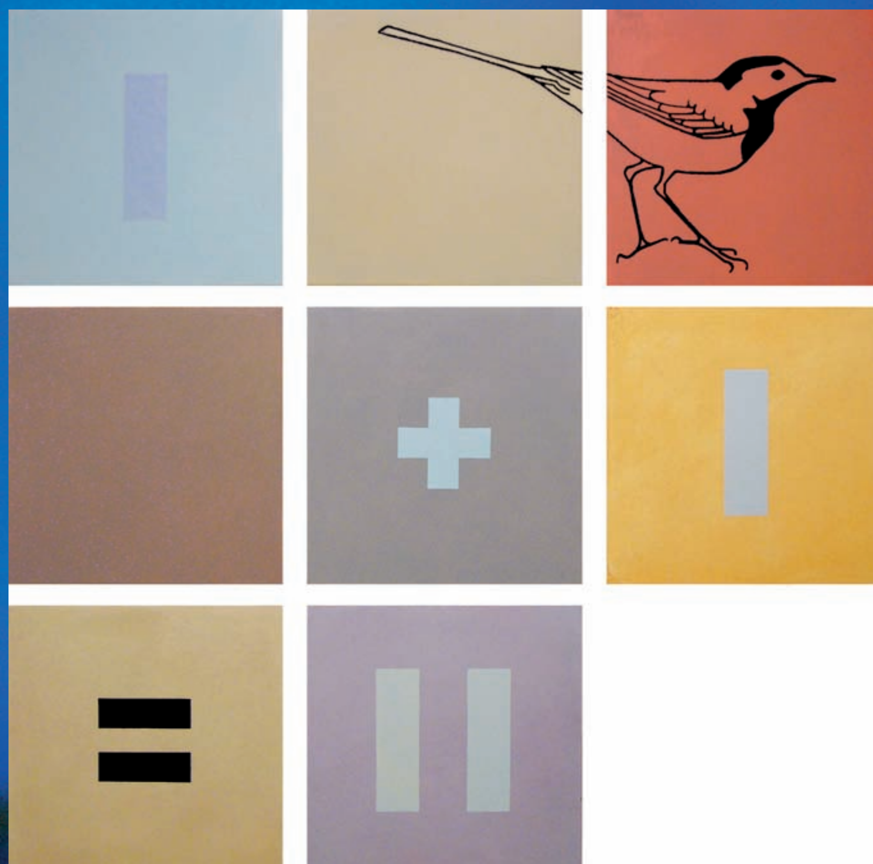
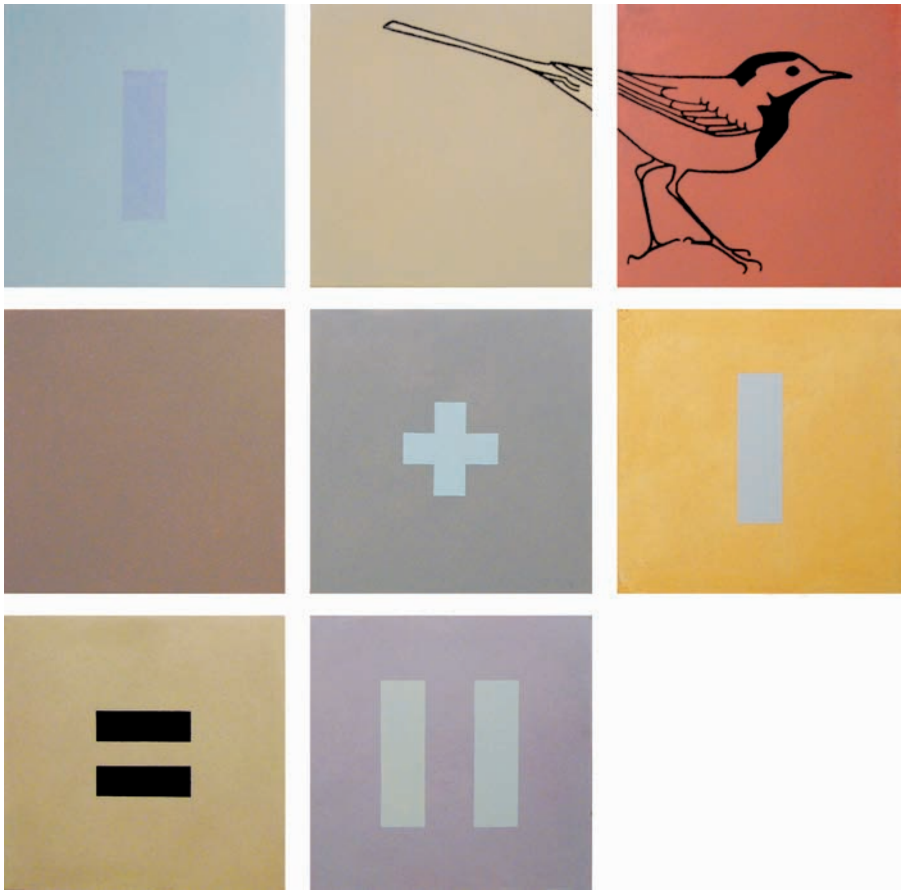
Publications of the Academy of Finland 10/09

The State and Quality of Scientific Research in Finland 2009



Academy of Finland
Research funding and expertise

The State and Quality of Scientific Research in Finland 2009



Edited by Paavo Löppönen, Annamaija Lehvo, Kaisa Vaahtera & Anu Nuutinen

Academy of Finland

Academy of Finland in Brief

The Academy's mission is to finance high-quality scientific research, act as a science and science policy expert and strengthen the position of science and research. The Academy's activities cover all scientific disciplines.

The main focus of the Academy's development activities is on improving opportunities for professional careers in research, providing resources and facilities for high-profile research environments and making the best possible use of international opportunities in all fields of research, research funding, and science policy.

The Academy has a number of funding instruments for various purposes. In its research funding, the Academy of Finland promotes gender equality and encourages in particular women researchers to apply for research posts and research grants from the Academy.

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Each year Academy-funded projects account for some 3,000 researcher-years at universities and research institutes.

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Cover image: Osmo Rauhala (2006): Game Theory, photo by Ville-Veikko Heinonen

Translated by David Kivinen

Layout: DTPage Oy

ISSN 0358-9153

ISBN 978-951-715-763-6 (print)

ISBN 978-951-715-764-3 (pdf)

Vammalan Kirjapaino Oy, 2010

Contents

Appendices

Description

Publisher	Academy of Finland	Date January 2010
Author(s)		
Title	The state and quality of scientific research in Finland 2009	
Abstract	The Academy of Finland conducts a review of the current state of science and research in Finland once every three years to coincide with its Research Councils' terms. The 2009 report is divided into three parts: a general overview, the Research Councils' reports, and future directions for development. This 2009 report on the current state of science and research has the following objectives: • to analyse scientific research in Finland and the national research system in a European and global context; • to assess the current state of science and research based on various indicators and comparisons; and • to outline future directions for the development of scientific research and the national research system. The general overview describes the development of the Finnish research system over the past few decades, with special reference to science and research activities within universities. In addition, it discusses the development of the international operating environment, the internationalisation of Finnish science and the Finnish research system, and the role of science in society. In the second part of the report, the Academy's four Research Councils discuss the strengths, weaknesses and opportunities of Finnish science and research in their respective fields. Furthermore, they deal with the state of doctoral education and research careers, research infrastructures and questions of scientific and social impact. The third part of the report provides a general assessment of the state of scientific research in Finland and the country's research system and outlines future directions for development. The Academy proposes that key players in the field join forces to draw up a national science strategy. In addition, the report calls for concrete development measures to • promote internationalisation, • advance doctoral education and research careers, • develop creative research environments, • update research infrastructures, and • strengthen the position of science in Finnish society.	
Key words		
Name and number of series	Publication of the Academy of Finland 10/09	
ISSN	0358-9153	
ISBN	Print 978-951-715-763-6	Pdf 978-951-715-764-3
Number of pages	288 p.	
Distributed by	Academy of Finland, POB 99, FI-00501 Helsinki, viestinta@aka.fi	
Published by	Academy of Finland	
Place and date of printing		
Other information	www.aka.fi/publications	

Kuvailulehti

Julkaisija: Suomen Akatemia

Päivämäärä: Tammikuu 2010

Tekijä(t):

Julkaisun nimi: Suomen tieteen tila ja taso 2009

Tiivistelmä

Suomen Akatemia laatii kerran tieteellisten toimikuntien kolmivuotisen toimikauden aikana Suomen tieteen tilaa ja tasoa arvioivan katsauksen. Vuoden 2009 raportti koostuu yleisestä osasta, tieteellisten toimikuntien valmistelemasta osasta ja kehittämisosasta. Tämän Suomen tieteen tila ja taso 2009 -raportin tavoitteita ovat:

- analysoida Suomen tieteellistä tutkimusta ja tutkimusjärjestelmää eurooppalaisessa ja globaalissa toimintaympäristössä,
- arvioida sen tilaa ja tasoa erilaisten mittareiden ja vertailujen avulla,
- esittää analyysien ja arviointien pohjalta Suomen tieteellisen tutkimuksen ja tutkimusjärjestelmän kehittämissuuntia.

Raportin yleisessä osassa tarkastellaan Suomen tutkimusjärjestelmän kehitystä viime vuosikymmenien aikana ja tutkimusjärjestelmän rakennekehitystä erityisenä painotuksena yliopistojen tutkimustoiminta. Lisäksi siinä eritellään kansainvälisen toimintaympäristön kehitystä ja Suomen tieteen ja tutkimusjärjestelmän kansainvälistymistä sekä tiedettä yhteiskunnassa.

Suomen tieteellisen tutkimuksen tilaa käsittelevässä osassa tieteelliset toimikunnat tarkastelevat Suomen tieteen vahvuuksia, heikkouksia ja mahdollisuuksia kukin omilla tieteenaloillaan. Ne erittelevät myös muun muassa tohtorikoulutusta ja tutkijanuraa, tutkimuksen infrastruktuureita sekä tieteellistä ja yhteiskunnallista vaikuttavuutta.

Raportin kehittämisosassa esitetään yleisarvio Suomen tieteen ja tutkimusjärjestelmän tilasta ja tasosta sekä joukko kehittämissuuntia. Akatemia esittää, että Suomeen laaditaan kansallinen tiedestrategia keskeisten toimijoiden yhteistyönä. Lisäksi siinä esitetään konkreettisia kehittämistoimia

- kansainvälistymisessä,
- tohtorinkoulutuksessa ja tutkijanurassa,
- luovien tutkimusympäristöjen kehittämisessä,
- tutkimuksen infrastruktuurien ajanmukaistamisessa,
- tieteen asemasta suomalaisessa yhteiskunnassa.

Asiasanat:

Julkaisusarjan nimi ja numero: Suomen Akatemian julkaisuja 10/09

ISSN: 0358-9153

ISBN: Painetulle kirjalle annettu tunnus: 978-951-715-763-6; Pdf-versiolle annettu tunnus: 978-951-715-764-3

Sivumäärä: 288 s.

Julkaisun jakaja: Suomen Akatemia, PL 99, 00501 Helsinki, viestinta@aka.fi

Julkaisun kustantaja: Suomen Akatemia

Painopaikka ja -aika:

Muut tiedot: www.aka.fi/julkaisut

Presentationsblad

Utgivare	Finlands Akademi	Datum Januari 2010
Författare		
Titel	Vetenskapens tillstånd och nivå i Finland 2009	
Sammandrag	Finlands Akademi publicerar en gång under de vetenskapliga forskningsrådens treåriga mandatperiod en översikt över vetenskapens tillstånd och nivå i Finland. År 2009 består rapporten av en allmän del, en del som de vetenskapliga forskningsråden svarar för och en utvecklingsdel. Syftet med rapporten Vetenskapens tillstånd och nivå i Finland 2009 är: • att analysera den vetenskapliga forskningen i Finland och det finländska forskningssystemet i en europeisk och global kontext, • att bedöma vetenskapens tillstånd och nivå med hjälp av olika mätare och jämförelser, • att utifrån analyser och utvärderingar föreslå utvecklingslinjer för den vetenskapliga forskningen och forskningssystemet i Finland. I rapportens allmänna del granskas det finländska forskningssystemets utveckling under de senaste decennierna och de strukturella förändringar som där skett, med särskild fokus på universitetsforskningen. Vidare analyserar rapporten utvecklingen i den internationella omvärlden, den finländska vetenskapens och det finländska forskningssystemets internationella roll samt vetenskapens ställning i samhället. I den del som behandlar forskningens tillstånd i Finland granskar de vetenskapliga forskningsråden inom sina respektive forskningsområden den finländska vetenskapens styrkor, svagheter och möjligheter. De analyserar också bland annat doktorsutbildningen och forskarkarriären, forskningens infrastrukturer samt forskningens vetenskapliga och samhälleliga genomslag. I utvecklingsdelen presenteras en allmän bedömning av vetenskapens och forskningssystemets tillstånd och nivå i Finland. Därtill behandlas en mängd olika utvecklingsriktningar. Akademin föreslår att de centrala aktörerna inom vetenskapen tillsammans utarbetar en nationell vetenskapsstrategi för Finland. Därtill bör utvecklingsåtgärder vidtas inom • det internationella samarbetet • doktorsutbildningen och forskaryrkets ställning, • utvecklingen av kreativa forskningsmiljöer, • uppdateringen av forskningens infrastrukturer, • vetenskapens ställning i det finländska samhället.	
Nyckelord		
Seriens namn och nummer	Finlands Akademis publikationer 10/09	
ISSN	0358-9153	
ISBN	ISBN-nummer för bokversionen 978-951-715-763-6	ISBN-nummer för pdf-versionen 978-951-715-764-3
Sidoantal	288 s.	
Distributör	Finlands Akademi, PB 99, 00501 Helsingfors, viestinta@aka.fi	
Förlag	Finlands Akademi	
Tryckort och -datum		
Övriga uppgifter	www.aka.fi/publikationer	

Foreword

The Academy of Finland has issued a report on the state of Finnish science and research once every three years since 1997. This 2009 report aims to:

- analyse Finnish science and research and the Finnish research system in their European and global contexts;
- assess their current state and quality based on various indicators and comparisons; and
- outline directions for the development of Finnish science and research and the Finnish research system.

Scientific research in Finland is faced with a multitude of development challenges. It is vitally important that at this juncture we engage in robust discussion about future areas of development using the best evidence available. This report is the Academy's contribution to stimulating such discussion about the future of Finnish science. The report serves the Academy's research policy and strategic planning purposes. I am convinced that the information and analyses presented herein will also contribute significantly to the formulation of national science policy.

The Steering Group for this report comprised Markku Mattila (chair), President of the Academy of Finland; Professor Eila Helander (University of Helsinki, Board of the Academy of Finland); Professor Jorma Lammasniemi (Executive Vice President, VTT Technical Research Centre of Finland); Paavo Löppönen, Director, Development and Evaluation (Academy of Finland); Professor, Vice Rector Marja Makarow (University of Helsinki, Chief Executive of the European Science Foundation as of 1 Jan 2008); Riitta Mustonen, Vice President, Research (Academy of Finland); Professor, Pirkko Nuolijärvi (Director of Research Institute for the Languages of Finland, Board of the Academy of Finland); Professor Erkki Oja (Helsinki University of Technology, Board of the Academy of Finland); Professor Paavo Pelkonen (University of Joensuu, Board of the Academy of Finland); and Professor Kalervo Väänänen (University of Turku, Board of the Academy of Finland). Professor, Vice Rector Heikki Ruskoaho (University of Oulu) was appointed as member of the Steering Group as of 1 March 2008 and Leena Vestala (Ministry of Education) as of 1 April 2008.

The working group who produced this report included Director Paavo Löppönen (chair); Senior Science Adviser Annamaija Lehvo; Science Adviser Anu Nuutinen; and Project Officer Kaisa Vaahtera.

Special thanks are due to the Academy's Research Councils and to the experts who contributed to their deliberations. All in all, more than 400 experts have contributed to the preparation of this report (see Appendix 1). I wish to thank all the people who have taken part in this significant and demanding undertaking.

The Board of the Academy of Finland has approved this report at its meeting on 25 August 2009.

Helsinki, 8 September 2009

Markku Mattila
President

Introduction

The Academy of Finland issues a review of the current state of science and research in Finland once every three years to coincide with the terms of its Research Councils. The first report was published in 1997, and the previous one in 2006. The 2006 report was a compilation of a number of documents: it included a bibliometric analysis of Finnish science (Lehvo & Nuutinen 2006) and the first ever national science and technology foresight report (FinnSight 2015).

This 2009 report aims to:

- analyse Finnish science and research and the Finnish research system in their European and global contexts;
- assess their current state and quality based on various indicators and comparisons; and
- outline directions for the development of Finnish science and research and the Finnish research system.

The report is divided into three sections: Section I provides a general overview of the Finnish research system; Section II includes the reports compiled by the Academy's four Research Councils; and Section III discusses the key issues of development. Chapter 1 in Section I reviews the development of the Finnish research system over the past few decades, and Chapter 2 discusses the structural development of that system, focusing particularly on university research. Chapter 3 explores the development of the international operating environment, the role and position of Finnish science within that environment, and the internationalisation of Finnish science and the Finnish research system. Chapter 4 deals with science in society: the role of science and research in decision-making, in the innovation system and education and the social impact of science. In Section II, the Research Councils provide their assessments of the strengths, weaknesses and possibilities of Finnish science. Section III outlines directions for the development of scientific research and the research system.

Although the three Sections of the report create a coherent text, each Chapter in the general Section and each Research Council review on strengths, weaknesses and opportunities in their respective fields can be read independently.

Many countries regularly publish analytical reports that monitor the development of national research and innovation systems and assess their relative strengths and weaknesses. In the United States, *Science and Engineering Indicators (SEI)* has been published every two years since 1973 (National Science Board 2008). SEI is a volume compiled primarily on the basis of existing data from statistics, databases, questionnaires and scientific studies in an easily accessible format. It provides insights into national trends and international linkages in R&D, science education in elementary, secondary and higher education and public attitudes and understanding about science and technology. A major area of focus is on labour statistics in science and engineering fields, an issue of great interest in the United States because of the large proportion of immigrants in the country's R&D workforce.

France (L'Observatoire des Sciences et des Techniques 2009), the Netherlands (NOWT 2008) and Norway (NIFU 2007) publish science and technology indicator reports on a regular basis, but in each case the focus is very different. In the French report the main interest is to see how R&D in the country compares with the rest of Europe and the world, and to identify regional strengths and weaknesses in France and Europe. The main emphasis in the Dutch report is on the application of bibliometric methods for purposes of assessing the performance of the country's universities and research institutes and the international position of Dutch research.

Canada (Council of Canadian Academies 2006) and Japan (NISTEP 2009) offer much more far-ranging and ambitious analyses than these three countries. Canada uses a wide array of indicators and questionnaires to identify scientific and technological strengths and emerging fields in the country. Japan combines indicators describing the national research and innovation system with extensive questionnaires that cover such aspects as the impact of research and the position of science in society. NISTEP also offers analyses of current trends and the level of R&D in advanced countries using bibliometric methods. This is coupled with highly extensive foresight reviews.

