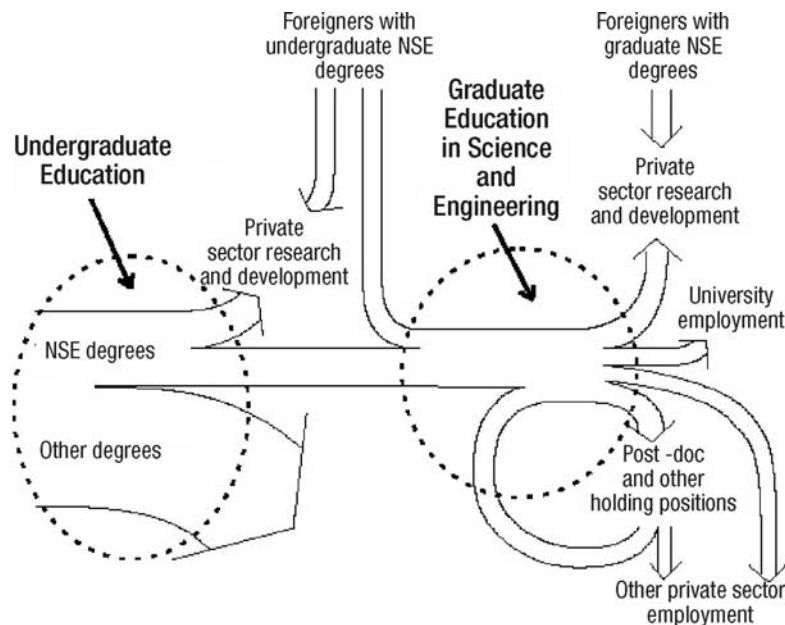
Figure 46. Production process of scientists and engineers in the United States. Source: Romer (2000) p. 25

Issues raised by the National Research Council about research careers in life sciences (which can be applied to most S&E fields) are persisting. 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) is 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 (such as 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.

3.7 Case study results for Finland, Australia and the USA

Thirty (30) research students studying in the fields of geospatial science, wireless communication, biosciences, and materials science and engineering from three universities[22] were case studied 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 (such as specialist training, conference attendance, study tours) and, in a few cases, longer visits to other universities.

Finland

Nine of the 10 University of Oulu research students had been internationally mobile during their PhD studies (Table 24). The tenth student is planning mobility activities. Mobility activities usually include 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 CRC also referred to 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 of the students participated in a study tour in San Diego and Lund in southern Sweden as part of Biocenter's Biobusiness course (which is discussed further in the next chapter). Two students were based at other universities in Europe for an extended period of time. One student from the 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.*

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

Four of the 10 University of Oulu research students are from abroad (two from Italy, one from the USA and one from India) and 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, whilst the other three were

Table 24. 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, USA (Boston), China and Singapore	
Student 2	✓ Conference/forums/workshops in Portugal, France, Germany and The Netherlands	
Student 3	✓ Two conferences in USA (Boston)	
Student 4	✓ Conference/forums/workshops in Hawaii, USA (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 USA (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 to USA (San Diego) as part of 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 US and likely to remain in Finland	
Biocenter Oulu		
Student 6	✓ Seeking postdoc position in Canada or Central Europe	
Student 7	✓ Seeking postdoc position in USA 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

planning to work in the Europe or North America. It is interesting to note that two of 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 from sometime*. The other Finnish student intending to work abroad is likely to return to Finland leading to brain circulation:

> *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 are *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 discussed the importance of international mobility to networking and high quality research:

> *We want people to be able to go to an event, network, having 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 bests, 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 sand connections with key research centres around the world.*

> *We have research agreements with MIT, ETH (Swiss Federal Institute of Technology) in Zurich, University of NSW 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.*

Australia

Table 25 shows that only three of the 10 RMIT research students (from two departments) have been 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 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 US, 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 of these students used the facilities of other local universities.

Five of the 10 RMIT research students have graduated since participating in this 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

Table 25. 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	
Student 7		✓
Student 8		✓
Student 9	✓ Conference in USA	
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	
Student 7		✓ Seeking Australian university teaching/research position
Student 8		✓ Government non-research position
Student 9	✓ Migrated to Australia and seeking postdoc position in USA	
Student 10	✓ Migrated to Australia and seeking research work in Australian university or company	

resident of Australia (of Asian nationality) seeking a postdoc position in the USA; and Student 10, a recent permanent resident and of Asian nationality, is seeking a research position in an Australian university or company. Student 7 is a domestic student seeking a teaching and 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 that 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 USA 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 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 was a permanent resident, of Asian nationality and seeking a post doc in the USA) believed that she was more likely to undertake a post doc position overseas than domestic students: *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 success 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 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.*

United States

Three students case studied from the University of Illinois at Urbana-Champaign (UIUC) were internationally mobile during their studies (Table 26). Two students attended international conferences outside of the United States and one student was awarded an East Asia and Pacific Summer Institutes for US Graduate Students (Australia) 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 regularly attending relevant conferences, meetings, workshops and specialist training, and/or collaborating with other universities:

> *I worked 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.*

Four of the students were international students. The students from China and India were both seeking postdoc positions in the USA. 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.* The two students from Argentina intended to return home. Family and cultural ties was the reason given by one of these students: *I think in Argentina that is where my roots are. The culture is different. They are much more sociable people than here. People here are colder and live to work.* None of the six local (US 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.

Table 26. 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 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 students from India seeking a postdoc position in USA (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 the 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

3.8 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.

Finland, along with Australia and the United States, has a range of programs in place which aim 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 research students and graduates. The issue for Australia is the "brain drain" of domestic research graduates. The United States has relied heavily on a supply of foreign students and researchers for some time and events of recent years are suggesting that it is no longer the primary destination for these people.

Finland is well aware of the obstacles it faces in attracting foreign research students and graduates. Those that have made it to Finland were attracted to the high level research environment and as a whole are satisfied with the quality of information and guidance provided. As a result, nearly half of those people surveyed in 2004 are 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. Therefore, Finland should continue its efforts to encourage more student exchanges but with a greater focus on attracting research students. This includes more innovative approaches (including funding opportunities) to attract foreign research students and graduates to Finland. More effort is also needed to encourage Finnish research students and graduates to work abroad where they can establish international networks. Although most of the Finnish research students who were case studied participate in international conferences, workshops and/or courses, this study recommends mobility initiatives that are longer in duration in order to establish strong and ongoing networks.

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. Finland, Australia and the United States are proud of its ability to employ researchers at rates that are consistently above the OECD average and for its efforts in expanding the number of research jobs (particularly in industry for Finland and the United States). However, those with doctoral degrees 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 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 their programs have not prepared them to work in other sectors and demand for research graduates in industry is not sufficient. Freeman (2004) recommended a number of ways to address these issues which must be considered in terms of demand and supply for S&T researchers for each country.

4 Knowledge production and distribution by research students (case studies)

The focus of this element of the conceptual framework is 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 these questions are framed around a discussion in this chapter about knowledge production and distribution in a national innovation system, the preferred capabilities of researchers within knowledge-based economies, and the relationship between national culture and innovation. 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 country in which the research students are undertaking their studies is characterised by cultural and structural attributes that encourage innovation.

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

- **Knowledge production** – 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 useful to industry, government or society) and are encouraged to constantly interact with and seek input from stakeholders (such as potential users of their research and practitioners from different fields). This

leads 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?*

- **Knowledge dissemination** – 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.

4.1 Knowledge production and distribution in a national innovation system

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 are considered in this study's analysis of how the 30 research students are receiving, creating and disseminating knowledge.

Before presenting the aspects of above literature which are most relevant to this study, it is necessary to describe what is meant by a **knowledge-based economy**. An Australian article by McKeon and Lee (2001) defines 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.

One of the best known (and cited) books on 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 (p. 3):

> 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.

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 trans-disciplinary 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[23] where knowledge is created. A team is formed temporarily to solve a problem (so flexibility and response time are crucial factors). Afterwards, team members will form different groups to 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 phenomena 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 to those involved through the process of production (who form and maintain communication networks) and as the practitioners 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 re-think 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 2.2 in this report describes 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, that is, it is embedded in human and social context, and is unable to be codified. In a more recent article, Lundvall (2000) continues 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) involves a large amount of trust[24] and social capital.

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 – such as 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 (e.g. R&D expenditures) and output measures (e.g. patents or high-tech products) but also by the use of the knowledge produced[25]. 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

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

24   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 was ranked second (2), Australia was ranked sixth (6) and the USA was ranked eighth (8).

25   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).

"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 increase the social payoff from past outlays by increasing the 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 search within the entire possible space of knowledge distribution.

4.2 Capabilities of researchers in knowledge-based economies

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) and Hans Schuetze (2000) 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 critique of a presentation about this study in Maastricht in 2003[26], 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 information and communication technology (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).

Lam's findings about the impact of the third generation model of R&D on knowledge workers and university-industry relationships are most relevant to this study. In the third generation R&D 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* (p. 11). Lam (2002) identified from her interviews 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).

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

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

Figure 47. R&D models of innovation and competence-building. Source: Lam (2002), p. 20

Lam (2002) found that **university-industry relationships** have also moved away from first and second generation R&D models in which knowledge flows were linear from academia to industry. In these earlier models the university was the primary source of fundamental knowledge and supplier of certified competencies. 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 that are made possible through these linkages[27]. In the case of technology transfer he argued that it

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27 University-industry linkages or forms of collaboration include corporate affiliation programmes, consortia for pre-competitive R&D (including centre 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).

Table 27. 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

"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 argued that universities must look at new forms of extension and dissemination beyond the traditional channels of teaching and scholarly publications. As shown in Table 27, 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. 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,

transfer and exchange. This 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 a book written by Dr. Mary Walshok in 1995 called *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.

4.3 National culture and innovation

Given the correlation between national culture and successful innovative activity, this study assumes that national culture is likely to have had an impact on the knowledge production by the 30 research students (as well as the research training environment in which it was undertaken). This section presents findings from key studies that have assessed this correlation. These studies have been largely informed by the research project into differences in values among IBM business employees from over 50 countries undertaken by Geert Hofstede from the late 1960s.

In his 1980 book, *Culture's Consequences*, Hofstede (2001) identified four independent **dimensions of national culture**: "power distance", "individualism", "masculinity" and "uncertainty avoidance". Informed by Michael Bond's Chinese Value Survey of 23 countries in 1985, Hofstede added the fifth dimension of Confucian dynamism or "Long-Term Orientation". See Table 28 on the next page for a description of these dimensions and rankings for Australia, Finland and USA (against the country means). Jones and David (2000) discussed the impact of these dimensions of national culture on innovation as part of their study on how national cultural affects the location of global R&D. They found that innovation success is more likely to occur in countries characterised by:

- *low power distance* – less formal hierarchy of authority and control, greater decentralisation of knowledge and responsibility, free exchange of information in both vertical and horizontal directions, and limited emphasis on rules and procedures to control operations
- *weak uncertainty avoidance* – a high level of tolerance for change and ambiguity, accepting and even embracing of risks associated with an uncertain future, and accepting of competition and colleague dissent
- *individualism* – high degrees of personal and professional freedom, autonomy and independence, and where individual initiative is encouraged and rewarded
- *masculinity* – greater emphasis on the tasks, levels of achievement and reward, and accepting of some degree of conflict and competition
- *long-term orientation* – a focus on hard work and perseverance, although change occurs more rapidly in countries with a low long-term orientation ranking.

Values for power distance and uncertainty avoidance were well below the country mean for Australia, Finland and the United States. These countries accept and are willing to take risks and consider the opinions of others – characteristics that serve innovation and entrepreneurship. Whereas Australia and United States are "masculine" societies, Finland is regarded as a "feminine" society with "a friendly atmosphere, job security and cooperation" and an "emphasis on relationships and group integration as opposed to individual achievement" (Jones and David, 2000, pp. 27-28). This helps to explain the lower individualism value for Finland compared to the other two countries. Both Australia
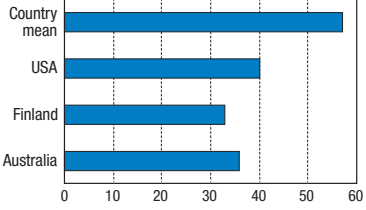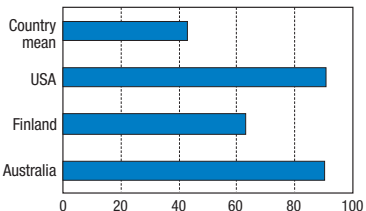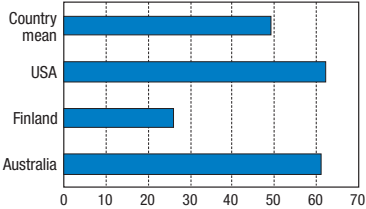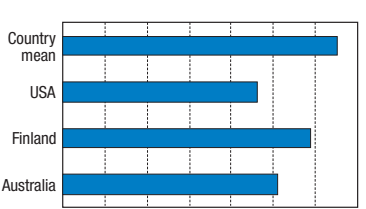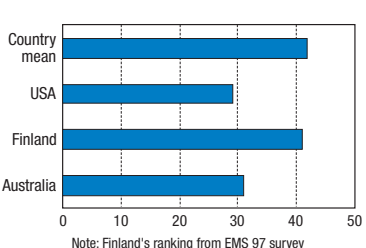
and the USA are countries with a fairly low long-term orientation in which traditions are said to not impede change.

The 1986 study by Rothwell and Wissema identified nine elements which govern the occurrence and nature of technological innovation, three of which are culturally dependent i.e. the need for the innovation, size and location of diffusion threshold, and the objectives of society. They found that technology and culture have a reciprocal relationship. On the one hand, new technology impacts on the culture of a nation, that is its norms, values, attitudes, social behaviour, institutions, and social organisation. On the other hand, new needs that arise from cultural or economic changes lead to the creation and adoption of new technologies. Rothwell and Wissema (1986) believe that governments have an important role in stimulating public acceptance of new technology through public policy and information. This is because the adoption of new technology often requires facing resistance and social change.

Herbig and McCarty (1993) found that innovative capacity is enhanced in countries with positive cultural and structural attributes. Such countries are characterised by open societies (i.e. they do not restrict information or control the direction on progress), a democratic political system and a competitive (capitalist) private economy. Herbig and McCarty (1993) developed an Innovation Matrix (Figure 48) where countries are placed in one of four quadrants based on positive and negative traits of culture and structure. They also recommended strategies to encourage innovative capacity within these quadrants. The USA is regarded as a Quadrant 1 society with positive structural and cultural innovation enhancers, although the negative aspects of government regulations and liability have caused a movement to the right over the last few decades. Australia is located in Quadrant 2 in which societies are regarded as having positive cultural traits but negative structural attributes (and therefore need to change structure through a Structure-Adaptation Strategy). Although Herbig and McCarty (1993) did not include Finland in their Innovation Matrix, you would expect it to be located on the left in Quadrant 1 because of its strong innovation policy and supporting institutional structures but towards the bottom of this quadrant because of its lower individualism and masculinity (cultural dimension) rankings.

Scott Shane examined why some societies invent and innovate more than others and the impact of cultural influences on national rates of innovation. His 1992 study compared the per capita number of invention patents granted to nationals in 33 countries in 1967, 1971, 1976 and 1980 with Hofstede's power distance and individualism values for these countries. Table 29 shows that Finland consistently increased their inventive activity during the periods studied, whereas activity in Australia and the United States declined after 1971. He found that inventiveness is more likely to occur in less hierarchical and individualistic societies where there is more communication between people,

Table 28. Geert Hofstede's cultural dimensions: values for Australia, Finland and the USA

Power Distance Index (PDI) focuses on the degree of equality, or inequality, between people in the country's society. A high Power Distance ranking indicates that inequalities of power and wealth have been allowed to grow within the society. These societies are more likely to follow a caste system that does not allow significant upward mobility of its citizens. A Low Power distance ranking indicates the society de-emphasises the differences between citizen's power and wealth. In these societies equality and opportunity for everyone is stressed.	Bar chart (scale 0–60): Country mean ≈ 57, USA ≈ 40, Finland ≈ 33, Australia ≈ 36
Individualism (INV) focuses on the degree the society reinforces individual or collective achievement and interpersonal relationships. A high Individualism ranking indicates that individuality and individual rights are paramount within the society. Individuals in these societies may tend to form a larger number of looser relationships. A Low Individualism ranking typifies societies of a more collectivist nature with close ties between individuals. These cultures reinforce extended families and collectives where everyone takes responsibility for fellow members of their group.	Bar chart (scale 0–100): Country mean ≈ 27, USA ≈ 91, Finland ≈ 63, Australia ≈ 90
Masculinity (MAS) focuses on the degree the society reinforces, or does not reinforce, the traditional masculine work role model of male achievement, control and power. A High Masculinity ranking indicates the country experiences a high degree of gender differentiation. In these cultures, males dominate a significant portion of the society and power structure, with females being controlled by male domination. A Low Masculinity ranking indicates the country has a low level of differentiation and discrimination between genders. In these cultures, females are treated equally in all aspects of the society.	Bar chart (scale 0–70): Country mean ≈ 50, USA ≈ 62, Finland ≈ 26, Australia ≈ 61
Uncertainty Avoidance Index (UAI) focuses on the level of tolerance for uncertainty and ambiguity within the society i.e. unstructured situations. A High Uncertainty Avoidance ranking indicates the country has a low tolerance for uncertainty and ambiguity. This creates a rule-oriented society that institutes laws, rules, regulations, and controls in order to reduce the amount of uncertainty. A Low Uncertainty Avoidance ranking indicates the country has less concern about ambiguity and uncertainty and has more tolerance for a variety of opinions. This is reflected in a society that is less rule-oriented, more readily accepts change, and takes more and greater risks.	Bar chart (scale 0–70): Country mean ≈ 65, USA ≈ 46, Finland ≈ 59, Australia ≈ 51
Long-Term Orientation (LTO) focuses on the degree the society embraces, or does not embrace, long-term devotion to traditional, forward, thinking values. High Long-Term Orientation ranking indicates the country prescribes to the values of long-term commitments and respect for tradition. This is thought to support a strong work ethic where long-term rewards are expected as a result of today's hard work. However, business may take longer to develop in this society, particularly for an "outsider". A low Long-Term Orientation ranking indicates the country does not reinforce the concept of long-term, traditional orientation. In this culture, change can occur more rapidly as long-term traditions and commitments do not become impediments to change.	Bar chart (scale 0–50): Country mean ≈ 41, USA ≈ 29, Finland ≈ 41, Australia ≈ 31. Note: Finland's ranking from EMS 97 survey

Source: Hofstede (2001) and (2005)

greater incentives for people to invent, openness to change, freedom for creativity, and acceptance of the psychological characteristics of independence, achievement and non-conformity. Shane (1992) concluded that these societies are the best locations for R&D in multinational corporations, and firms operating within these societies are more likely to have innovative cultures. In his 1993 study, Shane argued that increasing a country's rate of innovation is not just a matter of increasing their investment in R&D and industrial infrastructure. Countries must also influence the attitudes of its citizens to those that encourage innovative

activity. He also found that wealthier countries are more likely to innovate, as they have stronger demand for labour-saving devices and new and differentiated consumer goods (as well as the ability to market these innovations). His comparison of 1976 results with 1980 results showed that the importance of power distance and individualism seemed to be waning, particularly in light of anecdotal evidence available at the time that suggested that many Asian economies (collective and hierarchical societies) were becoming more innovative - hence the inclusion of Japan in Table 6.
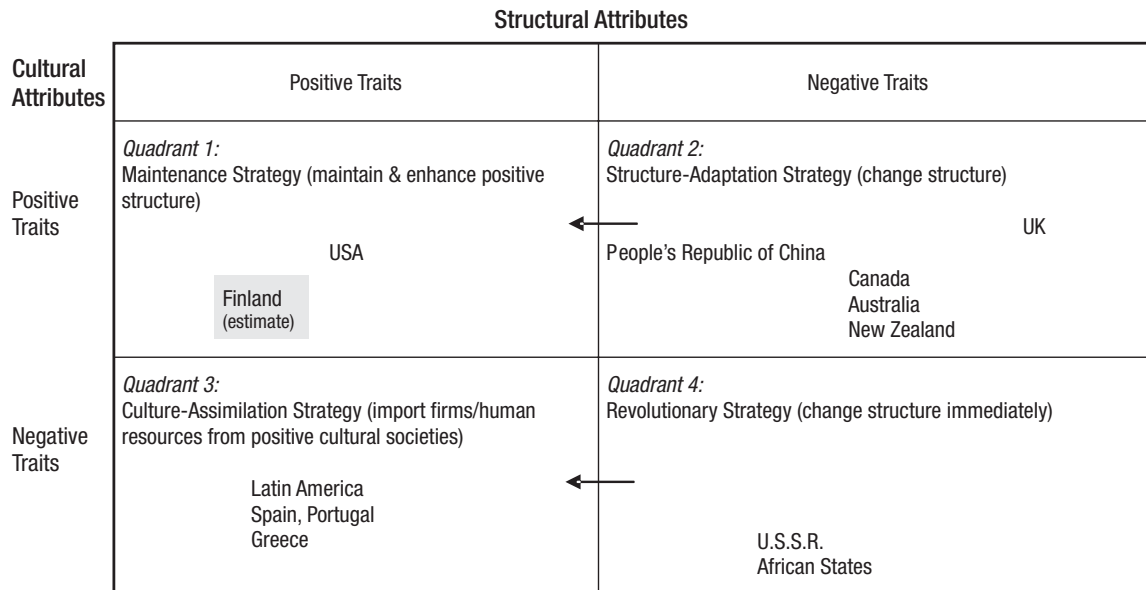
Figure 48. Innovation matrix. Source: Herbig and McCarty (1993) p. 25

A report about innovation in Finland prepared for the Industrial Innovation Working Group (Anderson Wright Associates, 1999) as part of Australia's national innovation summit in 2001 identified a number of cultural factors that are impacting on the implementation of Finland's national innovation system. Although Finland has a "very unusual language", it possesses the following cultural factors that are conducive to innovation (p. 3):

- The *sisu* characteristic of the Finnish people i.e. guts, determination, "what it takes"
- A long-established focus on design, supported by design prizes such as the Pro Finnish Design Prize
- A rapid takeup of new information technologies by business and consumers. At the time, Finland has the highest penetration per capita of the Internet in the world
- Almost universal English language skills in business and the professions
- Commitment to decentralisation, e.g. Kuopio's Science Valley
- A global outward-oriented perspective, despite living "on the edge".