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I The Finnish Research System: Development and Current State

1 The Finnish Research System: Long Lines of Development

The development of the Finnish research system from the 1960s to the present day serves to illustrate how science and technology policy and the organisations behind that policy follow certain historically and culturally determined paths in their development and how they change only slowly and incrementally. Socio-economic structures and the general orientation of public policy interact with this change. One important aspect of this change is to follow the concepts and experiences of other countries and to creatively apply them to national traditions and national objectives (Lemola 2002).

An examination of the Finnish case also goes to show how a concerted and sustained development effort in science and technology policy can move a country to the international forefront within a reasonably short space of time (Georghiou et al. 2003).

The development of Finnish science and technology policy can be divided into five stages:

1. Development of science and research infrastructure (1960s and 1970s)
2. Period of technological development (1980s)
3. Development of knowledge-based society: the national innovation system (1990s)
4. Period of consolidation (early 2000s)
5. Period of structural development (2005–)

Development of science and research infrastructure, 1960s and 1970s

The basic concepts of science and technology policy were adopted from other countries and adapted to Finnish society.

- Political system assumes active role: creation of Science Policy Council
- Rapid regional expansion of university system
- Creation of modern science funding system with the launch of new-form Academy of Finland
- Application of planning concept to university education and scientific research

In the late 1950s and early 1960s, funding for science and research in Finland was still very limited, consisting largely of budget funding from universities and research institutes and grants from two research councils. At around this time the OECD took up research and development on its agenda, highlighting its positive contribution to economic growth. Following the examples set by Sweden and the UK, Finland took the decision in 1961 to establish six research councils and positions for researchers and research assistants under these councils. The Science Policy Council was founded in 1963 as the Government's preparatory committee on matters concerning science and higher education. The new-form Academy of Finland was founded in 1969 as the ”central body for science administration”, and as in other West European systems it was given certain science policy powers.

In 1960, there were seven universities in Finland, and what is now the University of Lapland was established at the end of this period in 1979. With other educational institutions being turned into universities at the same time, their number now stood at 20. The OECD in particular worked to strengthen the role of science, research and universities in public policy planning (Tiitta 2004).

Period of technological development, 1980s

- Technology Committee
- Establishment of National Technology Agency (Tekes)
- National technology programmes: cooperation between universities and businesses
- Start-up of large-scale business R&D
- Academy of Finland research programmes
- Science Policy Council becomes Science and Technology Policy Council

In 1982, the Government adopted a technology policy resolution which outlined long-term directions for R&D as well as R&D funding based on recommendations by the Technology Committee (1980) and other bodies. The main objectives were to diversify the national production structure and to bolster economic competitiveness. A dedicated funding agency (Tekes) was created to channel the necessary funding, which immediately started to grow very sharply. Tekes's support was absolutely crucial for business R&D.

Tekes launched national technology programmes, which were highly significant in two respects: they quickly led to increasing cooperation between universities and businesses, which remains an important strength of the Finnish research system to the present day, and provided a solid foundation for the expansion of information and communications technologies and thus for the diversification of industrial production in Finland.

The transformation of science policy into science and technology policy was sealed by the renaming in 1986 of the Science Policy Council as the Science and Technology Policy Council.

Finland was the first OECD country to adopt the concept of national innovation system as a tool of science and technology policy planning in the late 1980s and early 1990s. This implied the adoption of a broad systemic perspective and bringing all actions and measures aimed at improving knowledge, skills and competencies under the same umbrella.

Development of knowledge-based society: the national innovation system, 1990s

- Perspective on development: innovation system
- EU membership: encouragement to internationalisation
- Government's additional funding programme: pushing Finland to the forefront
  - Creation and rapid expansion of the graduate school system
  - Creation of postdoctoral system
  - National Centre of Excellence strategy and Centre of Excellence programmes
- Priority given to competitive funding: Academy of Finland and Tekes

In the run-up to EU membership and especially following accession in 1995, opportunities for international science and research cooperation in Finland expanded exponentially. Finnish researchers seized the opportunity with both hands, as is evident from the participation rates in the Fourth Framework Programme at the time. EU

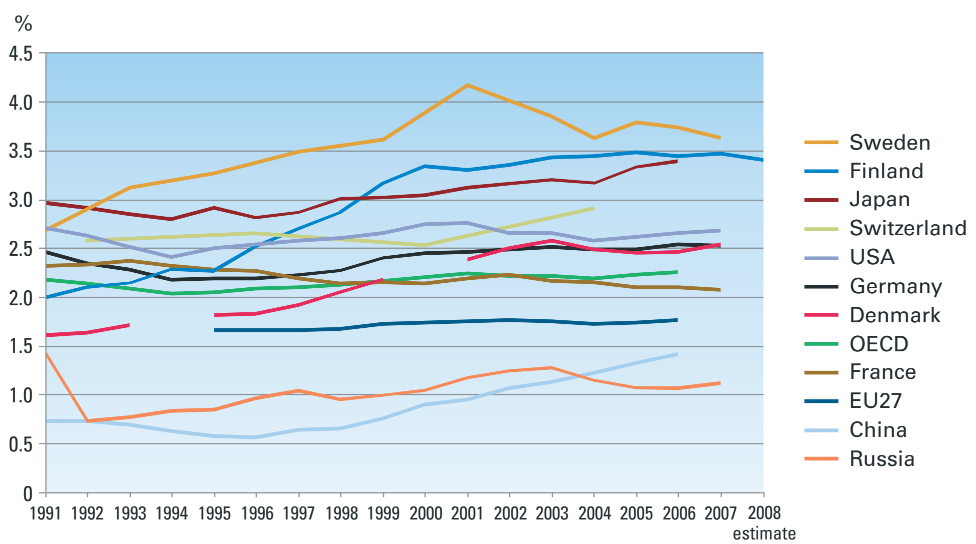

Figure 1. R&D investment as a proportion of GDP in selected OECD countries and in China and Russia.
Source: OECD 2008a.

cooperation has ever since provided an important springboard for the internationalisation of Finnish science and research.

In 1996 the Government took the decision to make a substantial investment in research and development. The purpose was to give a boost to the innovation system and in this way to stimulate the economy, business and employment. With this injection of extra funding into research and its various multiplier effects, Finland's investment in R&D increased within the space of just a few years from 2.3 per cent to around 3.2 per cent of GDP, one of the highest figures in the world.

With this decision the amount and share of competitive research funding increased significantly. Both the Academy and Tekes stepped up their research programme funding. The additional funding programme paved the way to the Centre of Excellence strategy, Centre of Excellence programmes and the Postdoctoral Researcher system. Furthermore, the monies were used to strengthen and expand the graduate school system and to upgrade universities' research equipment and facilities.

Period of consolidation, early 2000s

- Evaluation of 1990s investments, policies and actors
- Establishment of Finland's position as leading science and technology policy player in the world
- Strengthening of global cooperation

The early 2000s marked a period of evaluation and consolidation of the organisations and development measures undertaken in the 1990. Evaluations were conducted among others of the Academy of Finland, Tekes and Sitra, the Finnish Innovation Fund, and evaluations of universities started on a regular basis. The impact of the additional funding programme was also evaluated.

Finland established its position as one of the world's leading players in the science and technology policy field. Finland ranked consistently among the top performers in international comparisons that focused on such aspects as knowledge-based development and international competitiveness. Finland's main strengths were

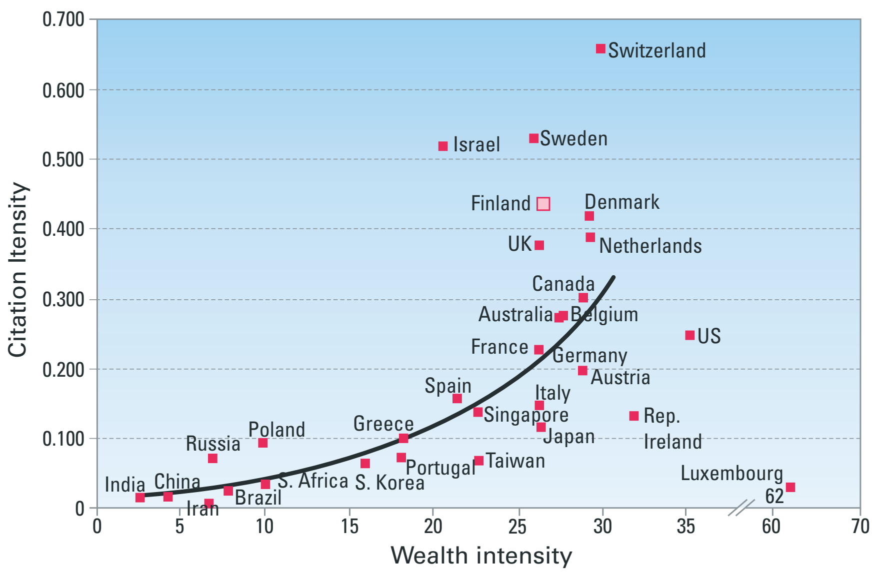

Figure 2. Comparing economic and scientific wealth. Citation intensity is the ratio of citations received by scientific publications to GDP, wealth intensity is GDP per person. (Data adjusted for 1995 purchasing power parity). *Source: King, D. The scientific impact of nations. Nature 430, 2004.*

identified as lying in investment in science and technology, education, researchers and the availability of researchers, and technological development. Relative indicators of scientific output and the quality of research also put Finland among the very best OECD performers.

The main focus of internationalisation was on strengthening cooperation with countries outside of Europe. Programme cooperation was increased among others with Japan, China, India and Canada. Priority was given to concrete research cooperation and to gaining access to global networks.

Development at the current stage is largely directed by the 2005 Government resolution on the structural development of the public research system (Finnish Government 2005). A major priority is to enhance the efficiency and impact of that system.

The achievement of these goals will require rigorous priority setting, more efficient organisational profiling and cooperation, and stronger political and administrative leadership.

Period of structural development, 2005–

- Government resolution in 2005 on the structural development of the public research system
- Universities Act
- Revision of the Act on the Academy of Finland
- Founding of Research and Innovation Council of Finland
- Structural development of sectoral research
- Strategic Centres for Science, Technology and Innovation
- Development of European Research Area (ERA)
- Strengthening of Nordic and global cooperation
- Development of economic and technological connections in research: innovation and evaluation of the innovation system

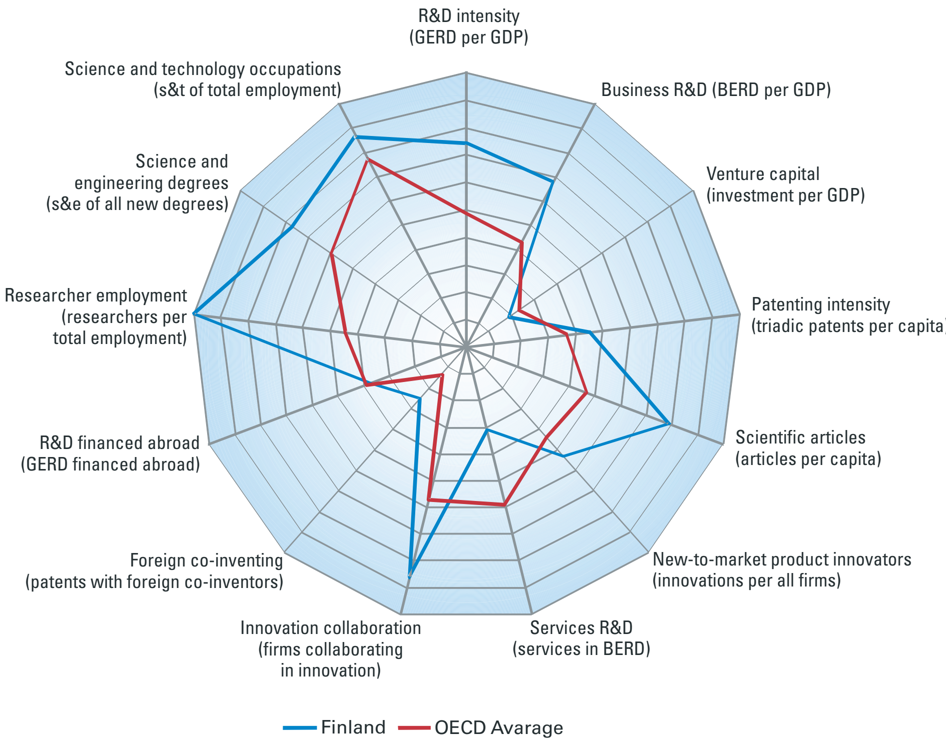

Figure 3. Profile of the Finnish research and innovation system. *Source: OECD 2008b.*

In higher education, resources will be combined to form larger units, and steps will be taken to increase networking.

New Strategic Centres of Science, Technology and Innovation are established. Strategic Centres bring together scientific research, technological development and innovation in selected areas through the cooperation of public research funding agencies, private business companies and universities.

The new Universities Act will give universities greater economic autonomy and afford them greater scope for strategic management.

The reform of sectoral research and the use of its results will be launched.

The impact of scientific research and its contribution particularly to R&D and innovation will be enhanced based on the Government's innovation report and other measures.

The European Research Area (ERA) is beginning to take shape and change the landscape of European research cooperation. The European Research Council (ERC) is working to strengthen the European potential in the global research competition. At the same time Finland is strengthening its global networks (e.g. FinNode) and its cooperation with emerging economies.

Figure 3 illustrates the main characteristics of the Finnish research and innovation system as compared to OECD averages. In a comparison with the world's leading science nations, the Finnish system has four distinctive characteristics. R&D investment as a proportion of GDP and private business investment in R&D have remained at the same high level that was achieved in the early 2000s. In Finland, business companies work much more closely with research institutes and universities than is the case in the OECD on average. Finland stands apart from other strong science nations most clearly in terms of the number of researchers per one thousand employed people. The fourth distinctive feature is that foreign funding for R&D is at a relatively low level. The number of scientific publications per person is at a relatively high level in Finland.

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2 Structural Development of the Research System

2.1 Introduction

International comparisons give a broadly positive picture of the development of the Finnish research and innovation system: for the past 15 years, Finland has consistently ranked among the best OECD performers on several indicators. These comparisons have particularly highlighted Finland's relatively strong and increasing investment in R&D, its sound institutional framework for R&D, the high level of education and the country's success in the information technology field. Furthermore, Finland has shown consistency and long-term commitment in pursuing its education, research and innovation policies.

In recent years, however, Finland's international competitiveness and position as an information society have weakened (OECD 2007, 2008a, 2008b, Evaluation…2009). The growth targets set for R&D funding have not been reached. Both structural and operational needs for change have been identified in public education and research organisations. International comparisons of research output and quality show that Finland has fallen behind the other Nordic countries. The information technology, forest and mechanical engineering sectors, all of which are of great importance to Finland, are also losing ground internationally. It is possible that current knowledge-based and technological strategies are too restrictive to effectively address the new emerging challenges.

A critical challenge for the quality of science and research in Finland comes from inadequate internationalisation within the research system (e.g. OECD 2008ab, 2009, Evaluation… 2009). In the higher education sector and throughout the research system, researcher mobility is at a relatively low level. There are also comparatively few foreign students and researchers in Finland. Universities and government research institutes have not opened up to a sufficient extent and taken full advantage of opportunities for internationalisation. Research policy has failed to give sufficient weight to making the best possible use of global competencies and to facilitating international engagement (e.g. Evaluation… 2009).

The priority areas identified for the development of the research system are to strengthen the quality and impact of research; to improve and develop researcher training; to create a genuine tenure track system; and to increase mobility within the research system. Furthermore, the need for internationally competitive R&D infrastructures is widely recognized. Some existing resources are scattered and need to be pooled and prioritised. The level and spread of education and competencies must be designed and allocated more rigorously on the basis of future needs.

2.2 Development of the research system

Funding of the research system

Finland is one of the world's most research-intensive countries, investing 3.37 per cent of GDP in R&D in 2008. This figure has increased consistently throughout the 1990s and 2000s. Nevertheless, Finland is now lagging behind the Government target of 4 per cent of GDP by 2011, as the figure has actually slipped back from around 3.5 per cent during the past few years. The target set for all EU members in the Lisbon Strategy was 3 per cent by 2010; in addition each Member State has defined its own national targets.

In Finland, business R&D investment came to 2.41 per cent of GDP in 2008. However, the growth rate for the private business sector is slowing. Public research expenditure as a proportion of GDP has hovered around one per cent for the past decade. In 2008 the figure stood at 0.96 per cent, just short of the EU one per cent target. However, the Finnish Government's investment in R&D is at high level compared to other EU countries.

In 2008, Finland's overall R&D investment came to 6.4 billion euros. The private business

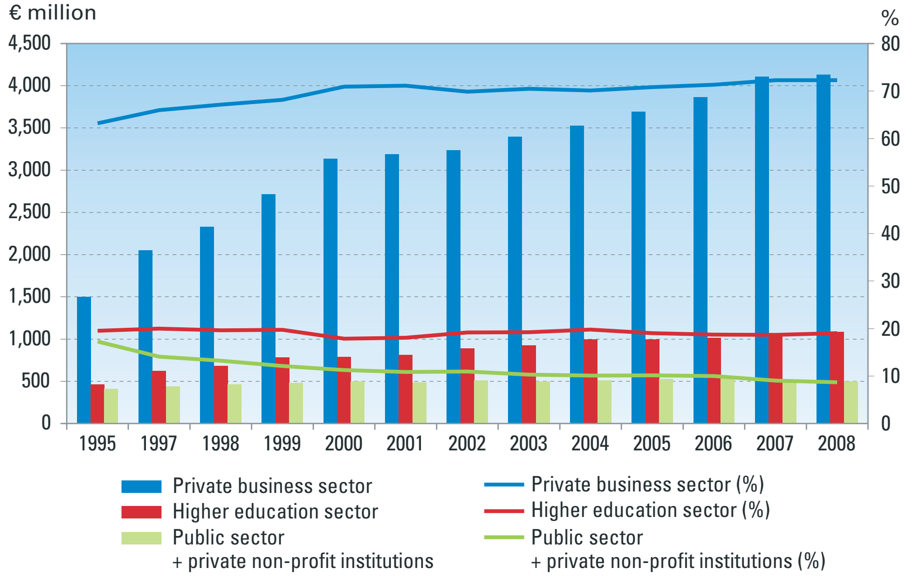

Figure 1. R&D expenditure in Finland* and breakdowns by sector in 1995–2008.
Source: Statistics Finland 2009.

* Deflated by GDP market price index (2000=100). Undeflated figures for 2008: total R&D expenditure 6.45 billion euros, with the private business sector accounting for 4.66 billion, universities for 1.23 billion and the other public sector for 0.56 billion.

sector[1] accounted for 72 per cent of this. The remaining 28 per cent came from public sources: 19 per cent from the higher education sector and 8.7 per cent from other public sector sources. Other funding came primarily from abroad, chiefly from the EU Framework Programme for research.

Finnish R&D expenditure increased from 1998 to 2003 by 38.9 per cent and from 2003 to 2008 by 18.6 per cent in real terms. The figures for the public sector were 8.1 and 0 per cent, for the higher education sector 36.1 and 17.3 per cent and for the private business sector 46.0 and 21.7 per cent (Figure 1).

Budget funding for R&D organisations totalled 1.8 billion euros in 2008 (Figure 2). Some 30 per cent of these funds were administered by Tekes. Universities accounted for 25 per cent and both the Academy of Finland and government research institutes for around 16 per cents in 2008. Other sources of budget funding consisted primarily of Ministry research funds, which were used to finance research projects either at research institutes within the administrative branch concerned or at other research organisations.

Overall public funding, including both budget funding and external sources, went primarily to the higher education sector and to the public sector (Table 1). The higher education sector received 13 per cent of its overall funding from the Academy of Finland, 8 per cent from Tekes and 7 per cent from Finnish business companies. Funding from foreign sources amounted to 9 per cent. The public sector, which includes government research institutes, received 13 per cent of its funds from Finnish business companies, 7 per cent from Tekes and two per cent from the Academy of Finland. Business companies financed almost 90 per cent of their own R&D. Tekes accounted for 4 per cent and foreign funding for 6 per cent.

1 1) Private business sector: industrial manufacturing and other industries; 2) Public sector: government administrative branches (including government research institutes), other public institutions, private non-profit institutions; 3) Higher education sector: universities, university hospitals, and polytechnics (since 1999).

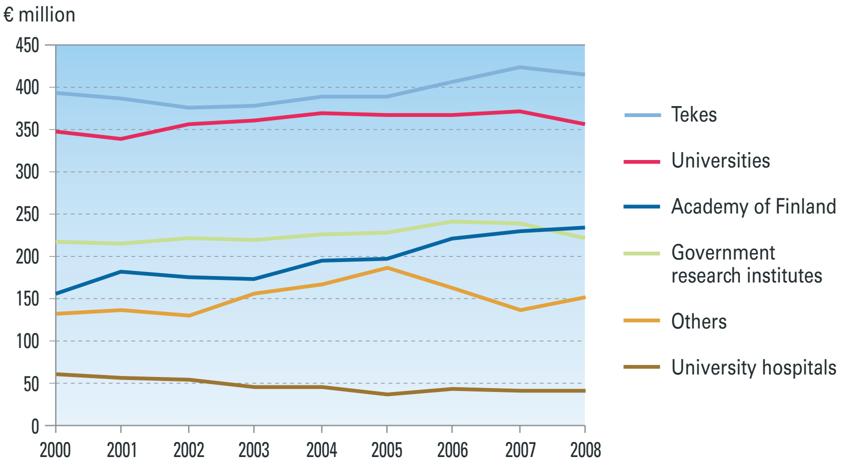

Figure 2. Funding for government R&D* by organisation in 2000–2008.
Source: Statistics Finland 2009.

* Deflated by index for central government consumption expenditure (2000=100). Undeflated figures for 2008: Tekes 526 million euros, universities 452 million euros, Academy of Finland 296 million euros, government research institutes 282 million euros, others 193 million euros, university hospitals 49 million euros.

In 2008, the Academy of Finland provided funding worth 287.2 million euros to support science and research projects and to promote research careers. The Academy's main funding instruments are research projects, research programmes and Centre of Excellence programmes, researcher training, Postdoctoral Researcher's projects, research posts and funding for foreign professor-level researchers invited to work in Finland.

In 2008, the bulk of Academy research funding or 232.9 million euros (81%) went to universities, while 26.7 million euros (9%) was allocated to government research institutes. Funding for

Table 1. R&D expenditure by source of funding in different sectors of performance in 2007. *Source: Statistics Finland 2009.*

			Sources of funding																	
	Expenditure total		Ministry of Education		Academy of Finland		Tekes		Government admin branches [b]		Other domestic public sources [c]		Domestic companies		Private non-profit institutions [d]		Foreign funding [e]		Shares total
Sectors	€ million	%	€ million	%	€ million	%	€ million	%	€ million	%	€ million	%	€ million	%	€ million	%	€ million	%	%
Private business	4,513.4	72	0	0	0	0	184.4	4	22.9	1	27.5	1	4,023.9	89	5.2	0	249.5	6	100
Public sector [a]	564.7	9	0	0	12.2	2	40.3	7	327.3	58	33	6	73.4	13	26.6	5	51.9	9	100
Higher education	1,164.6	19	515.9	44	152.1	13	92	8	136.4	12	52.4	4	81.6	7	28.8	2	105.4	9	100
Total	6,242.7	100	515.9	8	164.3	3	316.8	5	486.6	8	113	2	4,178.8	67	60.6	1	406.8	7	100

a Includes private non-profit institutions.
b Excluding Ministry of Education, Academy of Finland and Tekes.
c E.g. local governments, the Finnish National Fund for Research and Development, the Finnish Work Environment Fund, Finnvera, and the Social Insurance Institution. The euro figures for the higher education sector include universities' own assets.
d Private non-profit institutions, e.g. foundations and funds.
e EU funding from Framework Programmes and Structural Funds, foreign companies and funding e.g. from foreign universities, central agencies and international organisations.

foreign organisations amounted to 19.9 million euros[2] (7%) and for other research sites 7.7 million euros (3%).

Research funding from the Finnish Funding Agency for Technology and Innovation Tekes in 2008 amounted to 516 million euros, which was shared between 1,983 projects.[3] Universities and government research institutes received 223 million euros (43.2%), while business research, development and innovation received 208 million euros (40.3%). Loans for business research and innovation amounted to 85 million euros (16.5%).

Funding for universities

In universities, overall research expenditure increased in real terms by 36 per cent from 1997 to 2002. This trend slowed in the early 2000s. From 2002 to 2007, real expenditure growth was down to 9 per cent, with total research expenditure in universities standing at one billion euros.

The main source of external funding for universities was the Academy of Finland, which accounted for 31 per cent of all funding from external sources in 2007 (Figure 3). Tekes accounted for 18 per cent and private businesses for 15 per cent. The main source of foreign funding was the European Union, which accounted for 11 per cent.

By major fields of science, the bulk of university research expenditure in 2006 was spent on natural sciences, social sciences, medical sciences and engineering research. Budget funding was more evenly divided between different fields of science than funding from external sources. In all major fields of science except the humanities and social sciences, over half of total research expenditure is covered from external sources (Figure 4). In both these fields the share of external funding is on the increase. The Research and Innovation Council of Finland recommends that that share should not be allowed to exceed 50 per cent.

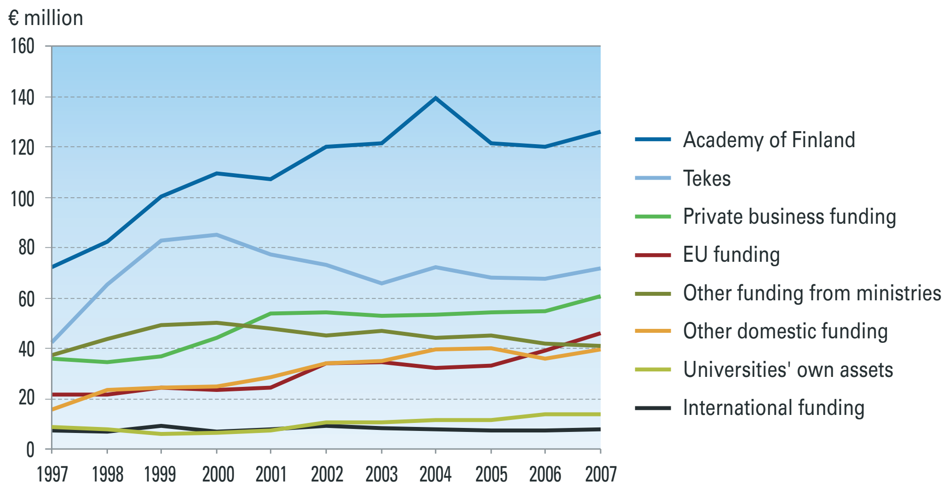

Figure 3. Research expenditure in universities* by sources of non-budget funding in 1997–2007.
Source: Statistics Finland 2009.

* Deflated by Statistics Finland public expenditures price index item (2000=100) describing changes in university costs. Undeflated figures for 2007: Academy of Finland 151 million euros, Tekes 86 million euros, private business funding 72 million euros, EU funding 55 million euros, other funding from ministries 49 million euros, other domestic funding 47 million euros, universities' own assets 16 million euros, international funding 9 million euros.

2 Includes membership fees to international associations.

3 Includes funding worth 31 million euros from EU Structural Funds.

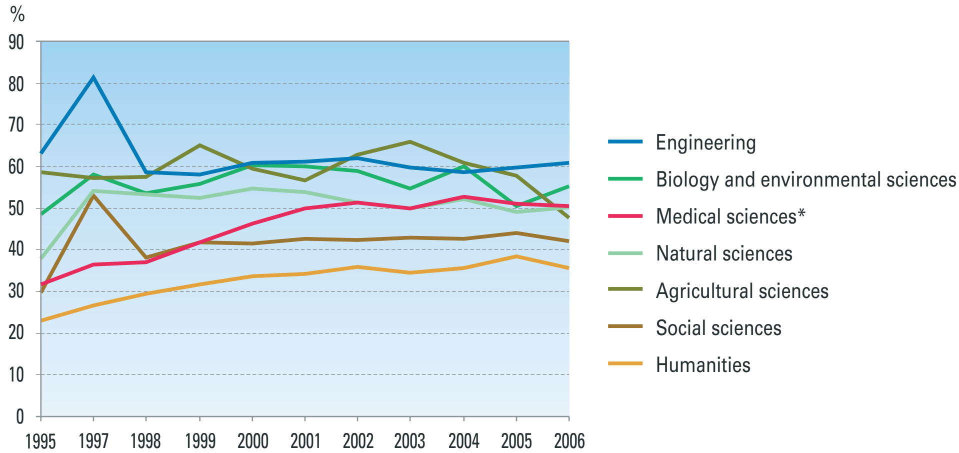

Figure 4. External funding as a proportion of total university research expenditure by major field of science in 1995–2006. *Source: Statistics Finland 2009.*

* If external funding for university hospitals is included in the figures, the share of external funding in medical sciences in 2006 came to 65 per cent.

Supporting research infrastructures

Research infrastructures are an integral part of the national education, research and innovation policy strategy. In 2006, the European Strategy Forum on Research Infrastructures (ESFRI) drew up a roadmap outlining development needs for research infrastructures (European roadmap… 2006). The EU Competitiveness Council subsequently recommended that Member States prepare their own national infrastructure development plans.

In Finland, an overview and international evaluation of national research infrastructures was conducted in 2008 with Ministry of Education funding (National-level infrastructures 2009). According to the report, public investment in the maintenance of nationally significant infrastructures in Finland comes to 130 million euros a year. Furthermore, some 30 million euros is spent on membership fees to international infrastructures. In 2009, it is estimated that expenditure needs on urgent infrastructure projects amount to around nine million euros. Over the period from 2010 to 2016, urgent funding needs will add up to over 200 million euros.

The report observed that some nationally significant research infrastructures are outdated and fragmented, and that there is not enough cooperation to make the best possible use of them. There is no centralised and coordinated funding system for upgrading and renewing infrastructures, or for the financing of new national projects. Participation in major international infrastructure projects also requires domestic investment and coordination.

Investment in research equipment within the Finnish higher education sector has been relatively modest (Figure 5). The OECD has compared the ratio of expenditure on major research equipment and facilities in the higher education sector to total R&D expenditure within this sector in different countries.

Conclusions

Finland is falling behind the Government's target of expenditure 4 per cent of GDP on research and development. The growth of private business sector investment in R&D has grounded to a halt. Finland's public expenditure on research and development as a proportion of total R&D investment is relatively low at 28 per cent. Any ambitions to increase public R&D funding are further frustrated by the current climate of economic recession. During periods of recession business companies cut back on their R&D expenditure. This increases the role of public incentives.

Finland has chosen to invest in a system of public R&D funding that is allocated on a competitive basis via the Academy of Finland and Tekes. A large proportion of public research funding has gone to applied research.

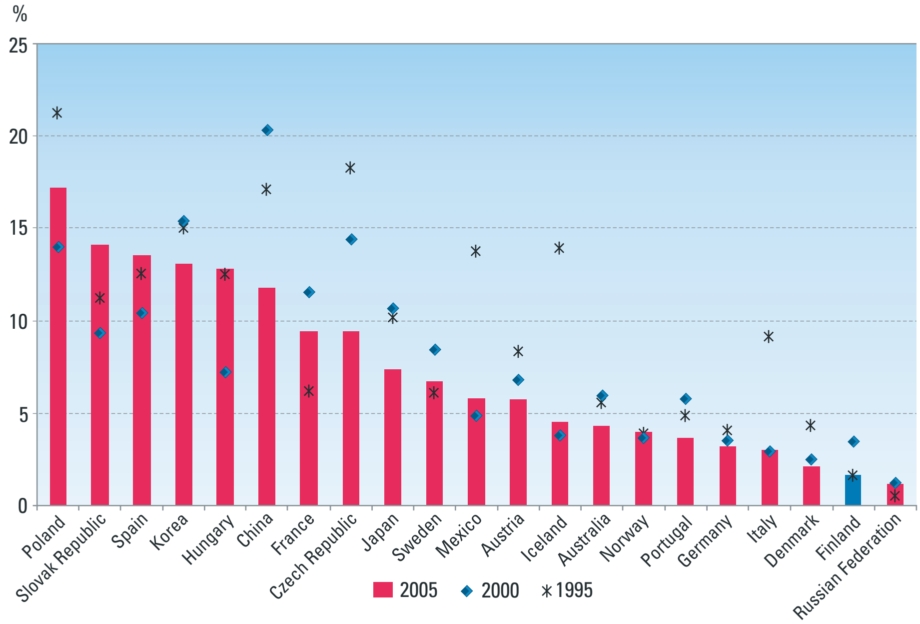

Figure 5. Investment by OECD countries* in major research equipment and facilities as a proportion of total R&D investment in the higher education sector in 1995, 2000 and 2005.
Source: OECD 2008c, OECD R&D Database 2007.

* Data missing for 11 OECD countries. Figures additionally included for China and Russia.

The growth of funding for universities has slowed in the 2000s. In many fields of science external sources now account for more than 50 per cent of total university funding, exceeding the maximum level recommended by the Research and Innovation Council.

Research infrastructures have received relatively low levels of investment in Finland. Nationally significant research infrastructures are in urgent need of additional funding. The Finnish funding system for research and development lacks a coordinated mechanism for supporting research infrastructures.

2.3 Human resources of research

PhD education

The Finnish higher education system has been developed in line with EU harmonisation objectives. The Ministry of Education's education and research development plan for 2007–2012 sets the target for new PhDs at 1,600 a year (Ministry of Education 2007a). Today, the number of PhDs awarded stands at around 1,500 a year. From 1998 (n=988) to 2008 (n=1,526), the figure increased by 54 per cent, in the past five years (2003–2008) it has gone up by 21 per cent. By field of science, the slowest growth in the number of graduating PhDs in 2003–2008 is recorded for medical sciences (11%) and the fastest for arts (53%) (Figure 6). The proportion of women among PhD graduates has increased significantly in all fields (Figure 7). In 2008, women accounted for over half of all PhD graduates in all other fields except the natural sciences and engineering.

Under the results-based funding system currently in force between the Ministry of Education and universities, the level of basic Ministry funding to universities has been determined primarily on the basis of degree targets and their attainment, with due consideration to the differences between different fields of study. The number of doctorates completed has carried particularly great weight in this funding scheme. The Ministry of Education is currently in the process of developing a new funding model in which rewards will increasingly depend on the quality and outputs of research and education.

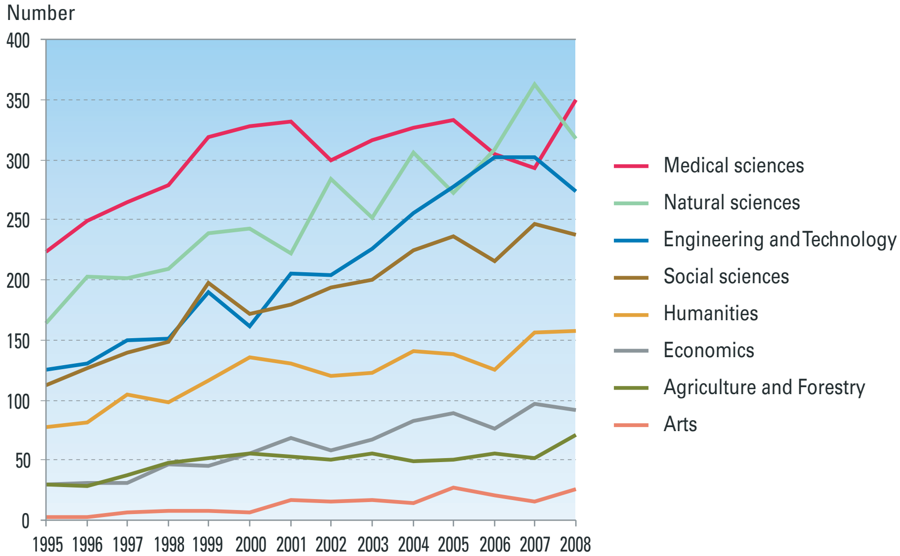

Figure 6. Number of PhD graduates by field of science in 1995–2008.
Source: Kota database, Ministry of Education.

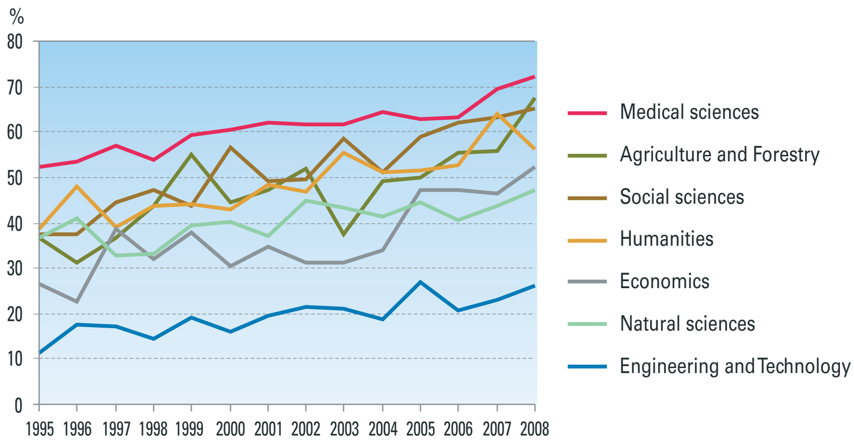

Figure 7. Proportion of women among PhD graduates by field of science in 1995–2008.
Source: Kota database, Ministry of Education.

The international panel of experts that reviewed the Finnish innovation system also made critical note of this undue emphasis on the number of degrees awarded. It concluded that research and its quality should receive greater weight in the university funding system than is current practice. The quality of research output should be reviewed and assessed separately for different fields of research. Furthermore, it is important that universities are informed well ahead of time about new funding principles and criteria so that they can make the necessary adjustments. (Evaluation… 2009.)

The median age at doctorate is comparatively high in Finland. In all major fields of science the median age of PhD graduates is over 30 years (Figure 8). In the humanities and social sciences the corresponding age is around 40 years. The only fields where median ages have slightly dropped over the past 10 years are natural sciences and engineering. The aim is for doctoral students to complete the PhD in four years, and the graduate school system has helped to bring this target closer.