The report by the House of Representatives Standing Committee on Science and Innovation, *Riding the Innovation Wave, The Case for Increasing Business Investment in R&D* (June 2003) found aspects of Australian culture and the way Australia's projects itself to the world was one of the impediments to business conducting R&D in Australia. Below is an extract taken from this report that uses direct quotes from submissions that is received to explain this point further:

Australia's "brand" image as a country was said to relate to tourism and sports rather than to business *but gold medals in the swimming pool will not pay the national debt*. One witness stated that *culturally, in Australia we accept the hero sportsman, but we are not really quite so sure about business people*; and another person said that the main impediments to greater private investment in R&D in Australia … *are founded on a long period of lack of national recognition of the importance of R&D to our society. Our sports heroes or artists often gain instant recognition while our technologists are usually inconspicuous. This feature is evident in our various honours lists, "Australian of the Year" and similar opportunities for national recognition* (p.73).

Table 29. Hofstede's scores and number of inventions per capita multiplied by one million

Country	IDV	PDI	1980	1976	1971	1967	Rank (1980)	Rank (1967)
Australia	90	36	43.4	64.13	75.66	63.73	16	16
Finland	63	33	91.5	61.39	75.76	50.11	10	20
USA	91	40	166.2	200.52	269.61	258.03	4	3
Japan	46	54	328.7	285.13	234.24	137.63	1	9

Source: Shane (1992) p. 45

Thomas Friedman attributed American's innovation success to cultural factors in his article called *The Secret of Our Sauce* published in the New York Times on March 7, 2004:

> America is the greatest engine of innovation that has ever existed, and it can't be duplicated anytime soon, because it is the product of a multitude of factors: extreme freedom of thought, an emphasis on independent thinking, a steady immigration of new minds, a risk-taking culture with no stigma attached to trying and failing, noncorrupt bureaucracy, and financial markets and a venture capital system that are unrivalled at taking new ideas and turning them into global products.

4.4   Case study results for Finland

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 30 contains the topics and funding sources for these students. Appendix 12 describes their R&D work in more detail. This section starts with a summary of the University of Oulu and the two participating centres. The remainder of the section analyses the case studies in three areas informed by element 2 of the conceptual framework: knowledge production, knowledge dissemination and capability development.

The University of Oulu was formally established in 1985. It is currently structured around four focus areas: Information Technology, Biotechnology, Northern Issues and 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 technolo-

Table 30. 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 supported by funding from FibroGen Inc
Student 8	Protein-ligand interaction: affinity calculations	Graduate research position
Student 9	Theoretical studies on prostate specific proteins	Graduate research position
Student 10	Interactions of SCP-2L and TPR-domain of PEX5 at the molecular level	Seeking funding from European Commission to continue Master's research at PhD level

gies. 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, of which 53% was 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 it 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, and 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.

Knowledge production

a) Context of application

Centre for Wireless Communication: 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* (who were case studied) *are full-time employees. We both have a university requirement regarding thesis progress and the projects requirement. We (CWC) live and die with projects, if we don't have projects we don't have people. Some projects are closely aligned with research (PhD) 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/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 stated *that the main reason why the sponsors come 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 (both funded through the FUBS 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 compa-*

nies who want to produce money, profit. It is going to bene-fit 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 Coordinator of Infotech stated that the CWC has *good postgraduate courses and their research is unquestionably top quality. 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.* The Director of the CWC is aiming to reduce the completion time to *five years as a maximum.*

Biocenter Oulu: Five students were case studied from three research groups within Biocenter Oulu. In four of these cases, the research can be regarded as "oriented basic research" that was expected to contribute to a broad base of knowledge aimed at solving a particular problem or opening up other possibilities. One supervisor 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 the three students from the Biocomputing Group is likely to *springboard* further studies by the scientific community. As stated by the supervisor of the 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.*

Student 6 is using his research results to develop 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 this research.

b) Interaction with stakeholders

Centre for Wireless Communication: As part of reporting arrangements for industry projects, the research students regularly meet 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. In the case of another student: *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 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 feedback 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 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.*

As discussed on the next page, the five research students from the CWC are also encouraged to interact with experts and peers through conference and workshop attendance.

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 US company (Student 7). At the time, neither of these students had 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.

Knowledge dissemination

a) Dissemination of findings

Centre for Wireless Communication: All five research students regularly disseminate results about their research as part of the project reporting arrangements to their sponsors (Table 31). Relevant results are usually embedded in reports and presentations to sponsors made about the larger project. The CWC all hosts seminars where staff and students present their work. The five 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 referred to 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 you are allowed to go to that conference to present your results.* These guidelines were also discussed by the Director of the CWC:

> *We have some guidelines for that. 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 is 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.*

Biocenter Oulu: Research students from Biocenter Oulu are also encouraged to present their research results at conferences and in journals. Two of the students 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.*

Table 31. 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	

b) 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 32) indicates 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 when students own the IPR and transfer it to the university they are entitled to 60% of profits generated from the invention.

Centre for Wireless Communication: 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.*

Three of the students had been involved in patent applications as part of the overall project. However, they 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*. Another student stated that although the intellectual property belonged to the sponsor 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*. Another 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*.

One of the supervisors believes that selling all the rights to the industry sponsors *is not a big issue because what we get in returns is we get much better financial compensation for*

Table 32. 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 programmes, 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, 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)

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 the student is undertaking his research doesn't adequately support commercialisation opportunities:

> *There is a lot of commercialisation possibilities. I know if his environment was let us say the 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 as 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. It is always a good feeling for the research that you are doing something useful.* 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 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 their PhD. 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 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.*

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:

- *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 can understand and learn 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 it is 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.* He 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.*

Biocenter Oulu: The supervisor of the students from the Biocomputing Group discussed the "journey" that two of his 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.* He 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 with was 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.

PhD 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 in

Sweden. Two of the students who were case studied had participated in the programme and another student was planning to participate in the next programme.

Key findings of element 2 for Finland

The unique model of research training embedded in industry funded projects at the CWC means that PhD 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, the research students have an opportunity to gain feedback about their own research. However, the degree to which these students can get direct feedback from sponsors about their PhD research varies with one student stating that the sponsors may not even be aware that they are undertaking academic research. Another issue is the length of time taken to complete research training whilst working on these projects. Research results of the students in the Biocomputing Group are 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 both the CWC and Biocenter Oulu were using to assist 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.

4.5 Case study results for Australia

Ten (10) research students enrolled in a Doctorate by Research in two departments (The Department of Biotechnology and Environmental Biology and the 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.

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.

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 or 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.

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

To be eligible to enrol in a PhD at RMIT University, students must have a Master's degree from RMIT or have qualifications or experience that are deemed equivalent. Master 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 Master's 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.

Knowledge production

a) 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. Findings from Student 3 were expected 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: Research being undertaken by three of the students was 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 the 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, and developers and service providers were also expected 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 that with further research could lead to applications in the future.

b) Interaction with stakeholders

Before discussing the extent to which these students interacted with stakeholders, it is worth noting the funding sources of these students because this indicates the involvement of stakeholders (i.e. partners in funding applications) 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 and industry partners. Two students received PhD scholarships from the CRC for MicroTechnology as part of projects supported by industry. Three students were funded by internal RMIT scholarships and one student 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 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 Linkage grants. The degree of interaction seems 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.

Department of Biotechnology and Environmental Biology: 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 based on 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 (RIRDC). Student 2 (APAI/Linkage grant) visited a commercial VET lab and a milk factory and surveyed 17 labs in Australia and New Zealand as part of her data collection. Student 3 (IPRS) has not interacted with potential users, although he has created national and international links with scientists who are 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) regularly meets 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 meets 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 and as a result 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.* Research being undertaken by Student 7 (internal RMIT scholarship) is supported by a Victorian Government department but their role at the time of the case study was limited to *bits I fill in, valuation specific information, that she might no 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 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 (the supervisor) 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 pol-

icy 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 most cases their research occurred within their own disciplines.

Knowledge dissemination

a) Dissemination of findings

Similar to Finland, Mode 1 methods of journals and conference papers were the main methods that the students were using or planned 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

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

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 that were case studied from this department made presentations at the 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, most students did not have a strategy in place to widely disseminate their results to stakeholders as the results were produced.

b) Incentives

As stated in section 2.6, 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 two of the 10 RMIT research students had attended an international conference during their studies, due mainly to funding limitations. RMIT 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 (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 RMIT research students were required to sign intellectual property statements when they enrolled because they were funded through Linkage grants or CRC scholarships. 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.* However, the intellectual property agreement signed by the student at the commencement of the project meant that he would get around 10% of any commercial income which is 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, resulting in an agreement that according to her supervisor *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 of for that matter in Victoria.*

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 development (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 (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 student's social ability to co-operate and communicate with different kinds of people and experts ("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 referred to the increased confidence of the student, which had improved his ability to communicate:

> *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 who were case studied 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.

Key findings of element 2 for Australia

As indicated in the descriptions of their R&D work in Table A3 in the appendix, all students had an excellent understanding of the reasons for undertaking their research (linked to a problem) 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 10 research students in both departments 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, this would involve further research beyond the study. 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.*

Students were aware of the stakeholders who could benefit from their research. The level of interaction with and dissemination of results to stakeholders by these students 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 are 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 (for those students in industry projects) 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".

4.6 Case study results for the USA

Ten (10) research students undertaking a Doctorate 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 were case studied in the first half of 2004. Table 35 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. The university has 40,360 students (of which 11,066 are graduate and professional students), and 7,900 staff. It has also employed 11 Nobel laureates and 18 Pulitzer Prize winners. Students come from across the United States and around 100 countries. There are 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, and in 2002 was ranked 19th of all US 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.

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,

Table 35. 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 US 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

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 US 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: 12 units of thesis work and 12 units of course work. A student entering with a Master of Science degree must complete 16 additional units of graduate work: 10 units of thesis work and 6 units of course 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 this 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 inter- 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 involving the active participation of two faculty members from two different Beckman Institute groups. Three students that were case studied from the Institute had been awarded a Beckman Institute Graduate Fellowship.

The *Department of Crop Sciences* was formed in 1995 by merging faculty from the former Department of Plant Pathology, crop scientists from the former Department of Agronomy, and entomologists interested in integrated pest management from the former Office of Agricultural Entomology. In 2004, there were 66 faculty members and over 100 graduate students. 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 Master 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 United States Department of Agriculture's Soybean Germplasm Collection (the world's largest collection of wild relatives of soybeans) and the Maize Genetics Cooperation-Stock Centre (which contains the world's largest collection of maize mutants and chromosomal aberrations). The Department also supports the Crop Sciences Graduate Organization (CSGO) which is a university-recognised organisation which is chartered to promote social and educational interactions among its graduate students.