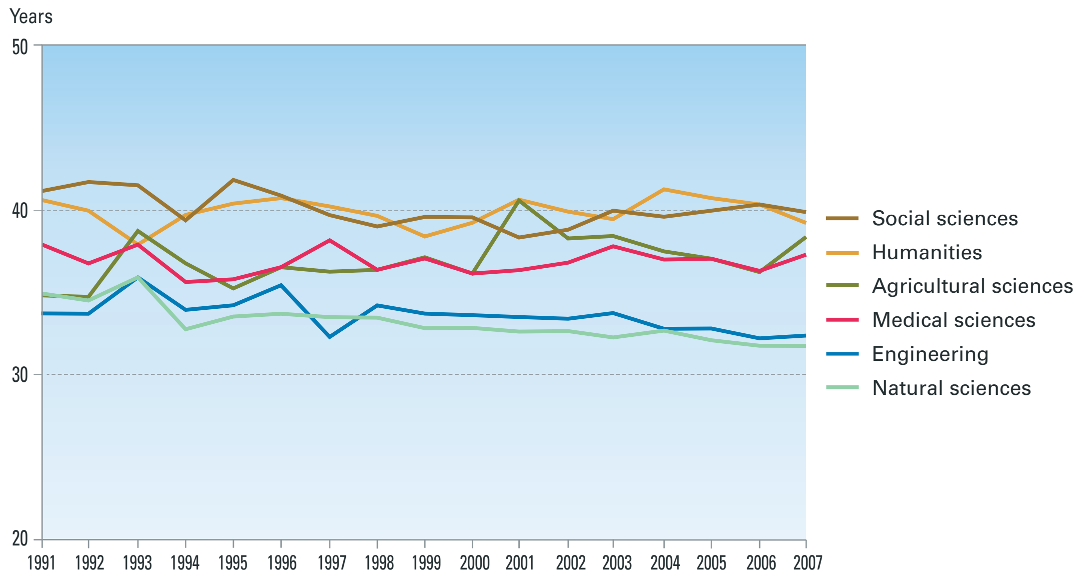

Figure 8. Median ages of PhD graduates by major fields of science in 1991–2007.
Source: Statistics Finland, www.stat.fi.

It is also noteworthy that despite these goals of shorter graduation times, there has been no change in the amount of time taken to complete the Master's degree. The median time to completion of higher university degrees was 6.0 years in 2000–2005 and 6.5 years in 2006–2007 (Statistics Finland, www.stat.fi).

In 2008, just over 40 per cent of the annual 1,500 PhDs were completed at a national graduate school. In 2006–2007 the corresponding proportion was around one-half. In engineering fields the largest share or almost 80 per cent of PhDs were completed at graduate schools (Table 2). In economics, less than one-quarter of all doctoral theses were researched at graduate schools.

The number of graduate school places is highest in the natural sciences and engineering fields, which account for over half of all graduate school places (Table 3). Medical sciences have the second highest share of all graduate school places at 17 per cent, with the social sciences holding 16 per cent. This breakdown by different fields of science changed slightly in connection with the allocation of graduate school places from 2010 onwards.

In 2007, there were 1,453 graduate school places, at the beginning of 2010 the number stands at 1,600. The aim is to bring a great number of PhD students who are currently outside the graduate school system within reach of more efficient researcher training. The target is to raise the proportion of foreign students to 20 per cent by 2012 (Ministry of Education 2007a). In 2007 foreign

Table 2. Number of PhDs awarded at graduate schools and share of all PhDs by field of science in 2006–2007*.
Sources: Academy of Finland; Kota database, Ministry of Education.

	PhDs from graduate schools	All PhD graduates	Share of PhDs from graduate schools (%)
Natural sciences	421	671	62.7
Engineering and technology	471	604	78.0
Agricultural sciences	60	108	55.6
Medical sciences	256	598	42.8
Economics	41	173	23.7
Social sciences	168	463	36.3
Humanities	105	281	37.4
Art studies	12	37	32.4
Total	1,534	2,935	52.3

* Data not available for individuals years.

Table 3. Number of graduate school places in the national graduate school system and breakdown (%) by field of science in 2007 and 2010. *Source: Academy of Finland.*

Graduate school places	2007		2010	
	number	%	number	%
Natural sciences	377	27.5	405	25.3
Engineering and technology	403	26.2	437	27.3
Agricultural sciences	49	3.4	55	3.4
Medical sciences	245	16.9	273	17.1
Economics	37	2.5	36	2.3
Social sciences	221	15.2	259	16.2
Humanities	99	6.8	105	6.6
Art studies	23	1.6	30	1.9
Total	1,453	100	1,600	100

students accounted for 15.8 per cent of all full-time students at graduate schools.

In 2008, the Ministry of Education delegated all decision-making on graduate schools as well as related development and monitoring functions to the Academy of Finland. In 2009, the Academy appointed a graduate school support group that was charged with preparing the 2010 graduate school call and with developing procedures for monitoring and evaluating the graduate school system. Furthermore, the support group will assess the impact of the graduate school system, review different tools and strategies for assessing the demand for PhDs, and promote best practices and internationalisation at graduate schools.

Development of research personnel and the academic research career

In Finland 2.3 per cent of the active workforce is currently employed in R&D,[4] which is the highest figure in the OECD area (Figure 9). In 2008, some 80,000 people worked in research and development, with the number of person-years totalling around 56,000. These high figures are explained among other things by the rapid growth of research in the Finnish information industry, the high rate of

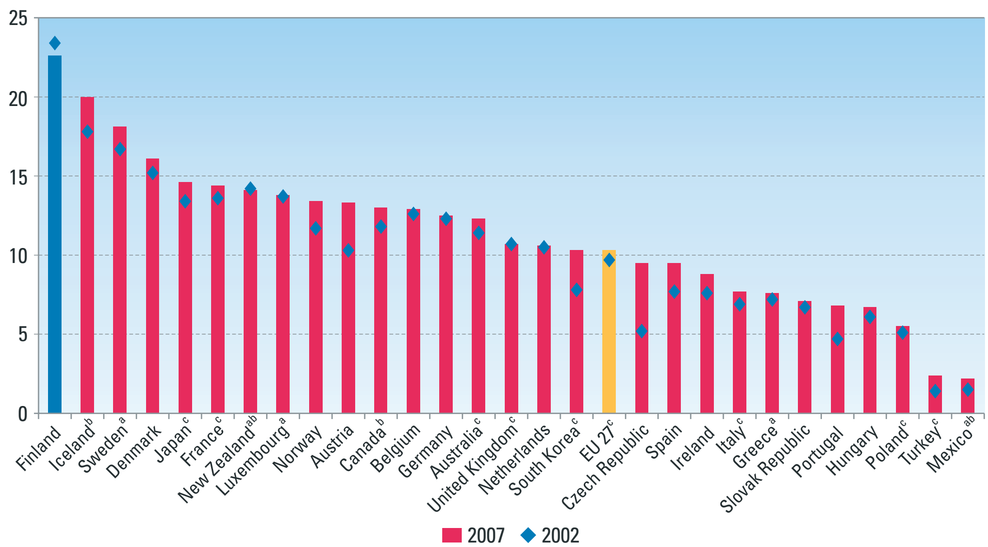

Figure 9. R&D personnel per 1,000 employed persons in OECD countries* in 2002 and 2007.
Source: OECD 2008a, Main Science and Technology Indicators.

* Data for United States not available.
a Data for 2003.
b Data for 2005.
c Data for 2006.

4 *R&D personnel* includes categories ISCO-2: Research Professionals, ISCO-1237: R&D Department Managers, and ISCO-3: Technicians and Associate Professionals (OECD 2002, Frascati manual… 2002).

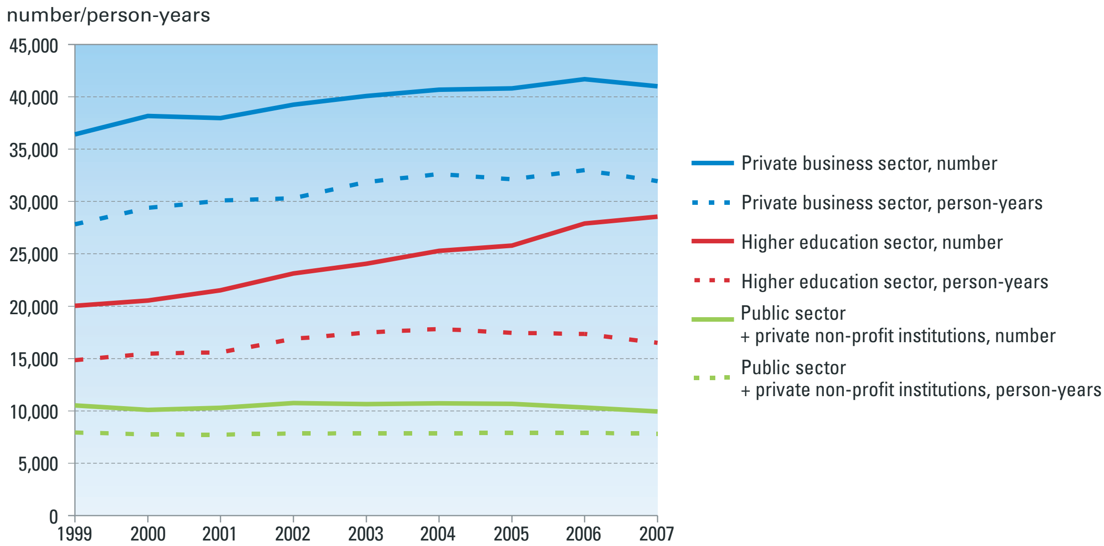

Figure 10. Number of R&D personnel and person-years in research by sector in 1999–2007.
Source: Statistics Finland 2009.

tertiary education in the population and increased R&D funding. Staff numbers and person-years in R&D have increased in both the higher education and business sectors (Figure 10). In the higher education sector the number of research staff has increased by 23 per cent, but the number of person-years has dropped by two per cent in 2002–2007. The number of person-years in research has been falling since 2004. This is mainly due to the growth of short-term and part-time employment.

In 2007, PhD graduates accounted for 14 per cent of R&D personnel; 10 years ago the figure was 10 per cent. In the higher education sector the corresponding proportion was 28 per cent and in the public sector 4 per cent in 2007. (Statistics Finland, www.stat.fi.)

In its Education and Research Development Plan for 2007–2012, the Ministry of Education suggests that the number of PhD graduates among research personnel should be raised to 20 per cent by 2020. The aim is to increase the relative number of PhDs working in research and other positions outside of the university system (Ministry of Education 2007a). With the exception of only a few fields, employment prospects for PhDs have been good in Finland.

Women accounted for 35 per cent of all R&D personnel. In the higher education sector and the public sector the proportion of women was one-half, compared to slightly less than 45 per cent 10 years ago. In the private business sector the share of women was around 22 per cent, and that figure has dropped slightly in the past 10 years.

An analysis of the number of research person-years[5] shows that this figure began to drop in 2004. In 2002, the number of research person-years per one thousand employed persons in Finland was 16.4 per cent, in 2007, the figure was down to 15.6 per cent (Figure 11). Finland and Sweden are the only OECD countries recording a drop in the number of research person-years from 2002 to 2007.

In the **higher education sector**, the number of research personnel in 2008 totalled around 28,500. Universities and university hospitals accounted for

5 Includes categories ISCO-2: Research Professionals and ISCO-1237: R&D Department Managers (OECD 2002, Frascati Manual… 2002).

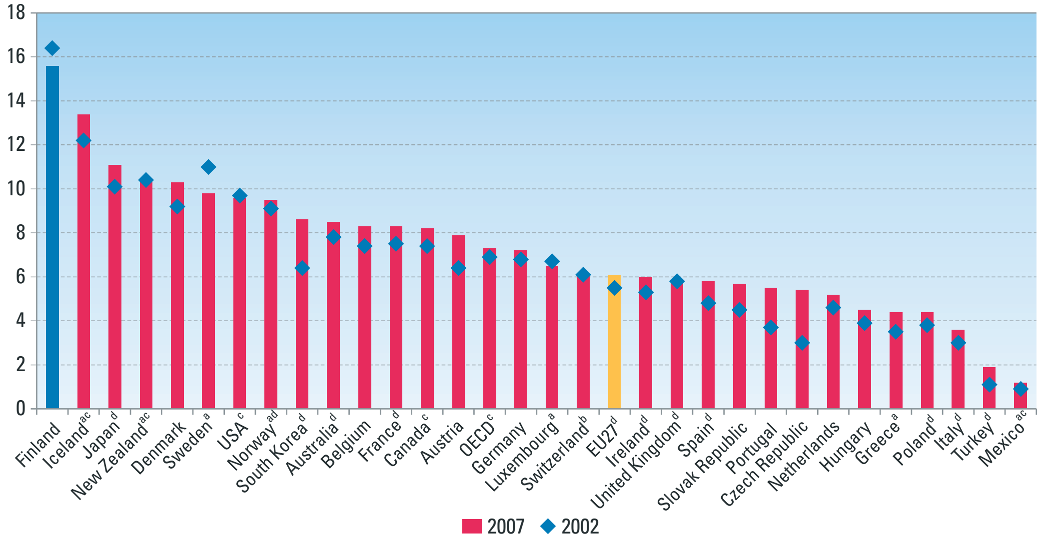

Figure 11. Number of research person-years per one thousand employed persons in OECD countries in 2002 and 2007. *Source: OECD 2008a, Main Science and Technology Indicators.*

a Data for 2003.
b Data for 2004.
c Data for 2005.
d Data for 2006.

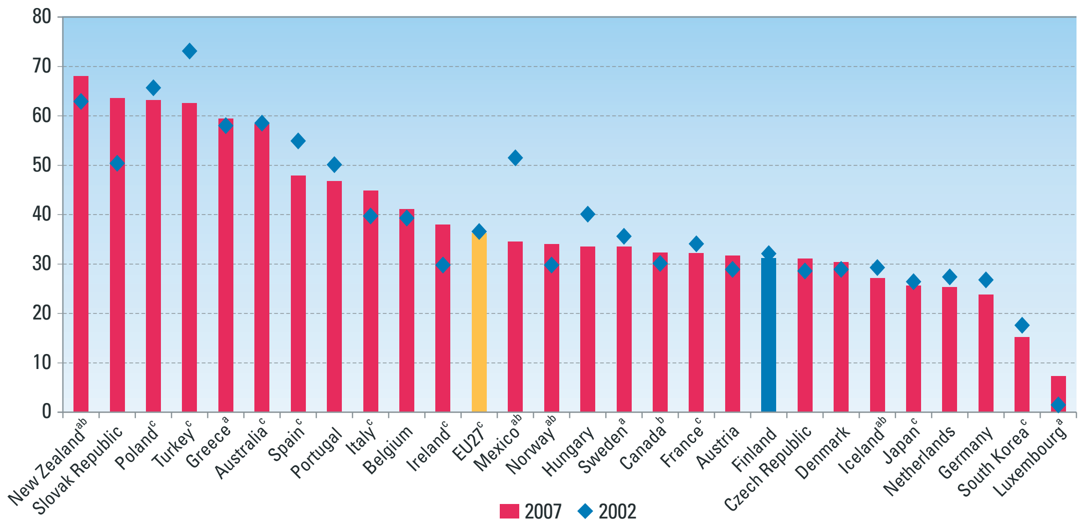

Figure 12. Universities research personnel as a proportion of total R&D personnel in OECD countries* in 2002 and 2007. *Source: OECD 2008a, Main Science and Technology Indicators.*

* Data for the United States and the UK missing.
a Data for 2003.
b Data for 2005.
c Data for 2006.

some 24,000 persons and polytechnics for around 4,500. Researchers working in the higher education sector accounted for 31 per cent of total R&D personnel, which is lower than the EU27 average of 37 per cent. The figure has dropped slightly from 2002 to 2007 (Figure 12).

At universities, the number of research personnel has risen by 38 per cent from 1997 to 2007 (Figure 13). During the same period the number of PhDs working at universities has increased by 87 per cent. The number of PhDs as a proportion of research personnel was 23 per cent in 1997 and 32 per cent in 2007.

In universities, research personnel numbers are highest in the natural sciences, standing at around 6,000 in 2007 (Figure 14). The corresponding figure for the social sciences, medical sciences and engineering fields was around 4,000 in 2007. In 2007 women accounted for 44 per cent of university research personnel, ten years later the figure had slipped back to 40 per cent. The proportion of women among research personnel increased in all other fields except the natural sciences (Figure 15). The proportion of women was highest in medical sciences and lowest in engineering sciences.

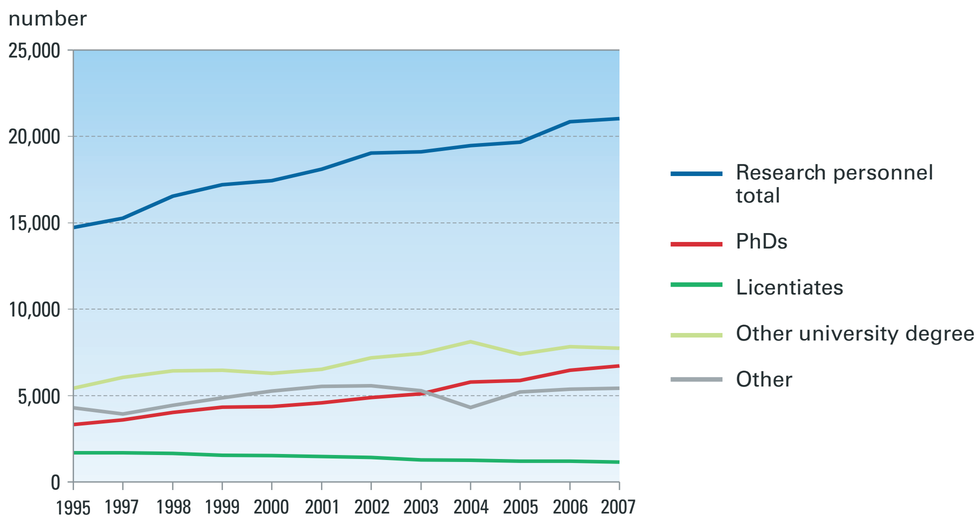

Figure 13. University research personnel by degree in 1995–2007.
Source: Statistics Finland 2009.

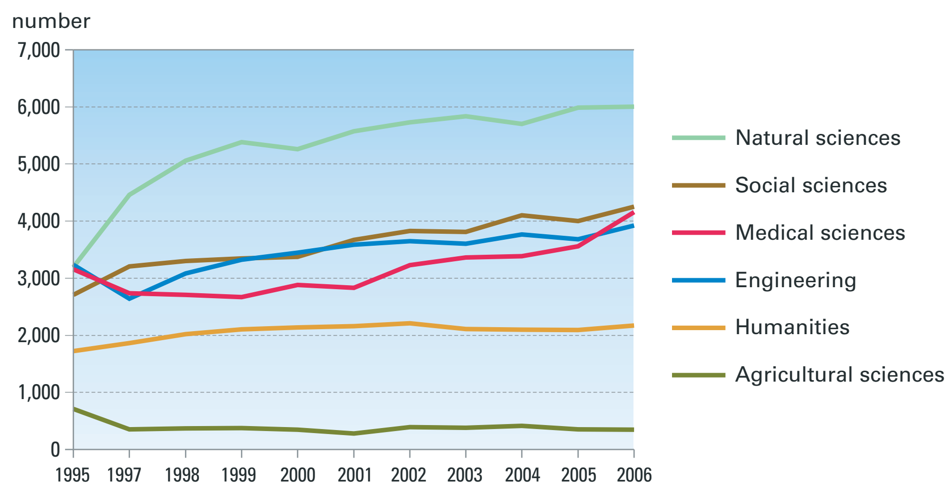

Figure 14. Number of university research personnel by major fields of science in 1995–2006.
Source: Statistics Finland 2009.