Knowledge production

a) Context of application

Department of Materials Science and Engineering: Student 1 is providing new knowledge to the aluminium industry and scientific community about "creep" in the hot rolling process, which is *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 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: Three students who were cased studied from the Beckman Institute were enrolled in PhD programmes 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. This 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 stated that his student's research on improving 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.*

b) Interaction with stakeholders

Department of Materials Science and Engineering: Student 1 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 this 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.* Student 2 has been mainly exposed to specialists and scientists in his field of research and had 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 interact 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.* At the time, 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 has funded him to work with scientists at the University of Western Australia for two months.

Department of Crop Sciences: All the students case studied from this department regularly interact 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 being researched by Student 7 is *more of a northern pathogen I constantly have contact with people of the north, other universities, or companies.* She works closely with pathologists from the University of Wisconsin (at Madison): *We will run 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 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.

Knowledge dissemination

a) Dissemination of findings

Department of Materials Science and Engineering: In addition to conference papers and journal articles, the two students have participated in and presented their work at the department's weekly colloquium and seminar series held by particular research concentrations (Table 36). For example, Student 1 is 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 that he will publish in high quality international journals and present results at two or three major conferences.

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 gave a couple of presentations in the Beckman Institute, such as *the NSF-ITR seminar and Nano-Hour seminar. These seminars are mostly interdisciplinary in nature and many of them are related to nanotechnology.* Students also present findings in their own research group meetings which also provide an opportunity to practice conference presentations. All three students have 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 has on occasion *called up the editor like of Chemical and Engineering News or the editor of the MRS Boa and just self promote paper* and updates 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 patent disclosure: *I have all my students with new results submit their results to a conference first and be able to go 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 are the most common methods of knowledge dissemination for the five students from this department. Student 9 stated that her supervisor expects her students *to go to one meeting and present either a paper or a poster annually.* These students also distribute their results to extension specialists within their 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 results will 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 students also regularly present 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 has also attended small meetings where *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 present research results in their research group meetings, the department's seminar series and other activities organised by the university. 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 also hosted the 2004 Illinois Soybean Research forum where three of the students funded by the Illinois Soybean Program Operating Board presented posters to stakeholders.

b) Incentives

As already discussed, the research students are 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. One of the key considerations 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 the 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.*

Table 36. 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 (USA) 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	Dissemination of results by extension officer (at meetings and directly to farmers), and industry meetings/posters
Student 7	2 journal papers, 1 local workshop presentations	Industry meetings
Student 8	3 journal papers (2 planned), 6 abstracts	Industry meetings
Student 9	6 journal papers	Industry meetings
Student 10	2 journal papers, 1 book (co-author)	Industry meetings

Awareness of intellectual property rights were 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 are 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 supported by a 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 so on and so forth.*

One student believes there could be commercialisation possibilities *if we find a gene responsible for resistance*. Another student who had already been involved in a patenting application believes 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 fund 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" (Office of Technology Management, 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.

Capability development

Department of Materials Science and Engineering: The supervisor of Student 1 stated that she is 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 was the engineering group 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" when he stated: *He has learned a great deal. 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 believes the student has developed the ability of "aha" that is *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 department head discussed the need to ensure that research students are developing the necessary skills for their

future employment, which could be in research but also in management 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 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.*

Beckman Institute for Advanced Science and Technology: The supervisor of Student 3 referred 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 understood 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 also 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 he has improved his writing skills and has *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 believes 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 his improvement as: *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 also discussed her development 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 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 she has more responsibility because she is 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*.

Key findings of element 2 for the United States

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

The students are undertaking their research in a university that has a strong reputation for basic research and widely disseminating research results. Students are 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 are 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 Crop Sciences are also presenting their results at industry meetings and events. IPR arrangements at UIUC indicate that students own their results unless specific arrangements had been made. Only one student discussed specific arrangements where she was re-

quired to present her results to the industry partner before publishing them. Two other students believe that their results may have commercial potential.

Most of the supervisors discussed the improved ability of the students in terms of "know-how". Students are 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.

4.7 Summary

The purpose of this chapter was to determine the extent to which the 30 research students from the University of Oulu (Finland), RMIT University (Australia) and University of Illinois at Urbana-Champaign (USA) are 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 considers the context of application, involves stakeholders and leads to transdisciplinary results
- research results are 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 equips them with the four different types of economically relevant knowledge and the capabilities needed by employers in knowledge-based economies
- research is undertaken in a country with cultural characteristics that are conducive to innovation.

All 30 research students were undertaking research that to varying degrees was context related, that is it is useful to industry, government or society. The usefulness of their research is 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 or at conferences. Students are required to produce three to four international (and refereed) publications 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 were interacting with and disseminating 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 (and 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 able to interact with people from other disciplines through seminar series and the sharing of facilities.

Most of these 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 were mainly attending international conferences and meetings held in Europe with some students (particularly those from the CWC) travelling beyond Europe. Most of the Australian students were unable to attend 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.

Findings from key studies indicate that Finland, Australia and the United States have cultural traits that support innovation. However, Australian culture does not appear to have embraced innovation and the importance of R&D to the extent that the other two countries have. This study recommends that research is undertaken to examine the impact of national culture on research training environments and students' experiences.

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. Some models are actively en-couraging 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). The PhD thesis will contain recommendations that aim to assist Governments and universities to perhaps re-think 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.

5   Research training, human capital and economic growth

The third element of the conceptual relationship examines 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 involves explaining what is meant by human capital, how it is formed and measured. This is followed by a discussion about the economic and non-economic impacts of human capital that is largely informed by (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 to education for advanced research degrees and the relationship between education at the graduate or research training level and economic growth. Therefore, a basic approach has been taken to assess the relationship between research training, human capital and economic growth by using available literature to identify relevant statistical data and inform the analysis of this data for each country. The literature review has led to the following assumptions for the third element of the conceptual framework:

- 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 research professionals.

- Information on returns to research training is limited. However, it is assumed that returns are relatively high but are significantly reduced when the time taken to complete an advanced research degree is extended and research students commence full-time studies later on in life – as both factors increase the amount of income foregone (lowering private returns) and reduce the amount of income tax paid by individuals (lowering social returns).

- Research training represents a significant investment in R&D activities by a country and helps to build a highly qualified 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.

5.1   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). This process occurs in life-wide settings such as formal education, enterprise-based training, work environments, and informally through interest networks, families and communities. 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.

5.2   Measuring human capital

The main issue in measuring human capital is the difficulty in quantifying the knowledge, skills and attributes which are embodied in human beings. However, 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

Table 37. Indicators of human capital (tertiary education) and HRST stocks

	Australia	**Finland**	**USA**
Share of population aged 25-64 with tertiary level A and advanced research programs, 2002	20%	16%	29%
Number of students enrolled in advanced research programs	47,309 (2004)	22,105 (2004)	n.a.
Number of graduates of advanced research programs	6,321 (2003)	1,957 (2004)	44,200 (2003/2004)
Graduation rates at PhD level (proportion of population with a PhD)	1.3% (2002)	1.9% (2001)	1.3% (2002)
S&E graduates (in agriculture, science, and engineering, manufacturing and construction) as a proportion of total graduates of advanced research programs	44.9% (2002)	40.2% (2001)	36.9% (2002)
S&E degrees as a percentage of total new degrees, 2001	19.4%	29.4%	15.8%
Researchers per 1,000 total employment	7.2 (2000)	16.4 (2002)	8.6 (1999)
Business researchers as a percentage of total researchers	24.4% (2000)	55.1% (2002)	80.5% (1999)
Average annual growth rate of HRST	3.07% (1996-2001)	2.32% (1997-2001)	2% (1995-2002)
HRST occupations as a percentage of total employment	35.6% (2001)	32.5% (2002)	32.7% (2002)

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

measure **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 relevant to this study is shown in Table 37.

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 expen-
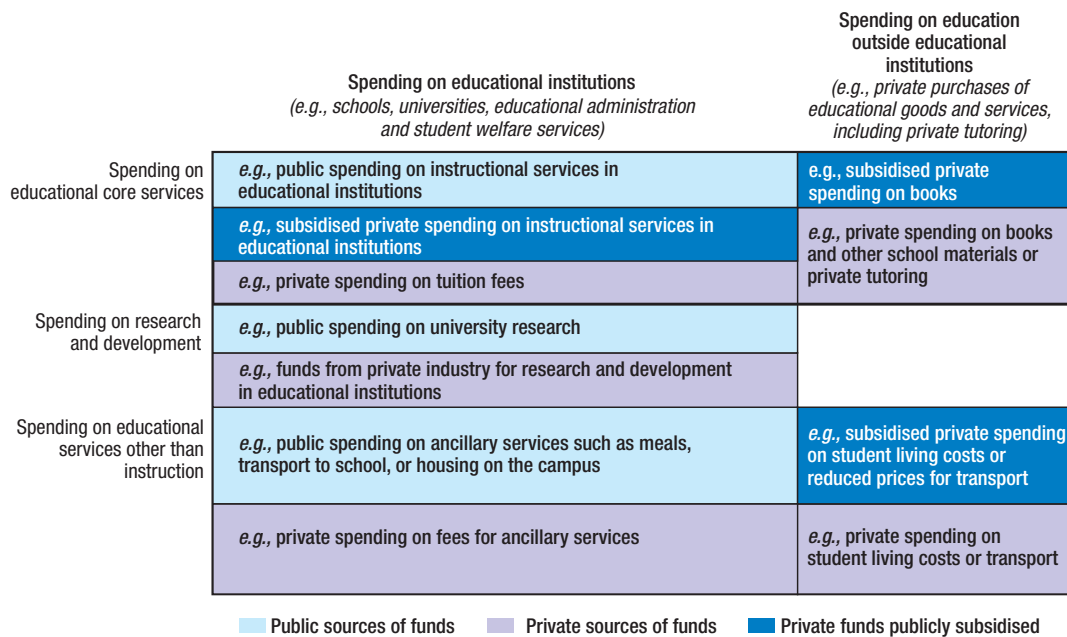

Figure 49. Classification of educational expenditure. Source: OECD (2004b) p. 197

diture (Figure 49): the location where spending occurs (such as schools, universities, 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).

This study is most interested in expenditure on tertiary type A and advanced research programs, expenditure on R&D at tertiary education institutions (which to some extent indicates commitment to a research culture), the nature and degree of private spending by research students, and duration of research training programs as an indicator of income foregone by research students. Indicators of a country's investment in human capital formation through tertiary education are shown in Table 38 Government funding levels for research training for each country is also relevant.

Individuals are encouraged to develop their knowledge, skills and attributes through education in return for enhanced earnings from the labour market. Individuals who complete tertiary-level education earn significantly more and are less likely to be unemployed than those with an educational attainment of upper secondary education and post-secondary non-tertiary education. Other measures of **returns** to investment in human capital (through education) are private internal rates of return and social internal rates of return (Table 39 on the next page). 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 atten-

dance in the United States (and 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 (e.g. on fees, books, 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. 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 by 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).