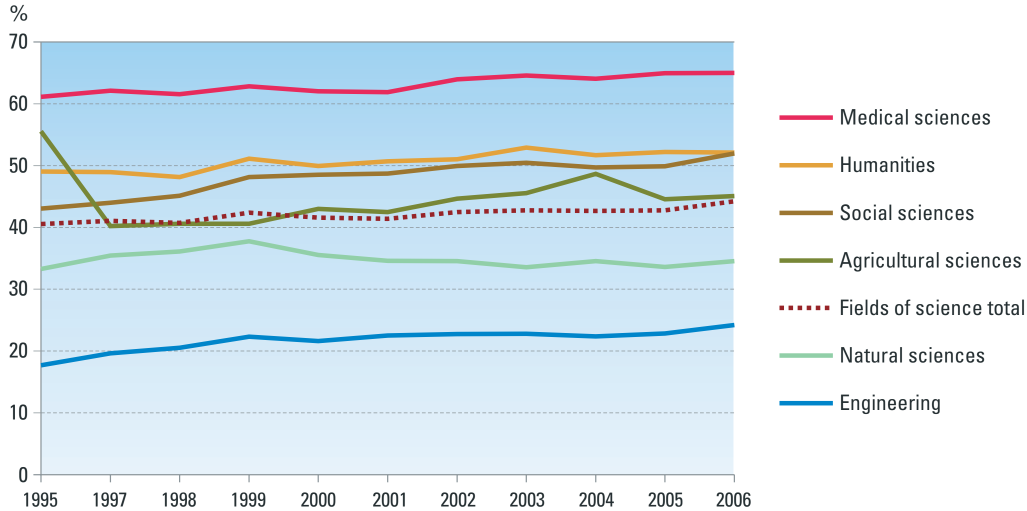

Figure 15. Number of women as a proportion of university research personnel by major fields of science in 1995–2006. *Source: Statistics Finland 2009.*

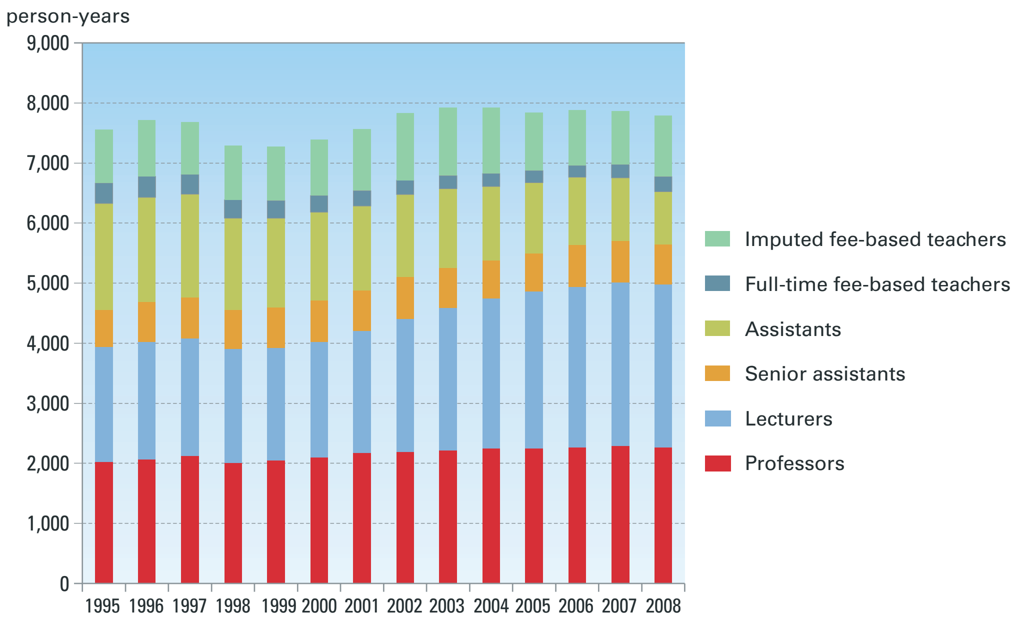

Figure 16. Person-years contributed by university teaching staff by job title in 1995–2008. *Source: Kota database, Ministry of Education.*

Figure 16 illustrates the development of the number of person-years performed by university teaching staff. Professors accounted for 29 per cent of university teaching staff, lecturers, senior assistants and assistants for 55 per cent and other teaching staff for 16 per cent in 2008. In 2008, one-quarter or 24 per cent of all professors were women (Figure 17). In 2008, there were a total of 555 women professors, and the figure increased by 16 per cent from 2003 to 2008.

The number of person-years contributed by university teaching staff has increased very little in recent years, despite the sharp increase in student enrolment (Figure 18). There is currently a severe

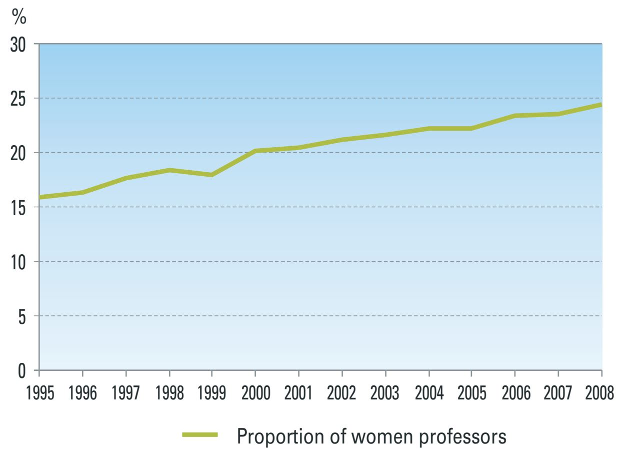

Figure 17. Proportion of women professors in 1995–2008. *Source: Kota database, Ministry of Education.*

imbalance in Finnish universities between student numbers and teaching resources: in Finland the student to teacher ratio is 20 compared to the average of around 16 in OECD countries (Figure 19, OECD 2008c).

The slight dip in student numbers that is seen in Figure 18 and 19 is explained by the move to the degree structure under the Bologna Process. The transitional period, with two concurrent sets of degrees awarded at the same time, ended in 2008 in virtually all fields of study.

Trends for teaching staff person-years in different fields of science are shown in Figure 20. In the past five years, person-years contributed by teaching staff have dropped in the natural sciences (-12%), in the humanities (-6%), engineering (-5%) and social sciences (-2%). In other fields the number of person-years has increased over the same period by 3–6 per cent.

The objective adopted in Finland is to ensure an adequate pool of qualified research personnel to meet the needs of the research and innovation system and society at large. Work is currently underway to develop a jointly-funded **research career system** to facilitate entry into an academic research career and career advancement. Ultimately, through the joint effort of different sectors, the aim is to make academic research career a more predictable and more attractive career option. (Ministry of Education 2006, 2007a, 2007b, 2008b.) Obstacles to international mobility will be removed in collaboration with other EU

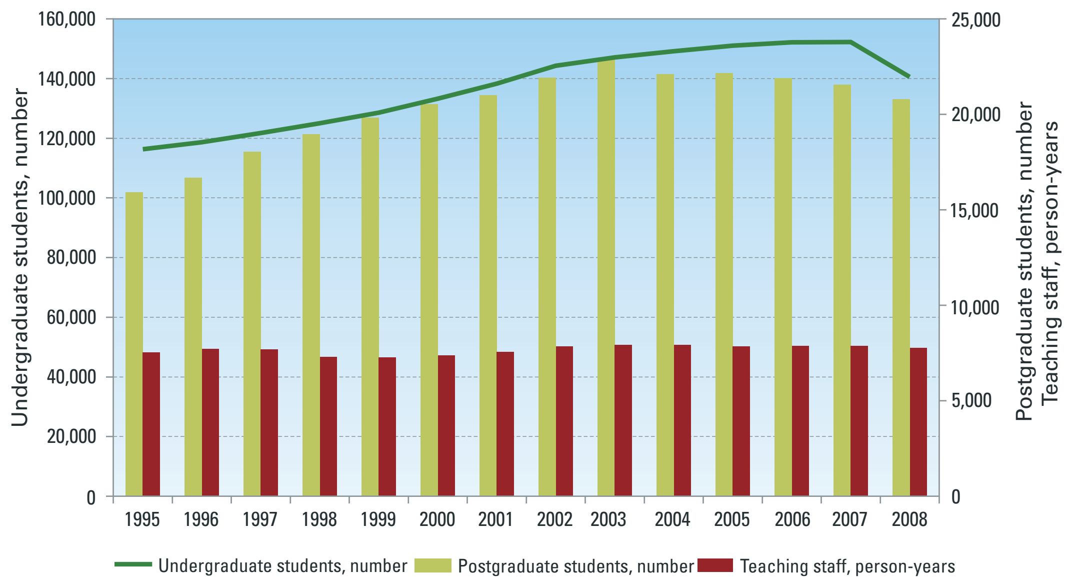

Figure 18. Person-years contributed by university teaching staff and numbers of undergraduate and postgraduate students* in 1995–2008. *Source: Kota database, Ministry of Education.*

* Numbers registered as postgraduate students.

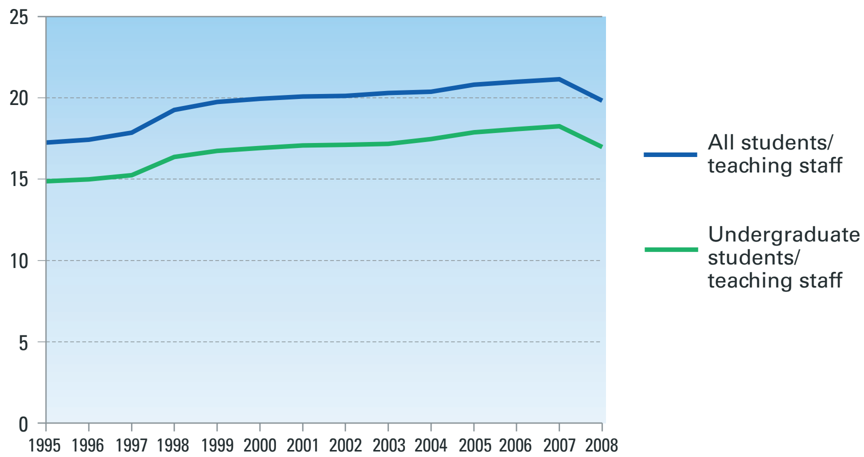

Figure 19. Number of university students relative to person-years contributed by teaching staff in 1995–2008. *Source: Kota database, Ministry of Education.*

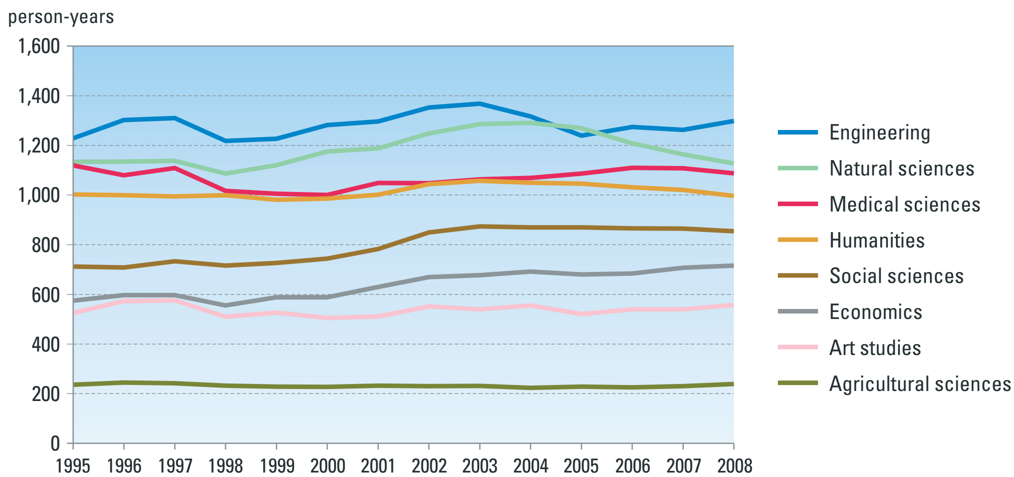

Figure 20. Person-years contributed by university teaching staff by field of science in 1995–2008. *Source: Kota database, Ministry of Education.*

Members under the guidance of the EU Commission (European Commission 2008a).

The four-tier research career structure proposed for adoption in Finland is based on the simultaneous development of funding instruments and the current system of research and teaching posts at universities and research institutes. The aim is to clarify the different stages of the academic research career in all sectors, to promote mobility both between different sectors and internationally, and to enhance career advancement based on outside evaluations. Through the adoption of legislative and other measures, the ultimate objective is to move from short-term job contracts to fixed-term employment. One of the aims of the new research career system is to create a career path that eventually leads the most successful researchers to an appointment with permanent tenure. Furthermore, research grants will be phased out in favour of the payment of regular salaries so that researchers can claim full social security and pension benefits. (Ministry of Education 2008b.) The most critical stages of the research career come immediately after PhD graduation, after the postdoctoral stage either abroad or at home, and at the point of establishing one's own research team.

In the four-tier model the first step involves researching the doctoral thesis and completing the doctoral degree. Positions on the second rung of the career ladder include postdoctoral researcher, senior scientist and university teacher. The third level comprises the positions of Academy Research Fellow, senior researcher, university lecturer and university researcher. The fourth tier consists of Professors, Academy Professors, Research Professors and Research Directors. Universities have undertaken to establish a harmonised set of job titles for the academic research career, and this work is now in its final stages.

One of the primary factors that continues to undermine the appeal of an academic research career is its lack of predictability. As it is, the research career typically consists of a series of short-term contracts that are funded from a variety of sources. In contrast to international practice, researchers in Finland cannot ensure the continuity of their scientific careers by producing good results. The lack of career predictability is also a major obstacle to recruitment. More attention must be given to recruitment selection criteria in order to tap the best research talent.

The same development challenges are identifiable in other EU Member States, too. The numbers who are interested in an academic research career are continuing to fall. Different fields of research differ in terms of career formation. Different stages in the research career are less than clearly demarcated, and there is also a lack of consistency in job titles and responsibilities. Researcher mobility between different sectors and different countries falls short of targeted levels.

Conclusions

Budget funding for Finnish universities has largely been allocated on the basis of the number of degrees awarded. The number of doctorates awarded currently stands at over 1,500, and over the past five years this figure has risen by around one-fifth. More than 40 per cent of all doctorates are earned within graduate schools. The mean age at doctorate is well over 30, which is higher than the international average. The median age at doctorate has fallen slightly in the past ten years only in the natural sciences and engineering fields. The proportion of women among PhD graduates has increased significantly in all fields.

Employment rates for PhD graduates have so far been high. It is important that the future need for PhDs in research and other positions in different sectors is carefully reviewed and assessed so that Finland's substantial investment in higher education is targeted to best effect.

The number of person-years spent on R&D as a proportion of the total active workforce in Finland is high, but no longer rising. The number of research personnel has also begun to fall. The number of PhD graduates has increased in the higher education and the public sector, but only marginally in the private business sector. The number of women as a proportion of R&D personnel has increased in all other sectors except private business.

In the **higher education sector** the number of researchers as a proportion of R&D personnel is lower than the average for EU countries and is falling. At **universities** the number of research staff is rising, but the number of person-years in research has been falling since the mid-2000s. The growth of short and fixed-term employment at universities is having an increasingly apparent impact. PhDs currently account for one-third of universities' research staff. One difficulty for Finnish research teams is that they often do not have enough senior researchers relative to the number of PhD thesis writers. There is also a shortage of teaching staff at universities to cater for the growing number of students. In the past five years the proportion of women professors has increased by 16 per cent.

Lack of predictability and short-term employment contracts combine to detract from the appeal of the academic research career. Researcher mobility between different sectors and different countries falls short of targeted levels. Work is now underway to put in place the four-tiered research career plan. That plan will help to meet the challenges that are largely the same as those encountered in other EU Member States.

2.4 Research environments and cooperation[6]

Creative and competitive research environments

There is good evidence that the creativity and output of research units is positively affected by various individual, environmental, structural and resource-based factors. At the individual level, passionate and inquisitive scientists are the main driving force of creative research environments. For them, a major incentive is to build an attractive career in science and research. Research is one of the most international professions of all. Researchers prefer to work in environments that offer the best research facilities. High-quality research environments provide the best opportunities for career advancement, adequate funding and high-quality research infrastructures.

A competitive and creative research team is characterised by good management and communication, a sound and balanced structure and its own distinctive culture. Creative tensions within the research environment and the achievement of equilibrium are important among others on the following dimensions:

- relationship between unit autonomy and external direction;
- relationship between researchers' independence and interaction;
- relationship of stability and security to disruption and challenges;
- relationship of junior to senior research staff;
- relationship of critical mass to the small team.

The development and maintenance of competitive and creative research environments has been a broad effort involving not only the organisations concerned, but also research funding agencies as well as science policy-makers. There exists a wide range of research funding practices and instruments in Finland that are designed to promote various objectives. Funding agencies usually have a number of different funding instruments intended for specific purposes. Research teams have to go to different agencies to get different funding components, and they apply to the same agency for funding through different instruments. Funding for creative and competitive research teams and research environments in Finland continues to remain predominantly fragmented and relatively short-term.

One of the key preconditions for competitive and creative research environments is having access to adequate resources. Funding must be sustained, adequate and flexible. Furthermore, there must be an appropriate balance between budget funding and external funding. Research infrastructures are not adequately provided for in the allocation of research funding. High-quality equipment and an efficient research infrastructure require that competent and well-trained staff are available to maintain and run them.

A creative research team and environment is often built up around one or a few personalities. All team leaders have the passion to do research and good ideas, but also good network contacts and good organisational skills. They also know how to convey and transmit their enthusiasm to others and to build up a research team that can break down barriers, question the old and create something entirely new. Management at universities is about management by expertise. The challenge for every manager and leader is to develop management as well as the researcher's role, but it is important that they also have the time to plan and do research and to instruct and inspire young people. In smaller teams in particular one possible new management strategy is a system of rotating management where senior researchers take turns to manage the team. Another strategy is network management. Here, instead of relying on the input of one single individual, all members of the research team are expected to contribute with new ideas and guidelines for research.

6 This chapter is based in part on the meetings of the three expert panels organised in late 2008 by the Academy of Finland and the University of Tampere Unit for Science, Technology and Innovation Studies (TaSTI). It also uses the background material prepared by TaSTI for these meetings (including Figure 21). The experts who took part in the panel are listed in Appendix 1.

The management of a research team requires a continuous and sustained effort and years of development. The dynamics and life cycle of every group involves periods of transition and crisis, the management of which presents exceptional challenges. The training of a new generation of researchers is an ongoing process of change. Researcher training of the highest order is a key criterion for every creative research environment. University research in Finland is characterised by short job contracts, which effectively undermines the appeal of the academic research career. Measures are needed to ensure greater continuity for research and researchers, but this is largely thwarted by the growing burden of administrative burdens associated with project management.