The measures of returns to investment in human capital through tertiary education provided by the OECD do not separate out earnings, unemployment rates, and private and social returns for advanced research programs. An early study that attempted to do so was by James Dyal who examined the private and social returns from investment in graduate education at the University of Illinois, 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

Table 38. Indicators of investment in human capital (tertiary education)

	Australia	Finland	USA
Expenditure on education as a percentage of GDP, 2001	6.0%	5.8%	7.3%
Expenditure on tertiary education institutions as a percentage of GDP, 2001	1.54%	1.73%	2.73%
Expenditure on R&D at tertiary education institutions as a percentage of GDP, 2001	0.42%	0.62%	0.26%
Expenditure on tertiary type A and advanced research programs per student (US dollars), 2001	$13,654	$11,143	$22,234 (all tertiary education)
Expenditure on R&D at tertiary institutions per student (US dollars), 2001	$3,488	$3,921	$2,136
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%
Expected years in tertiary type A education (in years), 2002	2.9 years	3.9 years	3.9 years
Average duration of studies of tertiary type A and advanced research program studies, 2001	2.6 years	4.5 years	n.a.
Cumulative expenditure on tertiary type A and advanced research programs per student over the duration of tertiary studies (US dollars), 2001	$34,954	$49,972	n.a.

Source: OECD (2004b)

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, 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. In terms of the benefits of graduate education, Dyal (1975, pp. 100-101) stated:

> 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.

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 graduate education 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 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.

Table 39. Indicators of returns to human capital (tertiary education)

	Australia	Finland	USA
Relative earnings of the population with tertiary type A and advanced research degrees (upper secondary = 100), 2002	Males: 160 Females: 159 Total: 148	Males: 190 Females: 172 Total: 181	Males: 202 Females: 185 Total: 195
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)
Unemployment rates all levels of education, 2002	4.5% (males) 3.1% (females)	6.5% (males) 6.2% (females)	4.7% (males) 3.4% (females)
Private internal rates of return for a tertiary degree or an advanced research degree:			
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)
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)
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)
Social internal rates of return for a tertiary degree or an advanced research degree:			
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)
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)
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)

Source: OECD (2004b)

5.3 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, Wykastra (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 (and 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 was 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 (which requires a qualified labour force) 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 knowledge of particular people or particular subcultures of people. This 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) also proposed that the rate of growth of human capital variables (which can also include educational achievement and scientific talent) is 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. However, 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.

Table 40. Possible indicators of economic and non-economic impacts of human capital

	Australia	Finland	USA
Economic impacts:			
GDP growth rates, 2004	3.6%	3.1%	4.4%
GDP per capita, US dollars, current prices 2002	$28,068	$26,495	$36,121
Labour productivity in the business sector, annual percentage growth, 2004	2.1%	3.8%	3.7%
Non-economic impacts:			
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%
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)
Life expectancy	80 years (2002)	78.2 years (2002)	77.1 years (2001)
Homicide conviction/committal rates per 100,000 persons	2.35%	2.54%	5.62%
Emissions of Carbon Dioxide (CO2), millions of tonnes, 2002	343	63	5652
Total primary energy supply per capita (tonnes of oil equivalent per capita) 2003	5.81	7.12	7.30
Life satisfaction and feelings of happiness	85.9%	87.2%	86.2%
Opiate/heroin abuse (percentage of population 15-64 years)	0.6% (2001)	0.1% (2002)	0.6% (2000)
Suicides per 100,000 persons	12.7% (2001)	21% (2002)	10.4% (2000)

Source: OECD (2005b)

There are several non-economic or social benefits that are linked to human capital investment. 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 40 contains a selection of economic and non-economic indicators that may be linked to human capital investment in education including research training. These indicators are assessed in the following section 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. A basic approach is taken to present data for Finland, Australia and the United States on human capital stocks, investments and returns; correlated economic and non-economic indicators; 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 50). 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.
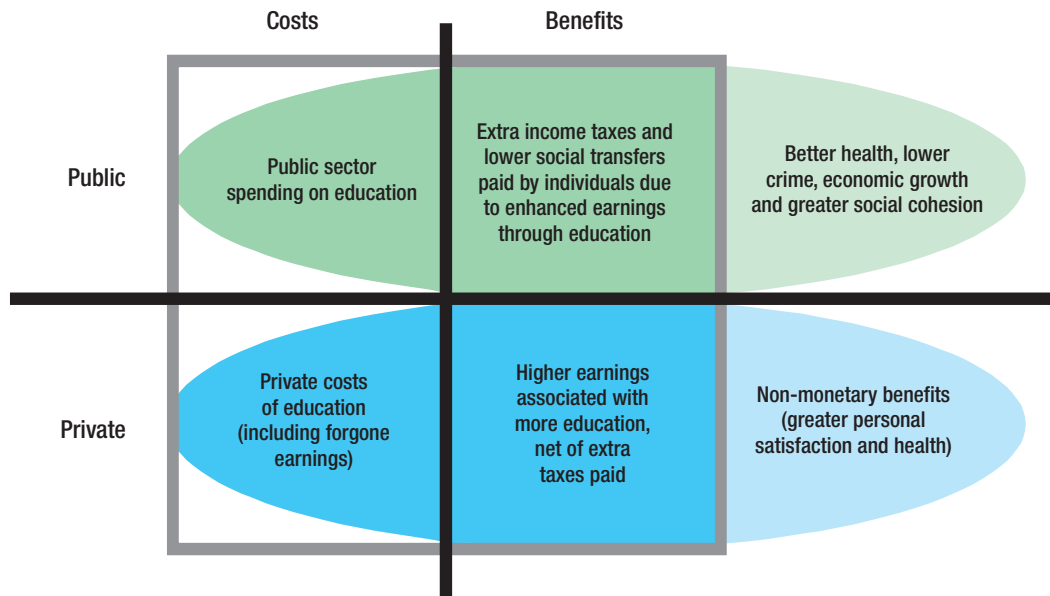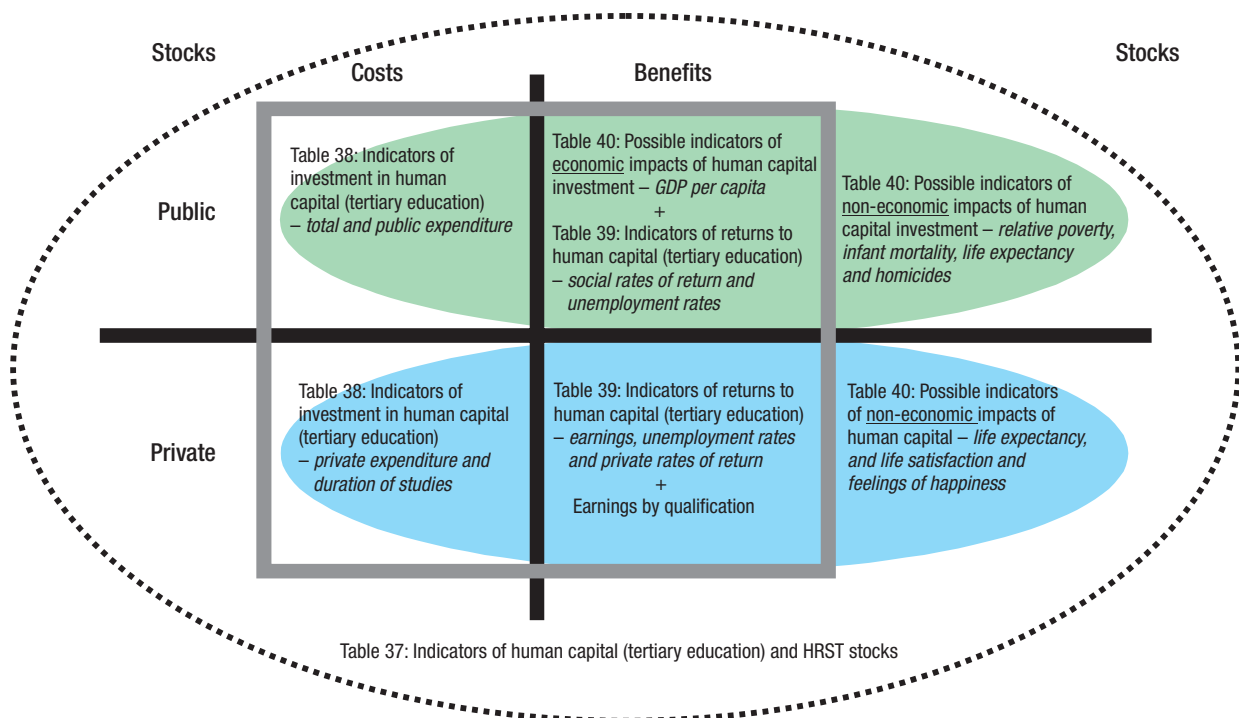
Figure 50. Costs and benefits of human capital investment (education). Source: OECD (1998a) p. 69

5.4 Results for Finland compared to Australia and the USA

Human capital stocks

The proportion of the Finnish population aged between 25 and 65 years with a tertiary type A and/or advanced research degree increased from 12% in 1996 to 16% in 2002 (Table 41). However, Australia and the USA continue to have a greater proportion of the population with university degrees (20% and 29% respectively in 2002). Finland's graduation rate for advanced research degrees of 1.9% was well above that for Australia and the USA (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 that complete a research degree in Fin-land graduate at the age of 29 years compared to 28 years for the USA and between 25 and 29 years for Australia.

Compared to Australia, United States and the OECD, Finland has a lower (and decreasing) share of *science* graduates in tertiary type A and advanced research programs, and a significantly higher (but falling) share of *engineering* graduates. In 2001, 7.2% of university graduates (with tertiary type A and/or advanced research degrees) in Finland were in science (compared to 10% for the OECD) and 20.8% were in engineering (compared to 11.8% for the OECD) (Table 42). Women accounted for a small share of S&T in all OECD countries. In 2001, Finland had a lower share of female science graduates than the OECD (5.3% compared to 8%) and a higher (but falling) share of female engineering graduates (6.5% compared to 4.5%). Overall, 28% of university graduates in Finland in 2001 were in S&E fields, compared to 19.4% for Australia, 15.8% for the USA, and 21.8% for the OECD.

Table 41. Population that attained a university degree (type A and advanced research programmes) by age group, 1996, 1998 and 2002

Age	1996				1998				2002			
	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 programmes (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 (1998a), (2000) and (2004b)

Table 42. University graduates in science and engineering, 1998–2001

TOTAL	Science				Engineering			
	FIN	AUS	USA	OECD	FIN	AUS	USA	OECD
1998	8.0%	11.5%	9.2%	9.6%	24.2%	7.9%	7.0%	12.4%
2000	7.9%	11.8%	9.3%	9.8%	24.0%	7.9%	6.5%	11.8%
2001	7.2%	11.9%	9.4%	10.0%	20.8%	7.5%	6.4%	11.8%
WOMEN	Science				Engineering			
	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%
2000	6.2%	8.6%	7.3%	8.0%	7.7%	3.0%	2.4%	4.4%
2001	5.3%	8.5%	7.3%	8.0%	6.5%	2.9%	2.4%	4.5%

Source: OECD (2004c)

The categories of human resources in science and technology (HRST) that are described in section 2.5 of this report include *HRST core* (people with an S&T university qualification who are employed in S&T occupations), *HRSTQ* (people with an S&T qualifications who are not employed in an S&T occupation) and *HRSTO* (people who do **not** have an S&T qualification who work in an S&T occupation). These categories form a country's HRST stock. Data from the OECD on human resources in science and technology (HRST) shows that Finland has experienced lower average annual growth in HRST between 1996 and 2001 of 2.32% (a ranking of 16th out of 27 countries) compared to 3.07% for Australia (1997–2001) and 2% for the United States (1995–2002). HRST accounted for 32.5% of total employment in Finland in 2002 (a ranking of 9th out of 28 countries) compared to 35.6% for Australia (in 2001) and 32.7% for the United States (in 2002).

Data from Eurostat show that HRST stocks and HRST core in Finland peaked in 2001 at 1,195,875 persons and 517,481 persons respectively (Table 43). In 2003, Finland recorded HRST stocks of 725,592 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.

Australia's HRST stocks have increased significantly from 1,987,000 people in 1991 to 3,054,000 people in 2001 (Table 44). Also, 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.

Employment in S&E occupations in the United States rose consistently over the past decade until 2002 (Figure 51). The National Science Foundation estimated there were 5,412,000 people employed in S&E occupations in 2002. There were around 3,540,800 million people in the HRST core in the US (i.e. those with an S&E qualification and employed in S&E occupations) in 1999, and people with doctorates (484,100) accounted for 13.7% of the HRST core.

Table 43. 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)

Table 44. Persons with selected occupations and/or in selected occupations, 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

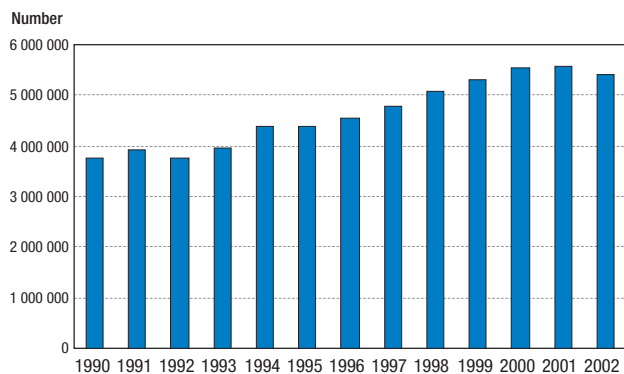Source: Australian Bureau of Statistics (1999) and (2003)

Figure 51. Employment in S&E occupations,
United States 1990 to 2002.
Source: National Science Foundation (2004)

Investment in human capital

Table 45 shows that in 2001 Finland invested more than the OECD country mean in tertiary type A and advanced research programmes. Educational expenditure on these programmes as a proportion of GDP was 1.7% in 2001 compared to an OECD country mean of 1.1%. In 2001, $11,143 was invested per student in these programmes in Finland compared to an OECD country mean of $9,495. However annual investment in Finland was lower than that for Australia of $13,654 and the USA of $22,243. Because

of the longer duration of studies in Finland (an average duration of 4.5 years compared to 2.6 years for Australia), Finland's invests more than Australia on a cumulative basis in tertiary type A and advanced research programmes ($49,972 compared to $34,954). Finland ranked 5th out of 14 OECD countries that provided cumulative data. Expenditure on R&D at tertiary institutions as a percentage of GDP in 2001 was 0.62% for Finland, which represents R&D expenditure per student of $3,921. This expenditure was above that for Australia of 0.42% (or $3,488), the USA of 0.26% (or $2,136), and the OECD country mean of 0.35% (or $3,921).

Private sources continue to account for a small proportion of educational expenditure on tertiary type A and advanced research programmes in Finland. In 2001, private sources accounted for 3.5% of educational expenditure on these programs, compared to 48.7% for Australia, 66% for the USA, and an OECD country mean of 21.8%. Consequently, the higher rates of private return in Finland (discussed in the next section) can be partly attributed to students not having to contribute very much to the costs of their education.

Returns to human capital

Salary data from national sources shows that people with a research degree earn more than those with lower qualifications. OECD data on relative earnings, private and social rates of return, and unemployment rates for those people

Table 45. Expenditure on tertiary type A and advanced research programmes, 1995, 1997 and 2001

	1995	1997	2001
Percent of GDP			
Finland	1.3%	1.4%	1.7%
Australia	1.5%	1.5%	1.4%
USA (all tertiary education)	2.0%	2.6%	2.7%
OECD country mean	1.1%	1.1%	1.1%
Annual expenditure			
Finland	$7,412	$7,192	$11,143
Australia	$11,572	$12,024	$13,654
USA	$19,965	$17,466	$22,234
OECD country mean	$8,781	$8,434	$9,495
Cumulative expenditure			
Finland	n.a.	n.a.	$49,972
Australia	$30,086	n.a.	$34,954
USA	n.a.	n.a.	n.a.
OECD country mean	$36,494	n.a.	$47,894

Source: OECD (1998a), (2000) and (2004b)

with tertiary type A and/or advanced research qualifications presented people indicate that people with a university degree earn more and are less likely to be unemployed than those with lower qualifications. Finland performs well in terms of relative earnings and private and social rates of return, however unemployment rates have only recently fallen to around the OECD country mean.

Average monthly earnings of people with a postgraduate degree in Finland are between 25.9% (for 25-29 year olds) and 54% (for 60-69 year olds) above earnings of people with an undergraduate degree. Earnings for people with a postgraduate degree increase with age, with new graduates aged between 25 and 29 years having the lowest monthly earnings of 2,748 euros a month (Table 46). Average annual income of employed persons with a doctoral degree in Australia (AUD $61,000) was almost 30% higher than average annual income of employed persons with a Bachelor degree in 2001 (AUD $47,000) (Table 47). It should be noted that most of those with doctorates in Australia in 2001 were 35 years or over (88.2%). People with a doctoral degree in the United States (US$89,965 for males) also earned more than those with a Bachelor degree (US$55,929 for males) (Table 48). The difference between these earnings is higher in the United States than in Finland and the United States at 55.5% for males and 51.5% for females in 2001.

Table 46. 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 47. Average annual income of employed people by level of education, Australia, 2001 ($AUD)

	Advanced diploma	Bachelor degree	Graduate certificate	Graduate diploma	Master's 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 48. 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	Master's 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 found that people with a tertiary type A and/or advanced research degree earn significantly more than those people with upper secondary education. In 2001, earnings for males with tertiary type A and/or advanced research qualifications in Finland were 90% higher than earnings for males with upper secondary education. For females the difference was 72% (Table 49). For males and females combined, those with tertiary type A and/or advanced research qualifications in Finland earned 81% more than those with upper secondary education in 2001. However this represents a fall from 85% in 1995. Differences in relative earnings (for males and females combined) for OECD countries ranged from 33% in New Zealand (rank-

ing of 21) to 110% in Hungary (ranking of 1). Finland ranked 7th out of 21 OECD countries for the difference in relative earnings in 2001, compared to 13th for Australia and 2nd for the USA.

Out of nine OECD countries that provided data on private rates of return to tertiary type A and advanced research qualifications, Finland recorded the second highest private rate of return for males (14.2%) and highest private return for females (15.2%) in 2001. Social rates of return in Finland were lower than private rates of return, with rates of 10.5% for males (a ranking of 4th out of 10 OECD countries) and 8.7% for females in 2001 (a ranking of 2nd).

Table 49. Relative earnings (upper secondary education = 100) and rates of return for tertiary type A and advanced research qualifications

	Relative earnings			Private RoR		Social RoR	
	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				
Australia	142	136	148				
United States	183 (1996)	184 (1998)	195 (2002)				

Source: OECD (1998a), (2000) and (2004b)

Table 50. 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 (1998a), (2000) and (2004b)

The unemployment rate for people with a tertiary type A and/or advanced research degree in Finland has fallen for both males and females (from 6% in 1996 to 3.1% in 2002), and is well below that for the Finnish population as a whole (6.5% for males and 6.2% for females) (Table 50). However, the unemployment rate for males with a university degree is slightly above the OECD country mean of 2.9%. Unemployment rates for people with a university degree are lower in Australia and USA.

Economic and non-economic impacts

The **economic indicators** of GDP growth rates, GDP per capita and labour productivity in the business sector are as-

sessed against the two indicators of human capital investment in Figure 52, Figure 53 and Figure 54 respectively. There appears to be no correlation between the human capital indicators and *GDP growth rates* (Figure 52) and *labour productivity in the business sector* (Figure 54). As discussed in this chapter, 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 53 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 tend to have higher GDP per capita.
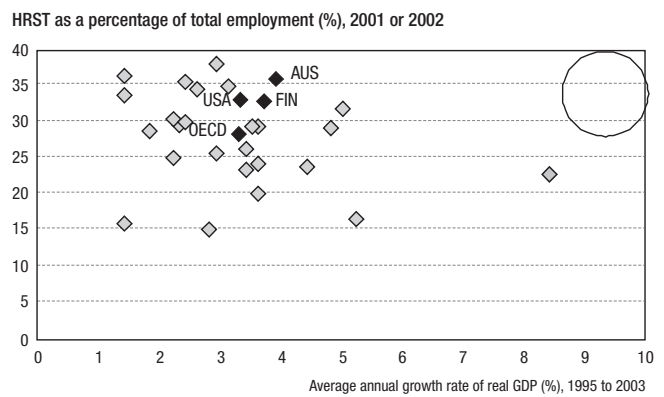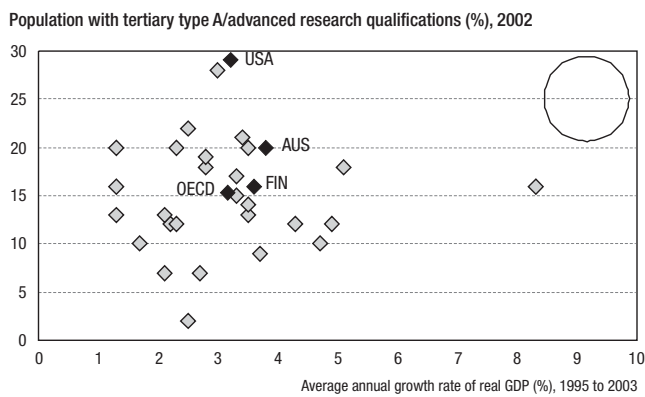

Figure 52. GDP growth rates and human capital. Source: OECD (2004a) and (2004b) and 2005(b), United Nations (2005)
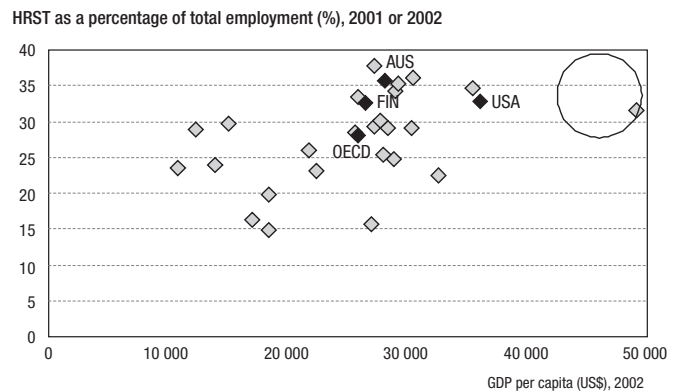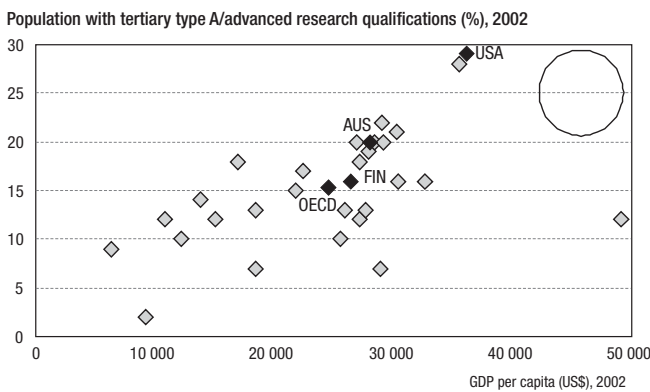