Diversity is an important asset for every research team: strong and creative research environments have a balanced mix of researchers of different ages, men and women, and people from different cultural backgrounds. Finland traditionally has a comparatively low number of researchers who come from different cultures. Furthermore, the number of PhD thesis writers in Finnish research teams is usually very high relative to the number of senior researchers. Nowadays women account for the bulk of doctorates completed in virtually every field, but they continue to remain underrepresented among senior researchers and professors.

Social capital assets in Finland are very strong, including openness, trust, interaction and networking. An atmosphere of freedom, openness and permissiveness coupled with constructive criticism is an asset for every creative research team. It is also important to have the support of one's own host organisation so that there is no unnecessary in-fighting for resources within the university or faculty.

Network contacts and interaction are crucially important to every creative research environment. Maintaining effective internal communication within the research team and interaction and exchange with various organisations both at home and abroad are paramount to the development of creative research environments. Forms and formats of communication may vary between different fields of research. Both formal and informal contacts are important. The increased use of electronic platforms does not eliminate the need for face-to-face meetings.

Creative research environments need to have good international contacts and active interaction. International engagement is a process of creating a multinational research community that involves mobility, importing new ideas from other countries and learning about various research customs and cultures. Finland has sought actively to recruit research talent from other countries. The latest instrument in this effort is the Finland Distinguished Professor Programme (FiDiPro), which is designed to attract foreign professors into Finland.

Forms of cooperation in university research

Finnish science policy and funding agencies have consistently encouraged research organisations to engage in as many different forms and areas of cooperation as possible. Diverse cooperation is one of the key funding criteria adopted by both the Academy of Finland and Tekes. The role of international cooperation is particularly pronounced in research projects. Cooperation across disciplinary boundaries and aimed at the application of basic research is encouraged especially in research and technology programmes, in Centre of Excellence programmes and in Strategic Centres for Science, Technology and Innovation. National graduate schools are an important science policy tool for promoting cooperation both between universities and more widely.

In their strategy work it is imperative that universities work closely with other actors within the region and the innovation system. The administrative arrangements adopted by universities are crucially important to this cooperation. The first requirement for effective intraorganisational cooperation and international cooperation is good management. University administration today lacks in coherence. Several universities have gone too far in delegating administration to faculty level and even to individual units.

Relations of cooperation are somewhat differently oriented and weighted in different disciplines (Figure 21). Cooperation within units is more or less equally regular in all fields. In medical science and natural

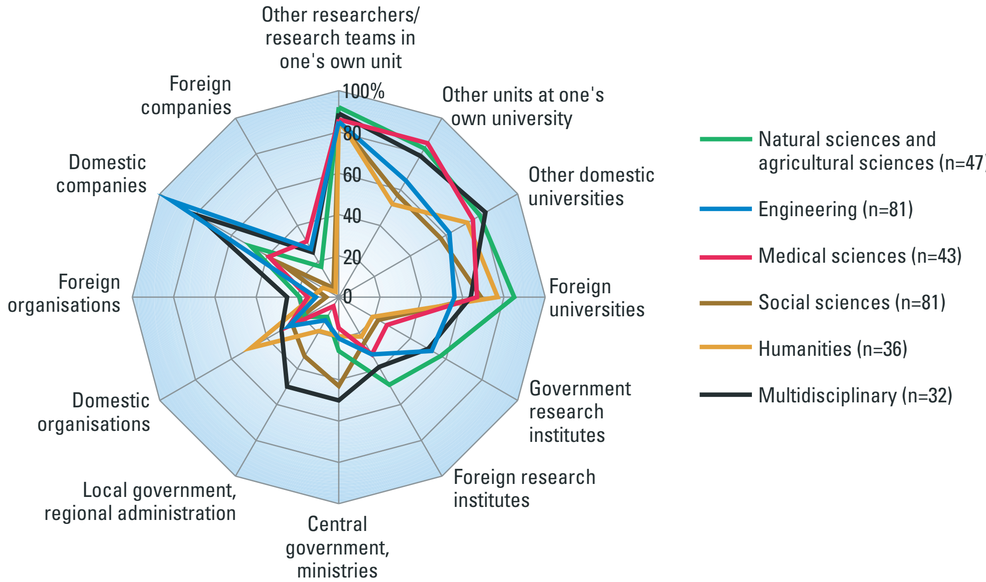

Figure 21. Frequency of cooperation at university units by field of science in 2006–2008. Percentage of respondents with regular or very much cooperation with the partner concerned. *Source: Unit for Science, Technology and Innovation Studies TaSTI, University of Tampere. Questionnaire 2008.*

science units cooperation with other units at one's own university was more regular than in humanities and social science units. Multidisciplinary units had more frequent cooperation with other domestic university departments than did other units. There were marked differences in the frequency of cooperation with domestic business companies. In engineering fields there was regular cooperation with business companies.

The most important motives for international research cooperation at universities were to obtain up-to-date scientific information or methods, to obtain complementary scientific information supporting one's own research evidence, to create networks, to promote career advancement in research, and to influence scientific development within one's own field. Other major motives for cooperation were to produce international publications, to gain increased exposure for one's work abroad, to obtain funding from domestic sources, to improve the quality of research, to succeed in competition, to obtain international funding and to gain first-hand experience of new procedures and approaches abroad and thus to gain new ideas and impressions. (Ahonen et al. 2009.)

There were marked differences between different fields of science (Table 4). In the natural sciences the main reasons for cooperation were to gain access to research equipment abroad, in engineering fields to make new business contacts abroad. In medical sciences the development and sale of commercial products was a more important factor than in other fields. In the social sciences research cooperation was most often motivated by comparative international studies. In multidisciplinary units success in the competition with other units in the same field and obtaining international funding were mentioned more often as reasons for research cooperation than in other fields.

The development of forms of cooperation in university research is dependent on the research agendas and priorities as defined by universities themselves. Nevertheless, university research is conducted as an integral part of the national research and innovation system. In the future, universities will have to develop and profile their research more closely in relation to sectoral research and business R&D and as part of broader centres of excellence. The development of the university's research profile implies both growing competition and increasing cooperation, and it involves strategic choices at different levels.

Table 4. Reasons for international cooperation at universities in 2004–2005. Percentage of responding units where reason for international cooperation was somewhat important, important or very important by field of science. Only those reasons are shown where statistically significant differences were seen between fields of science ($p<0.05$).
Source: Publications of the Academy of Finland 7/2009 (Ahonen et al.).

	Natural sciences (n=47)	Engineering (n=81)	Medical sciences (n=42)	Social sciences (n=81)	Humanities (n=36)	Multidisciplinary (n=32)
To use equipment located abroad	**30%**	14%	15%	1%	3%	10%
To conduct international comparative research	22%	20%	25%	**50%**	24%	35%
To establish foreign business contacts	13%	**30%**	24%	6%	6%	23%
To develop and sell commercial products	2%	13%	**17%**	3%	0%	6%
To obtain international funding	65%	56%	54%	35%	41%	**71%**
To complete successfully with other units in the same field	67%	56%	69%	51%	50%	77%

The increasing diversity of funding sources for university research and the mounting competition for the same funding sources has led to overlap between university and sectoral research. On the other hand, sectoral research has shown some tendency to expand across administrative boundaries; one example is provided by new research programmes. In 2009, the Finnish Government decided to commission a survey of research conducted at government research institutes with a view to identifying those areas that should more appropriately be covered at universities. The aim is to eliminate overlap and to strengthen the core functions of both universities and government research institutes. The survey will be coordinated by the Advisory Board for Sectoral Research under the joint supervision of ministries and universities. It will also help to clarify and improve cooperation between different organisations in the field.

Universities and government research institutes have concluded various partnership agreements in research, for instance to create joint professorships. There is only limited researcher exchange between the organisations. Academy and EU research programmes have played a particularly important role in enhancing cooperation between universities and research institutes in that they have given preference to research consortia involving partners from different organisations.

Among private businesses with innovation activity, one-third collaborate with universities and polytechnics and one-quarter with government research institutes. Almost half of the companies that had worked with universities and polytechnics rated them as significant partners. Universities and polytechnics were more important partners to major industrial companies than to smaller businesses in industry or services. (Statistics Finland 2006.)

Universities and business companies have many different kinds of cooperation: training, publishing, consultation, personnel exchange, informal interaction and network cooperation. The forms and mechanisms of this cooperation vary between different fields of science. In Finland cooperation between industry and academia has been highly flexible, and there are very few obstacles to that cooperation.

In keeping with the Government's resolution of 7 April 2005, the Science and Technology Policy Council (now renamed as the Research and Innovation Council of Finland) drafted in 2006 a national strategy for the establishment of internationally competitive science and technology centres of excellence. **Strategic Centres for Science, Technology and Innovation** are expected to have significant national economic and societal potential and to provide highly significant R&D input.

Table 5. Owners of Strategic Centres for Science, Technology and Innovation (situation as at 18 August 2009). *Sources: Strategic Centre websites. Data for Health and Well-being Strategic Centre from Managing Director Saara Hassinen.*

	Universities (foundations)	Polytechnics	Research institutes	Companies	Others
FIMECC Ltd	10	2	1	16	1
RYM-SHOK Ltd	3	2	2	37	5
CLEEN Ltd	10	0	5	28	0
TIVIT Ltd	10	4	1	22	3
Forestcluster Ltd	4	0	2	9	0
Health and well-being	8	0	4	16	0

The thematic focuses for Strategic Centres were selected in line with the national strategy. The one exception is the built environment, which is a later addition from outside the strategy. In 2009, there were six Strategic Centres (Table 5).

Once their operation has been established, Strategic Centres are expected to generate an aggregate annual volume of 50–100 million euros, depending on the thematic area. By 2012, Tekes plans to spend 20 per cent of its funding on Strategic Centres. Out of its funding authority for 2009, Tekes funding for Strategic Centre research programmes is estimated to rise to almost 50 million euros. This figure will be revised if the funding needs for programmes that meet the relevant criteria are greater. Academy will support Strategic Centre projects and other projects in these thematic areas through its various funding instruments on a competitive basis. Overall the volume of funding allocated to the Strategic Centre thematic areas is nationally significant.

The aim and purpose of the Strategic Centre concept is to establish constant contact and exchange between research excellence, technological development and innovation. Strategic Centres serve as communities for researchers, business companies and other organisations. They are applications driven, multidisciplinary and virtual communities. Initial preparations for Strategic Centres were coordinated by the Academy and Tekes, the actual preparations were completed by business and industry. The Strategic Centres have each developed their own research agendas.

Strategic Centres represent a collaborative approach to research in which longer funding periods offer the potential to achieve greater impact than can be achieved through the shorter-term funding of research programmes. Strategic Centres are built around consortia that combine several different perspectives and therefore strengthen multidisciplinary and interdisciplinary approaches. Because of these benefits the Strategic Centre concept could also be adopted in the humanities and social sciences. Strategic Centres are clearly business driven, which may be seen as a structural problem. Business companies are primarily concerned with producing results and applications as quickly as possible, whereas basic research requires a sustained and long-term effort.

Conclusions

Research is one of the most international professions. Researchers prefer to work in environments that offer the best research facilities. **High-quality research** environments provide excellent opportunities for cooperation and career advancement, adequate research funding and a high level of research infrastructure.

In Finland, most of the existing funding for creative and competitive research teams and research environments is fragmented and relatively short-term. Research teams have to go to different agencies to get different funding components, and they apply to the same agency for funding through different instruments.

Key areas of development for the promotion of creative and competitive research environments are to:

- provide more comprehensive resources for creative and competitive research teams;
- develop a resource allocation system for research infrastructures, comprising both infrastructure acquisition and development costs;
- advance international engagement, particularly with a view to raising the quality of research;
- promote and expand cooperation;
- promote the academic research career and researcher training, particularly to improve the predictability of the research career and to enhance the quality of research; and to
- support multidisciplinary and interdisciplinary research and education.

One persistent difficulty for Finnish research teams is that, by international comparison, they do not have enough senior researchers compared to the number of PhD thesis writers. The reason why this problem has persisted so long is that the allocation of budget funding for universities has been based on the number of doctorates awarded, while doctoral thesis writers have received their funding from various other sources.

Many research teams in Finland also lack in cultural diversity, which is a direct consequence of inadequate recruitment of foreign researchers. One of the tools applied in tackling this challenge is the Finland Distinguished Professor programme with which the Academy of Finland and Tekes have sought to attract foreign professors to work in Finland.

Finnish science policy and research funding have been specifically designed to encourage **cooperation**. Especially in the case of international cooperation and intersectoral cooperation it is necessary for each field of science to develop its own solutions. The different needs for cooperation in different fields are generally acknowledged and taken into account in the allocation of funding.

In the future, universities will have to develop and profile their research more closely in relation to sectoral research and business R&D and as part of broader centres of excellence. The growth of competition for resources coupled with increasing cooperation presents a major challenge for research organisations. The review of research activities at government research institutes that will be completed in 2010 is aimed at eliminating overlap, strengthening the core functions of universities and research institutes and at clarifying and improving cooperation between different organisations in the field.

Future cooperation between universities and business companies may be compromised by potential overlap in their division of labour. The increasingly active role adopted by universities in commercialising research may present a new challenge for cooperation. The development of commercial applications is a complex and expensive process. The main challenges are how to align and fit together the different skills and competencies of different organisations and how to create research-driven businesses despite the high costs of patenting and long lead times to product development.

Finland has made a substantial long-term commitment to develop Strategic Centres for Science, Technology and Innovation, which will cover subject areas that are thought to have significant national economic and societal potential. Strategic Centres are business driven, which presents a challenge for universities to contribute to the definition of their research focuses and to install basic research at the heart of their operation. The risk is that Strategic Centres are unable to reform industry branches by means of new frontier research.

2.5 Research output and scientific impact

Qualitative peer evaluations are an integral part of assessing the outputs and impacts of scientific research. The Academy's Research Councils have assessed the research outputs and impacts in their respective fields in separate reviews in Part II of this report. The discussion here looks at the output and impacts of Finnish research based on publication and citation analyses. The bibliometric data, methods and indicators are described in Appendix 2. Humanities and social science research are excluded from the present analysis because the Thomson Reuters data are not comprehensive enough for those fields.

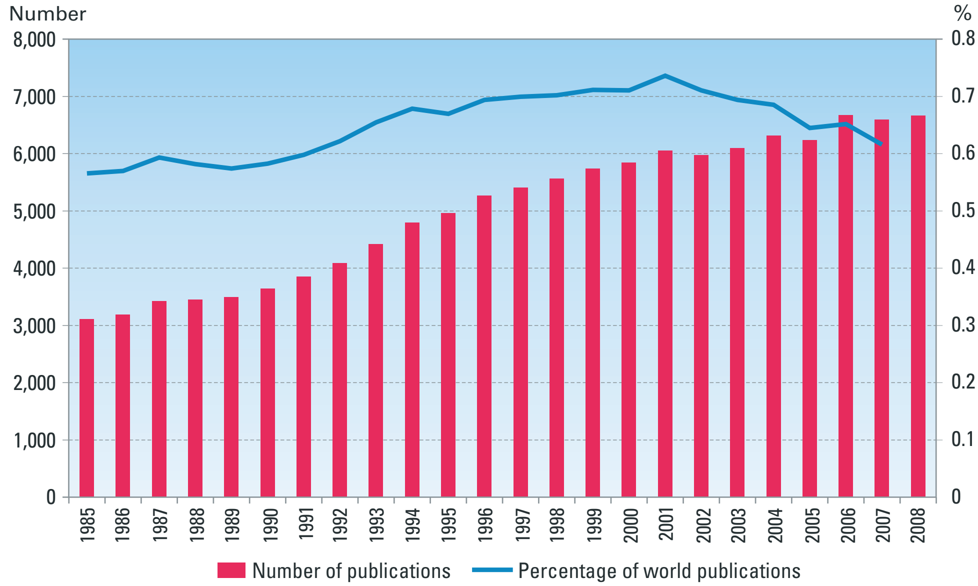

Figure 22. Number of publications from Finland and proportion of world publications in 1985–2008.
Source: Thomson Reuters databases, Swedish Research Council 2009.

Publication and citation analyses of Finnish research[7]

Measured by **the number of scientific publications**, the output of research in Finland increased quite strongly from the mid-1980s through to the 2000s, but this trend came to a halt in the late 2000s (Figure 22). In 2008, Finnish researchers produced 6,660 publications. Over the 20-year period from 1988 to 2008, the number of publications almost doubled. From 1988 to 1998, publication numbers increased by 60 per cent, and from 1998 to 2008 by 19 per cent. Over the past three years the number of publications has declined by 0.2 per cent.

The number of Finnish publications is just over 0.6 per cent of world publications. The growth of Finland's share of world publications turned around in 2001.

Universities account for almost 70 per cent of all scientific publications in Finland, government research institutes for around 17 per cent and private business companies for around 6 per cent. These shares have changed very little since the mid-1990s. (Lehvo & Nuutinen 2006.)

The **relative citation impact**[8] provides a rough measure of the visibility and scientific impact of research. The number of citations received by Finnish publications increased sharply and reached the world average (relative citation impact = 1) in the early 1990s (Figure 23). Finland's relative citation impact peaked at 1.05 during 2000–2002,

7 The data are sourced from Thomson Reuters (Philadelphia, Pennsylvania, USA© Copyright **Thomson Reuters®** 2009. All rights reserved). The methods of data analyses have been developed by the **Swedish Research Council** (e.g. data normalisation by type of publication and field of science, modification of discipline classifications, fractionalisation of publications and citations, and removal of self-citations; for details see Appendix 2 to the report). **The Academy of Finland** has obtained the data used in this report from the Swedish Research Council and produced the Figures and Tables and their analyses on that basis.

8 Finland's relative citation impact ("number of citations") = (number of citations received by Finnish publications/ number of Finnish publications)/ (number of citations received by world publications /number of world publications). The average level for all countries of the world = 1. If Finland's relative citation impact is 1.05, for instance, this means that Finnish publications have received five per cent more citations than world publications on average. See Appendix 2.