Figure 53. GDP per capita and human capital. Source: OECD (2004a) and (2004b) and 2005(b), United Nations (2005)
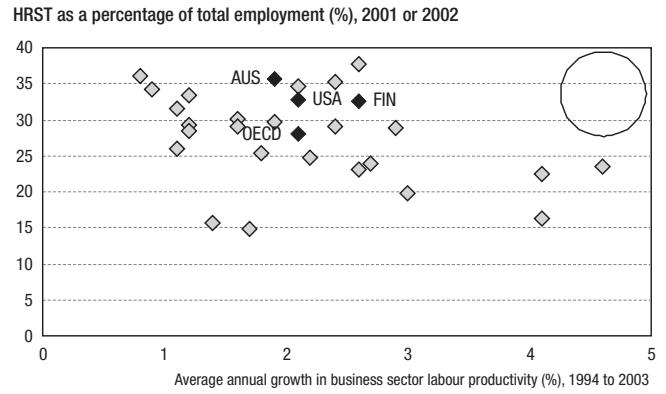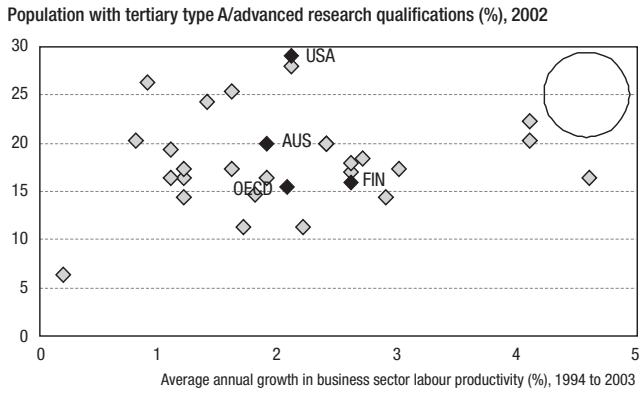
Figure 54. Labour productivity and human capital. Source: OECD (2004a) and (2004b) and 2005(b), United Nations (2005)

Figures 55 to 61 assess 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 seem to have lower relative poverty (Figure 55).

There is a positive correlation between HRST stocks and to a lesser extent, university attainment and *infant mortality* (Figure 56), *life expectancy* (Figure 57) and *homicide conviction/committal rates* (Figure 58) in many countries. This 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 a high levels of university attainment and HRST stocks.
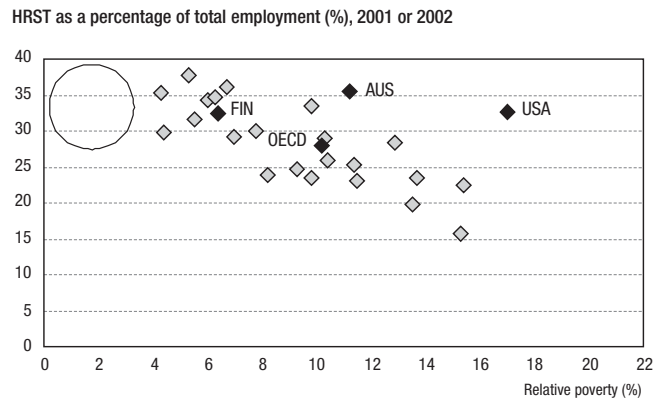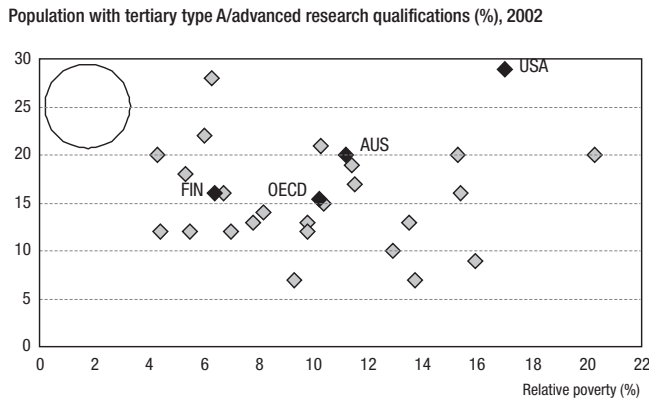

Figure 55. Relative poverty and human capital. Source: OECD (2004a) and (2004b) and 2005(b), United Nations (2005)
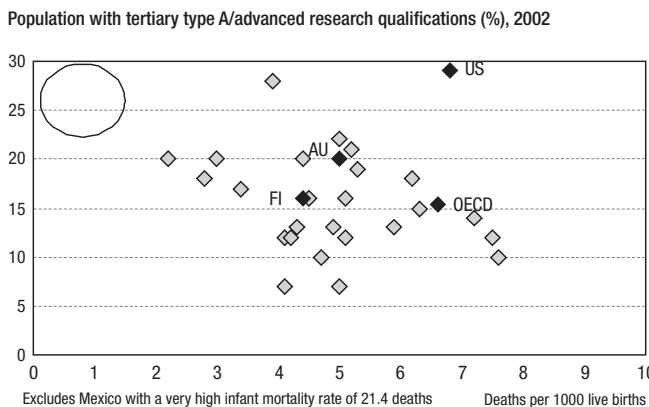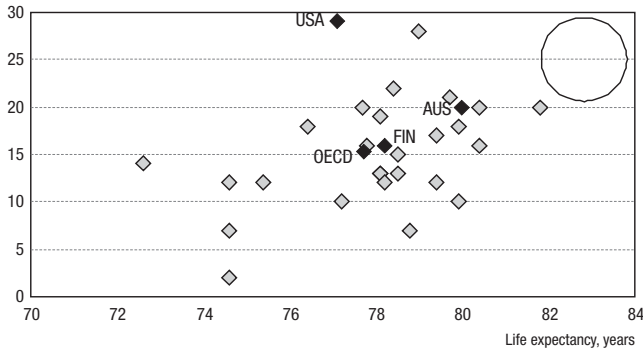

Figure 56. Infant mortality and human capital. Source: OECD (2004a) and (2004b) and 2005(b), United Nations (2005)

Population with tertiary type A/advanced research qualifications (%), 2002

HRST as a percentage of total employment (%), 2001 or 2002
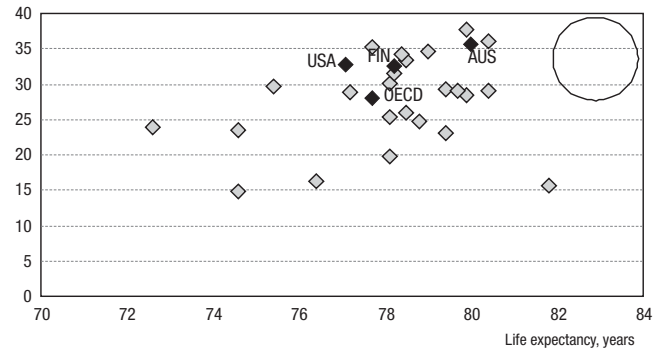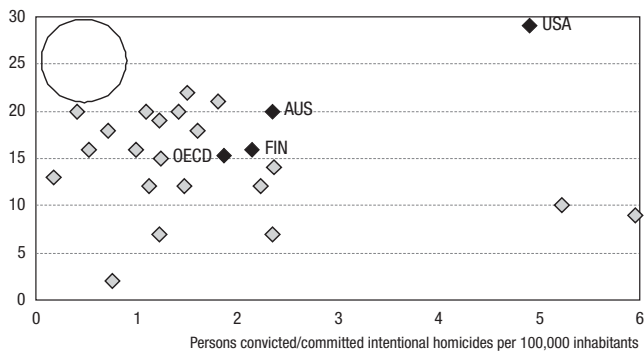
Figure 57. Life expectancy and human capital. Source: OECD (2004a) and (2004b) and 2005(b), United Nations (2005)

Population with tertiary type A/advanced research qualifications (%), 2002

HRST as a percentage of total employment (%), 2001 or 2002

Figure 58. Homicide conviction/committal rates and human capital. Source: OECD (2004a) and (2004b) and 2005(b), United Nations (2005)

There is no correlation between the two indicators of human capital investment and CO2 emissions (Figure 59) and suicide rates (Figure 61). Figure 60 suggests that countries with a high level of university attainment and HRST stocks have higher levels of life satisfaction and feelings of happiness.

Population with tertiary type A/advanced research qualifications (%), 2002

HRST as a percentage of total employment (%), 2001 or 2002

Figure 59. Emissions of CO2 and human capital. Source: OECD (2004a) and (2004b) and 2005(b), United Nations (2005)

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Population with tertiary type A/advanced research qualifications (%), 2002

HRST as a percentage of total employment (%), 2001 or 2002

Figure 60. Life satisfaction/happiness and human capital. Source: OECD (2004a) and (2004b) and 2005(b), United Nations (2005)