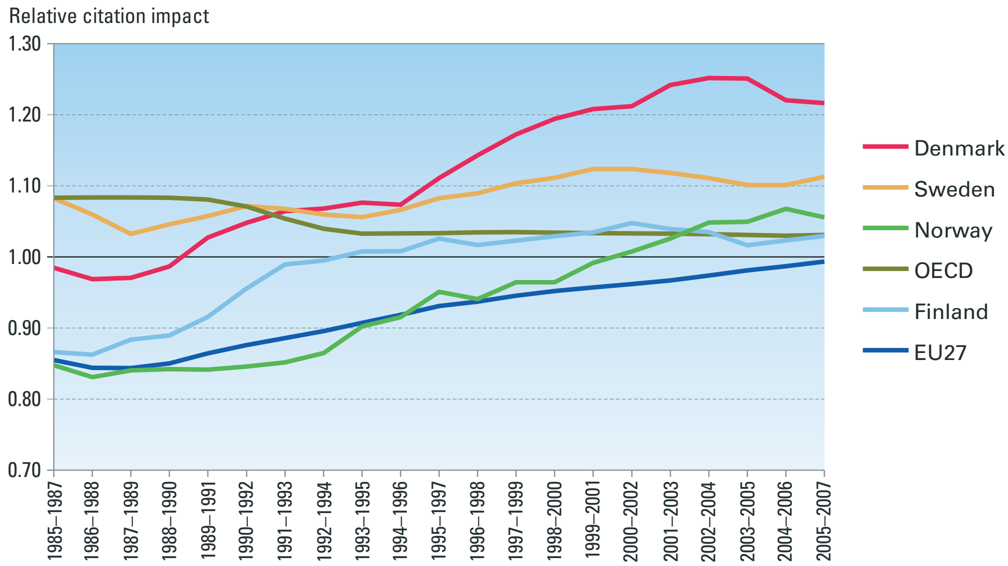

Figure 23. Relative citation impact for Finland and selected Nordic countries, OECD and EU27 countries in 1985–2007. *Source: Thomson Reuters databases, Swedish Research Council 2009.*

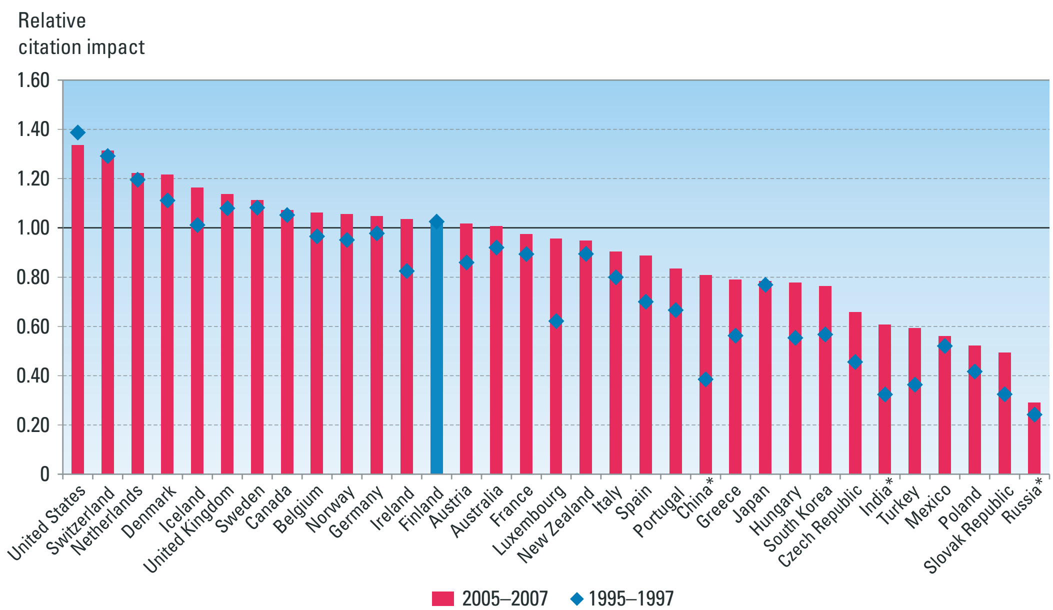

Figure 24. Relative citation impact for OECD countries and India, China and Russia in 1995–1997 and 2005–2007. *Source: Thomson Reuters databases, Swedish Research Council 2009.*

* Non-OECD countries.

when the number of citations received by Finnish publications was 5 per cent higher than the average for world publications. During the 2000s, the number of citations received by Finnish publications has been around 3 per cent higher than the world average. In a Nordic comparison, Finland's and Sweden's relative citation impacts have shown weaker trends in the 2000s than Norway's and Denmark's.

The average relative citation impact for EU27 countries reached the world average during the 2005–2007 period. The trend for OECD countries is declining, and during 2005–2007 OECD publications received three per cent more citations than world publications on average.

Finland's relative citation impact showed no change from 1995–1997 to 2005–2007 (Figure 24). Finnish publications received 3 per cent more citations than world publications on average. In 1995–1997 Finland ranked eighth among OECD countries, in 2005–2007 it was down to 13th place.

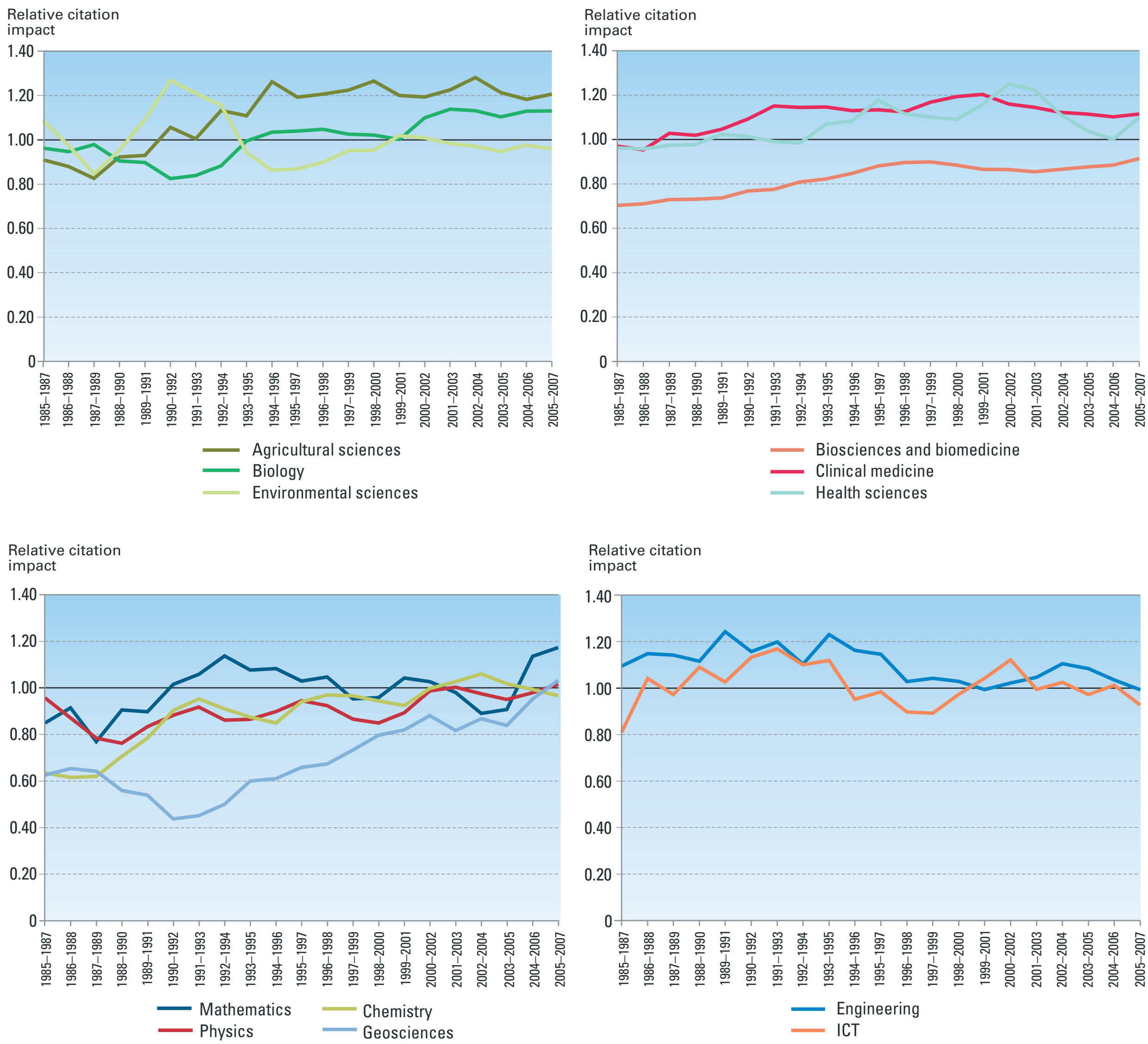

Figure 25. Finland's relative citation impact by field of science in 1985–2007. *Source: Thomson Reuters databases, Swedish Research Council 2009.*

With the exception of Finland and the United States, all other OECD countries recorded an increase in their relative citation impact from 1995–1997 to 2005–2007. The number of citations received by Norwegian publications increased to 6 per cent, taking Norway ahead of Finland. The United States, Switzerland, the Netherlands and Denmark have retained their position at the top of the table.

Figure 25 shows the development of the relative citation impact for different fields of science[9] in Finland. Overall the trends have been increasing, but in some fields the number of citations fall short of the world average (relative citation impact = 1) for 2005–2007.

In 2005–2007, the number of citations received by publications in agricultural sciences was 21 per cent higher and in the biology field 13 per cent higher than the world average. Environmental science publications received 4 per cent more citations than world publications on average.

Clinical medicine publications received 11 per cent more and health science publications 10 per cent more citations than the world average in these fields in 2005–2007. Biosciences and biomedicine publications received nine per cent less citations than world publications on average.

The number of citations received by mathematics publications was 17 per cent higher, by geosciences publications 3 per cent higher and by physics publications 1 per cent higher than the world average for 2005–2007. Chemistry publications received 3 per cent less, engineering publications 2 per cent less and ICT publications 7 per cent less citations that the world average in 2005–2007.

Of all Finnish publications, 8.5 per cent ranked among the top 10 per cent of publications receiving the most citations[10] in 2005–2007 (Figure 26). In 1995–1997, the corresponding proportion was nine per cent. On the OECD ranking, Finland has slipped back from 9th to 12th place. Other countries that have seen a decline in their share of the highly cited 10 per cent of world publications are the United States, Switzerland, Canada, Iceland and Japan.

Among all Finnish publications, 0.7 per cent ranked among the top one per cent of highly cited publications in the world in 2005–2007 (Figure 27). The corresponding proportion in 1995–1997 was 0.8 per cent. Finland's ranking among OECD countries has dropped from 10th to 15th. All the other Nordic countries are now ahead of Finland. Other countries that apart from Finland have seen a decline in their share of highly cited publications are the United States, Canada, New Zealand and Japan.

Figure 28 shows the number of Finnish publications as a proportion of the most-cited publications in the world by field of science. In geosciences 10.6 per cent, in health sciences 10.4 per cent, in clinical medicine 10.2 per cent and in physics 10.0 per cent of Finnish publications counted among the top 10 per cent of most-cited publications in the world in 2005–2007.

In the field of clinical medicine, one per cent of Finnish publications ranked among the top one per cent of most-cited publications in the world in 2005–2007. The next highest proportions were recorded for biology and agricultural sciences at 0.9 per cent; for mathematics and health sciences at 0.8 per cent; and for chemistry, environmental sciences and physics at 0.7 per cent.

9 Fields of science are described in Appendix 2. Citation impacts for research in the humanities and social sciences are not considered in this report. Thomson Reuters datasets provide only a fragmentary picture of developments in these fields, although in Finland the number of international publications produced in the humanities and social sciences has increased significantly.

10 The interest here is to determine the proportion of Finnish publications that ranks among the world's highly cited publications, for instance the top 10 per cent group. See Appendix 2.

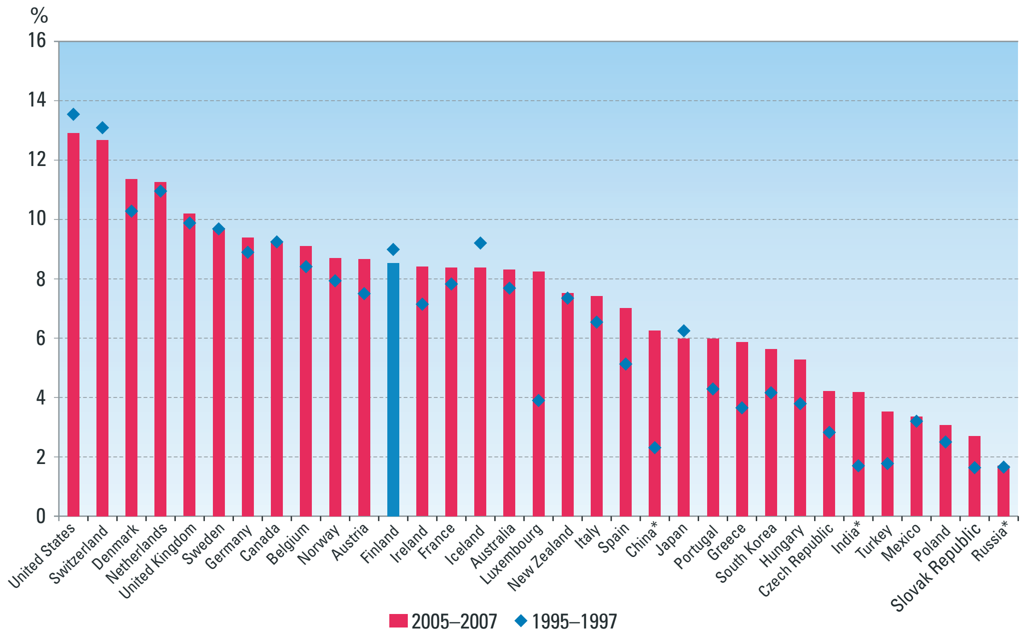

Figure 26. Proportion of publications in OECD countries and in India, China and Russia among the top ten per cent of the highly cited publications in the world in 1995–1997 and 2005–2007.
Source: Thomson Reuters databases, Swedish Research Council 2009.

* Non-OECD countries.

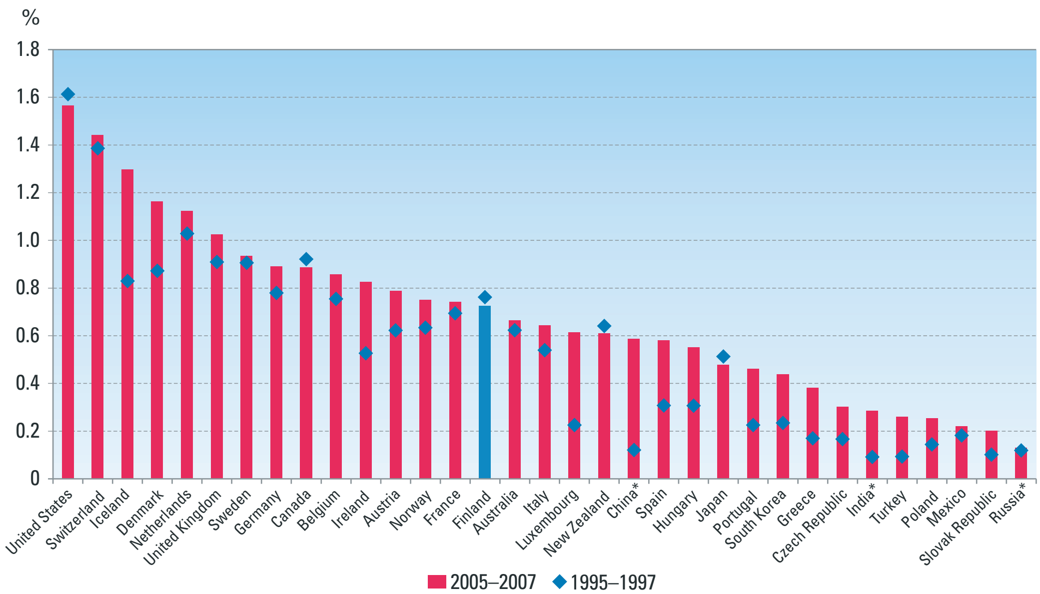

Figure 27. Proportion of publications in OECD countries and in India, China and Russia among the top one per cent of the highly cited publications in the world in 1995–1997 and 2005–2007.
Source: Thomson Reuters databases, Swedish Research Council 2009.

* Non-OECD countries.

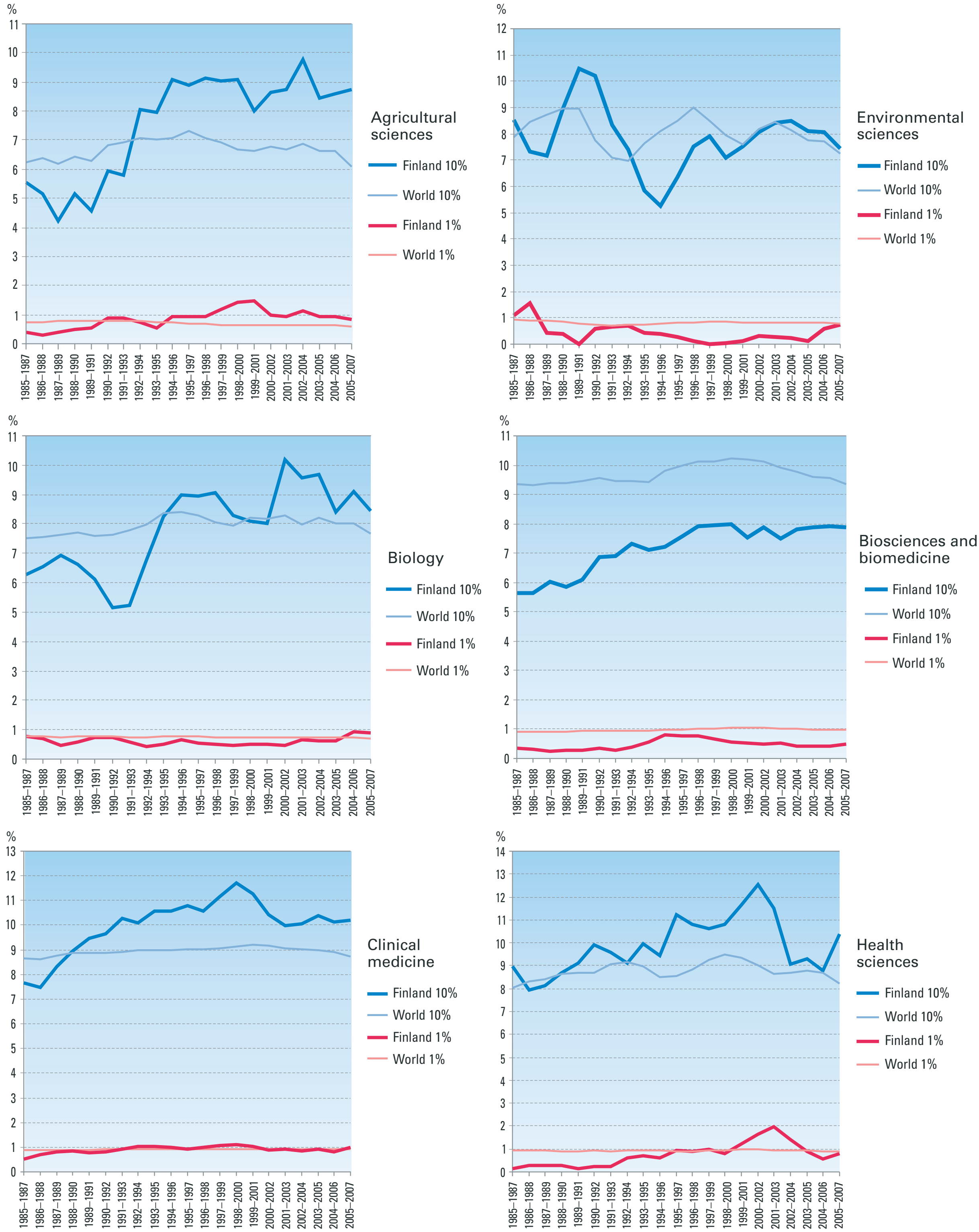

Figure 28. Finland's share of highly cited publications in the world by field of science in 1985–2007.* (See also page 48.)
Source: Thomson Reuters databases, Swedish Research Council 2009.

* Finland's share of each field of science means the share of Finnish publications in each field that rank among the most-cited publications in the world. The Figures describe the top 10 per cent and top 1 per cent of most-cited publications in each field of science. Three-year moving periods.