Population with tertiary type A/advanced research qualifications (%), 2002

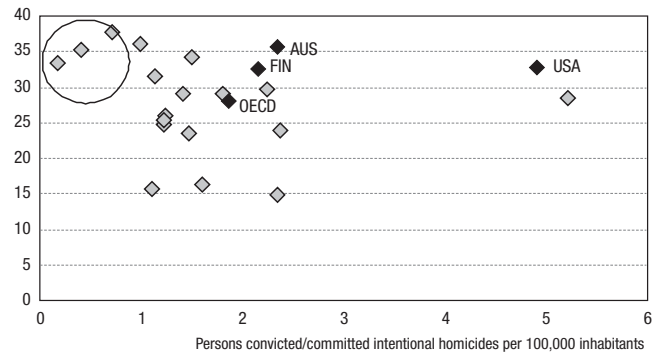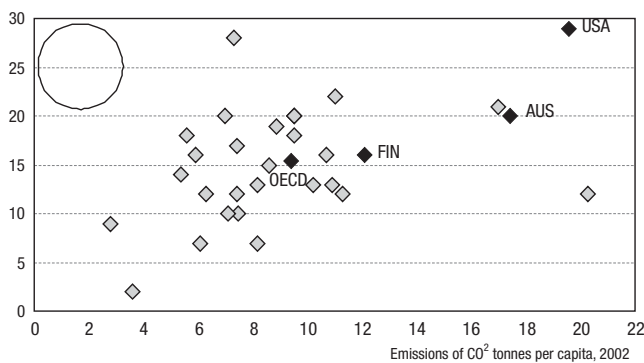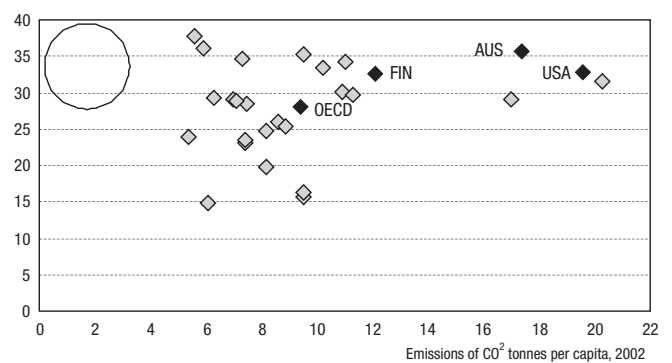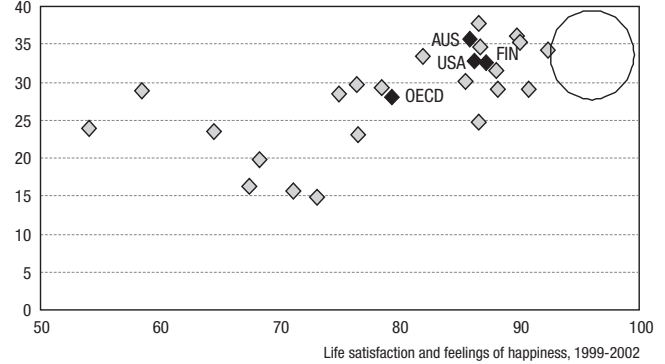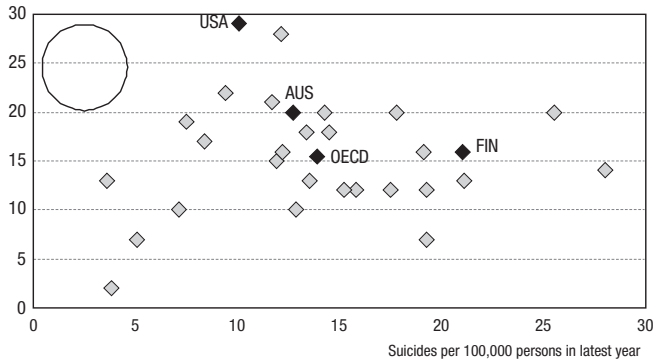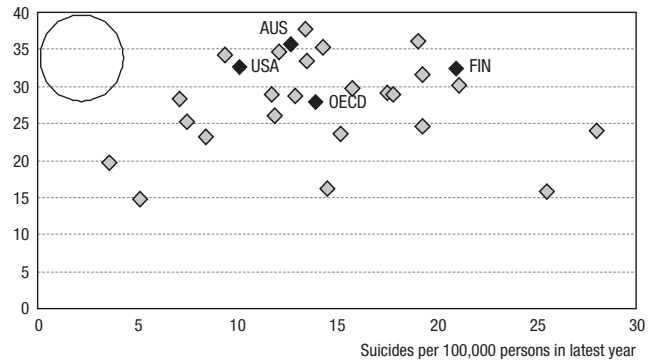HRST as a percentage of total employment (%), 2001 or 2002

Figure 61. Suicide rates and human capital. Source: OECD (2004a) and (2004b) and 2005(b), United Nations (2005)

5.5 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 literature that examines 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 pro-

ductivity in the business sector, CO2 emissions and suicide rates). Data on human capital stocks, investment levels and returns for Australia, Finland and the Untied 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 Finland within this framework.

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).

Finland produces a higher share of graduates in S&E fields than Australia, the United States and the OECD mean mainly due to the very high share of engineering graduates. However, the declining share of engineering graduates in
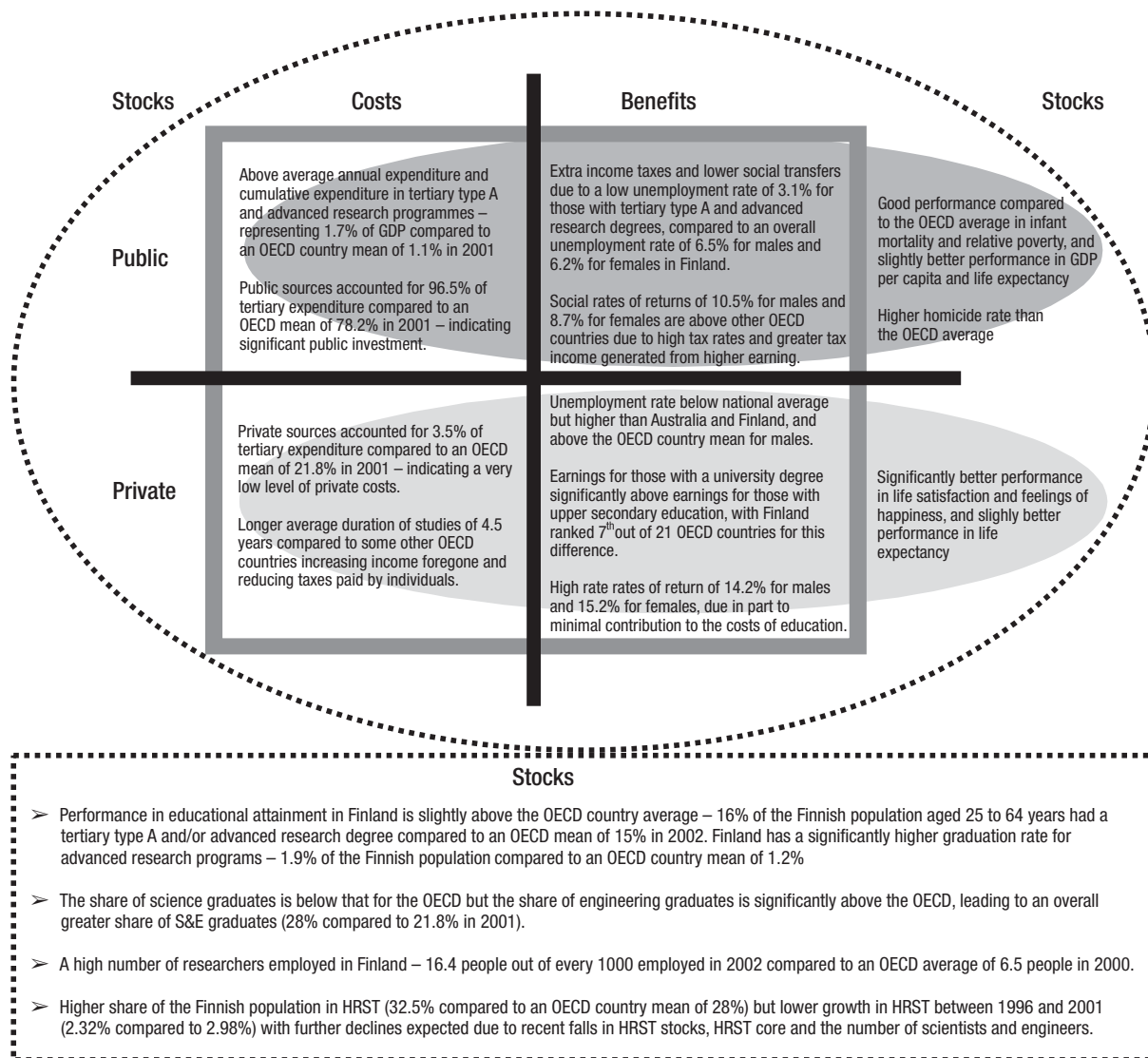
Figure 62. Summary of Finland's human capital performance and impacts

Finland 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 is 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 or 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 well above average 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 and to an even greater extent for the United States, there appears to be a negative impact on Finland's homicide conviction/committal rate.

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Appendices

Table A1. Strengths, weaknesses, opportunities and threats in Finland's national innovation system

National innovation SWOT overview	
Strengths	**Weaknesses**
• Innovation performance in high-technology manufacturing ins 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 of innovation across entire national economies. • Number of high-tech paten • 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 • High-tech patenting	• Innovation expenditures in services • Low attractiveness as a location of FDI • Small number of innovative SMEs • Low employment in medium tech industries • The low level of entrepreneurship
Opportunities	**Threats**
• Productivity potential and increased usage of ICT in the nor-manufacturing sector • The small size of the innovation system and dose relationships between the actors involved in the innovation system, allow rapid changes in priority setting. • Globalisation	• Globalisation • Dynamics of economy

Source: European Commission (2004) p. ii

Table A2. Recommendations from the sixth triennial review of the Science and 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 programmes 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 A3. 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 simply 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 per cent 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 maximizes 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 A4. 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 A5. Recommendations from the 2004 US 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 US continues to be the most fertile and attractive environment for innovation in the world. The major activities of the Leadership Network include:

- To produce 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.
- To establish 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.
- To give 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:

1. Strengthen 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.

2. Enhance 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 A6. 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 programmes French. Applications for EUI doctoral programmes 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 (2005)

Table A7. SWOT analysis of the internationalisation of Finland's R&D activities

Strengths

- Finland has become an active partner in international co-operation quite recently but rapidly: currently, a very high rate of participation in tire activities of international organizations
- Science, technology and innovation policy has been implemented on along term basis; investment in R&D is regarded as important
- Well-functioning education, research and innovation systems
- Openness, intensive co-operation and competitiveness of tire innovation system
- A high share of competitive R&D funding
- A high level of education among tire 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 Elf 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.

Weaknesses

- 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 exerts 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 GOP); a negative balance of investment.

Opportunities (and means)

- 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

Threats

- 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 Elf become weaker: more internal conflicts, less commitment and co-operation National interests are overemphasised in international cooperation
- 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 A8. Australian Commonwealth Government Endeavour Awards (postgraduate/postdoctoral)

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 A9. Reasons given by male and female respondents for emigration, Australia

Reasons ranked by popularity of response (n=2072)	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=1022)			
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 A10. 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:

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.

US 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 Post-doctoral 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 – USA: 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

US-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 Fatomei (2005)

Table A11. 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 3-8 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 A12. 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 US, 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 cano-

la 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 start-

ing 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 US 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 tech-

niques 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 co-operation 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 ex-tended 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 Master's 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 Master's 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 US 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 soy-*

bean 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.
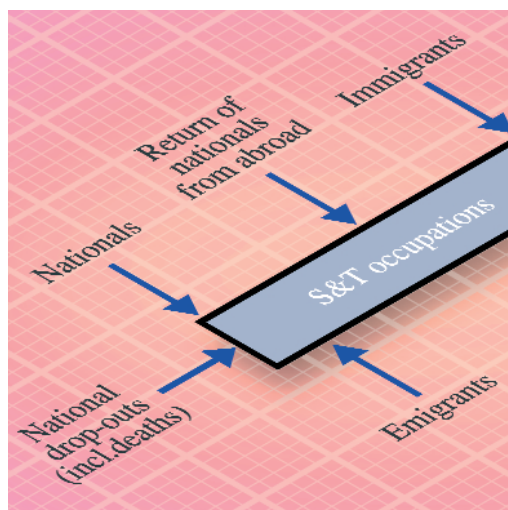
The first field study is being conducted at the UIUC's Swine Research Farm. Pigs (42) will be either fed 15N labelled corn or the conventional corn. The manure collected is acidified or non acidified. This field study will result in four different manures (faeces and urine) products: Acidified 15N labelled 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.*

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