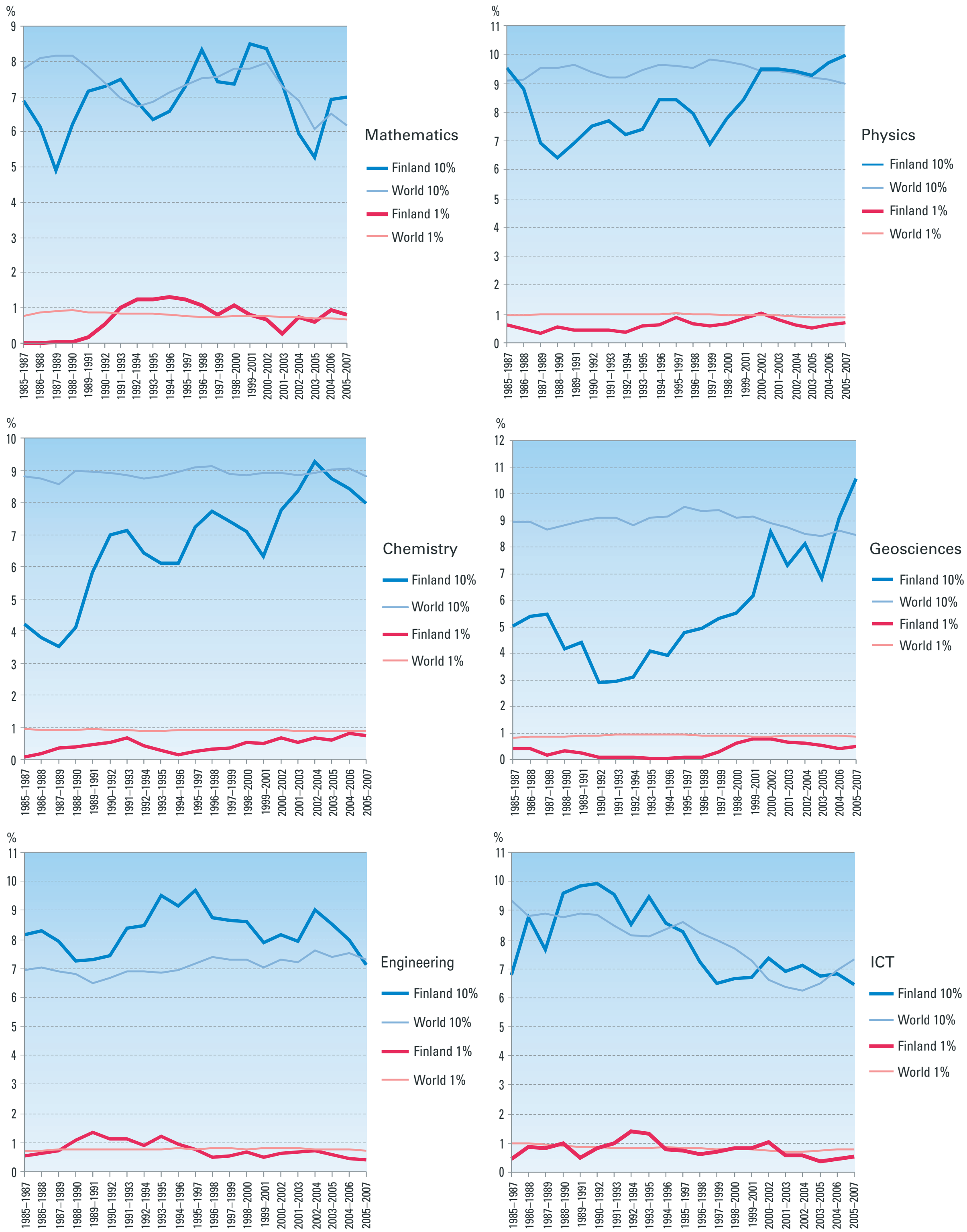

Figure 28. continued from the previous page.

Bibliometrics and world university rankings

It has become fashionable in recent years to rank world universities using various sets of criteria. Bibliometric indicators are a major criterion in virtually all these comparisons. The rankings are usually topped by American and Asian universities, while European universities follow at some distance on account of their internal heterogeneity. Nonetheless, the universities of Oxford and Cambridge, for example, usually rank among the ten best universities. In the Nordic countries the best performer is the University of Copenhagen. The Finnish university that shows up the highest in these rankings is Helsinki, which accounts for one-quarter of all the person-years in research performed at Finnish universities (Table 6).

The European Commission is in the process of developing a new ranking system which uses not

Table 6. Well-known university rankings using bibliometric indicators. *Source: University ranking websites.*

	Rankings of Finnish universities	
Times Higher Education World University Rankings (THE-QS) *Times Higher Education Supplement, United Kingdom*	Top world 500	2008/2005
	University of Helsinki	91/62
	Helsinki University of Technology	211/194
	University of Turku	246/275
	University of Kuopio	313/326
	University of Tampere	336/369
	University of Oulu	372/398
	University of Jyväskylä	391/247
Shanghai Ranking, Academic Ranking of World Universities, *Graduate School of Education, Shanghai Jiao Tong University, China*	Top world 500	2008/2003
	University of Helsinki	68/74
	University of Oulu	303–401/351–400
	Helsinki University of Technology	402–503/
	University of Jyväskylä	402–503/
	University of Kuopio	402–503/451–500
Leiden Ranking, *Centre for Science and Technology Studies, CWTS, Leiden University, The Netherlands*	Top European 250	2008
	University of Helsinki	16
	University of Kuopio	17
	University of Tampere	40
	University of Turku	77
	University of Oulu	102
	University of Jyväskylä	191
	Helsinki University of Technology	204
Ranking Web of World Universities, *Cybermetrics Lab, Consejo Superior de Investigaciones Científicas (CSIC), Spain*	Top world 1000	2009
	University of Helsinki	58
	Tampere University of Technology	236
	University of Oulu	309
	Helsinki University of Technology	320
	University of Tampere	375
	University of Jyväskylä	392
	University of Turku	472
	Åbo Akademi University	666
	University of Joensuu	708
	University of Kuopio	858

only quantitative but also various qualitative criteria. The aim is to develop a multidimensional assessment of universities' achievements that relies on systematic data collection. The first review will be published in 2011.

The main difficulty with these rankings is that it is impossible to find a neutral, value-free way of weighing different indicators. It has been shown that any change in the relative weight of different indicators is immediately reflected in the rankings. Whenever universities are characterised and their relative inputs and outputs are compared, it is necessary to take account of their institutional systems and their inherent multidimensionality. One of the factors impacting university rankings is their discipline makeup: universities that are more heavily oriented to medical and natural sciences are more likely to do well in these comparisons. It has also been shown that publishing in the English language has a direct bearing on ranking outcomes.

Besides rankings also positioning indicators are being developed. They are used to characterise the relative role and position of different stakeholders in the national innovation system. The indicators are designed to describe each individual unit, its distinctive characteristics, interactions, contacts, competition and cooperation (e.g. Bonaccorsi & Daraio 2007).

Conclusions

International comparisons suggest that the visibility and impact of scientific publishing in Finland are on the decline. Finland's rankings in OECD comparisons have dropped from the 1990s to the present day. Finnish publications have not been cited as often as publications from the other Nordic countries, for instance. The gap to Denmark in particular has widened rapidly for more than 10 years now, and Norway overtook Finland in the early 2000s. In Sweden, citation trends have been similar to those seen in Finland, although they remain at a higher level. On this criterion, then, the quality of scientific research in Finland is exactly comparable to the average for OECD countries. Given that around 70 per cent of all Finnish scientific publications are produced at universities, it is clear that any attempt to address the situation must start out by improving the facilities and framework conditions for research at universities.

Bibliometric indicators may serve as a useful tool in comparing the achievements of different research organisations, provided that the comparisons of inputs and outputs also take account of those organisations' institutional characteristics and their inherent multidimensionality.

2.6 Structural reforms of the research system in the late 2000s

Research system

In 2005, the Finnish Government adopted a resolution on the structural development of the public research system with a view to advancing R&D excellence in areas that are most critical to the national economy and general welfare. The resolution was based on assessments and separate reviews commissioned on the public research system. System-level development measures were focused on strengthening functional priorities, the national and international profiling of research organisations and selective decision-making based on foresight. The measures and recommendations were outlined in closer detail in the Science and Technology Policy Council's[11] policy document (Science and Technology Policy Council 2008). Measures have also been implemented to strengthen the role of the Research and Innovation Council as the Government's expert body on national science, technology and innovation policy, and to create stronger links between counselling and decision-making in this area. The Academy of Finland and Tekes are continuing to improve their funding and other cooperation in a bid to increase the impact of research.

A strategy was developed in 2006 for the creation of internationally competitive Strategic Centres for Science, Technology and Innovation. There are now six Strategic Centres in fields that are

11 Renamed as the Research and Innovation Council of Finland as from the beginning of 2009.

thought to be of crucial importance to business and industry and society in general. Significant funding is allocated to these centres.

Finland's R&D structures are currently in a stage of transition. In the higher education sector the overhaul has got off to a strong start on a wide front, whereas in the public sector and government research institutes the process has been slower to take hold.

In universities the reforms are aimed at giving universities the support and tools they need to reform themselves and to respond more quickly to changes in the environment, which is crucial to opening new innovative lines of research inquiry. The new Universities Act (2009) will afford universities greater economic autonomy. At the same time, university management, strategic planning and research administration will be strengthened. Decisions on the allocation of budget funding will increasingly be based on the quality of research and education. Universities will seek to improve their international competitiveness by focusing on and investing in the quality of research, multidisciplinary research and recruiting the best possible research talent. The provision of international education programmes will be increased. Efforts will be stepped up to strengthen the role of polytechnics in the field of applied research.

In line with the Government's 2007 resolution on the development of sectoral research, the Advisory Board for Sectoral Research has put in place the joint ministerial research concept on an experimental basis. In spring 2009 the Finnish Government took the decision to continue the structural reform programme for sectoral research and to invite ministries to submit their own proposals for reform. Based on those proposals, the Research and Innovation Council and the Advisory Board for Sectoral Research will together draft an action programme that will be incorporated as part of the broader programme for the structural development of the public research system. Funding for broad and multidisciplinary research projects shall be increased. The mission and composition of the Advisory Board for Sectoral Research will be updated with a view to providing more comprehensive coverage of the different areas of sectoral research. Furthermore, a survey will be undertaken to identify those aspects of research at government research institutes that are more appropriately delegated to universities. The aim is to remove overlap and to strengthen the core functions of research institutes and universities.

Central government in Finland also has an ongoing productivity programme that applies to all branches of administration and all central government offices and agencies and their personnel. The aim of the programme is to increase the productivity of public services and administration, to curb the growth of expenditure and to improve the efficiency of offices and agencies among other things through staff redundancies. The productivity programme has unequivocal effects on the structures of the research system and cooperation within that system, but as yet it is possible to examine the nature of those effects.

Universities

The role of universities in the research field is changing in Europe. There are five major trends in this development (European Commission 2008b). Most Member States are revising their legislation in order to give greater autonomy to universities. Likewise, Member States are paying more serious attention to the international respect enjoyed by universities and to identifying research excellence. Increased effort has also been invested in enhancing cooperation between industry and academia and in encouraging the choice of academic career paths. Finally, the amount of competitive and results-based funding as a proportion of total research funding has increased. All these trends are in evidence in Finland, too.

In the 1980s and 1990s, Finnish universities expanded and diversified among other things by adopting new fields of study and creating new faculties. A network of polytechnics was established alongside universities. The overriding policy objective in Finland has been to develop the country as an information and technology society, and at the

Table 7. Person-years spent in university research by discipline in 2006. *Sources: Statistics Finland 2008; Unit for Science, Technology and Innovation Studies TaSTI, University of Tampere.*

	Natural sciences	Engineering	Medical sciences	Agricultural sciences	Social sciences	Humanities	All total
University of Helsinki	36	3	29	7	13	12	100
University of Turku	39	2	32	0	19	8	100
Åbo Akademi University	45	20	1	0	24	10	100
University of Oulu	26	39	23	0	8	4	100
University of Tampere	11	0	39	0	40	10	100
University of Jyväskylä	45	1	7	0	35	12	100
University of Vaasa	12	12	0	0	64	12	100
University of Kuopio	34	4	54	1	7	0	100
University of Joensuu	50	0	0	15	24	11	100
University of Lapland	11	2	0	0	77	10	100
University of Technology	28	58	2	0	12	0	100
Lappeenranta University of Technology	13	63	0	0	24	0	100
Tampere University of Technology	33	61	0	0	6	0	100
Helsinki School of Economics	13	0	0	0	84	3	100
Hanken School of Economics	0	0	0	0	93	7	100
Turku School of Economics	1	0	0	0	98	1	100
Sibelius Academy	0	0	0	0	0	100	100
University of Art and Design	0	0	0	0	0	100	100
Theatre Academy Helsinki	0	0	0	0	0	100	100
Finnish Academy of Fine Arts	0	0	0	0	0	100	100

same time the focus of university education has shifted increasingly towards technology and engineering disciplines. In regional policy terms the emphasis has been on the university's role as part of the regional innovation system, whereby the university is seen as having an economically stimulating effect on its local environment.

The research profiles of different universities in Finland can be examined by looking at the relative share of different disciplines as a proportion of total research-years (Table 7). The University of Helsinki accounts for one-quarter of all research-years performed at universities. It recorded the highest number of research-years in all other fields except engineering. Because of the different nature of research in different fields, values within those fields are also different, and that poses a special challenge for university profiling. Interdisciplinary research aimed at collectively resolving science problems can be seen as a counterforce to the traditional discipline structure of academic research, and as a potential future success factor.

According to the international panel of experts who conducted an evaluation of the Finnish innovation system in 2009, key challenges for the development of universities are to raise the quality of research, to promote international engagement and to improve higher education with a view to meeting global and local challenges. Furthermore, steps are needed to improve the dissemination of research from universities to the rest of society. (Evaluation… 2009.) Structural development is one important tool in addressing those challenges.

In 2008, the Ministry of Education drew up a set of guidelines for the structural development of universities in 2008–2011 (Ministry of Education 2008a). This effort is aimed at improving the overall efficiency and quality of universities and at enhancing their impact and international competitiveness in the changing global operating environment. The higher education system shall be further developed in line with the dual model, i.e. on the basis of universities and polytechnics and where necessary consortia of the two.

The future aim is to reduce the number of universities and polytechnics, to develop clearer profiles for them and to have larger unit structures that have greater impact. In addition, universities and polytechnics have formed some strategic alliances primarily on a regional basis. Most of the new university structures will be in place and operational by 2012.

Work will be continued to develop the university curriculum, university degrees and degree programmes with a view to meeting society's needs for education and expertise. However, university structures may vary across different regions. The purpose is to eliminate overlap in education provision, to create more productive and efficient units and to step up cooperation in the provision of auxiliary support services.

In their own strategy work both universities and polytechnics take account of the goals of structural development and the national reviews conducted on specific fields. Based on the universities' new strategies, a new action programme for structural development will be drawn up for 2010–2012.

A university reform is also underway in Finland in a bid to strengthen universities' economic and administrative autonomy. The new Universities Act that lies at the heart of this reform was adopted in Parliament in summer 2009. The new Act repeals and replaces the University Act of 1998, which set out the functions of universities and guaranteed their autonomy and the independence of university research and education.

The aim of the reform is to create better framework conditions for universities in what is an increasingly international operating environment. Ultimately, the purpose is to put universities in a position where they can secure a more diversified funding base, compete for international research funding, cooperate with foreign universities and research institutes, allocate resources to top-level research and their strategic focus areas, and enhance the quality and effectiveness of their research and teaching.

Structural development projects in 2007–2010

- Merger of Helsinki University of Technology, Helsinki School of Economics and University of Art and Design Helsinki into Aalto University
- Merger of the universities of Joensuu and Kuopio into the University of Eastern Finland
- Merger of the University of Turku and the Turku School of Economics
- Tampere University of Technology established in the form of a foundation
- University consortium based on the close cooperation of the University of Lapland and the Rovaniemi Polytechnic and the Kemi-Tornio Polytechnic
- University consortium based on the close cooperation of the Saimaa Polytechnic, Mikkeli Polytechnic, the Kymenlaakso Polytechnic and Lappeenranta University of Technology
- Merger of Helsinki Business Polytechnic and Haaga Institute Polytechnic into HAAGA-HELIA Polytechnic
- Merger of EVTEK Polytechnic and Helsinki Polytechnic Stadia into Metropolia Polytechnic and Yrkeshögskola Sydväst and Svenska yrkeshögskolan into Novia Polytechnic
- Structural development of university libraries to increase cooperation between and reduce the number of libraries
- Joint university information management project

Under the new Universities Act, universities will become independent legal entities and have the choice of becoming either corporations subject to public law or foundations subject to private law. This will give them greater autonomy: universities will take over from central government as employers, they will be better placed to use their return on capital and to obtain additional revenue in the form of donations and bequeaths.

To make good progress in their strategy work it is essential for universities to work closely together and with other stakeholders in their region and in the innovation system. Together, the profiles of universities constitute a national web that covers society's education and research needs. According to the Ministry of Education the profile of each university may give different weight to research, undergraduate education, artistic activities, lifelong learning or innovation and regional activities. Based on their own strategy work universities will submit their own proposals concerning their missions, profiles and areas of focus for the 2010–2012 term.

Conclusions

Major structural reforms have been launched in Finland's public research system with a view to further enhancing the quality of research and development. In the higher education sector the overhaul has got off to a strong start on a wide front. In the public sector and government research institutes, the process has required a redefinition of objectives and measures and therefore has started more slowly. It is impossible to predict all the outcomes and impacts of these reforms, and therefore it is important to monitor the changes and their impacts as they unfold.

The quality of research has not been given sufficient weight in the allocation of budget funding to universities and government research institutes. Rewarding high-quality research is the most important way of encouraging Finnish researchers to participate in international cooperation and attracting foreign researchers into Finland.

There is some ambiguity about the functions and division of labour between universities, polytechnics and government research institutes. Work is continuing to develop the higher education system on the basis of the dual model, i.e. based on universities, polytechnics and new consortia of the two. A survey will be conducted of research conducted at government research institutes to identify those areas that should more appropriately be covered at universities.

It is necessary for universities to have greater autonomy so that the university system as a whole can work more effectively. To build up the necessary critical mass, universities must specialise in their areas of strength. This can best be achieved by providing incentives so that universities can decide for themselves on their specialisation. Changes in universities' institutional behaviour also requires incentives. This will underscore the development challenges facing universities' administrative and management systems.

Universities are currently at a major turning-point in their development, which will inevitably affect the way they profile themselves. In the future the profile of each university may give different weight to research, undergraduate education, artistic activities, lifelong learning or innovation and regional activities. The way that universities decide to profile themselves is influenced not only by ongoing structural development, but also by mounting competition among universities for public funding. This may lead to the development of three different kinds of universities: internationally high-level research universities, nationally significant research universities and provincial universities. The risk involved in this development is that some universities will provide teaching based on set results and textbooks rather than by conducting research. At universities that conduct their own research, students develop critical thinking skills and also learn how new information and knowledge is produced and created.

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3 Finland on the World Map of Science

Of all the institutions of society, science is by nature the most international. The validity of scientific results is entirely independent of the nationality and place of residence of the researchers behind those results. Furthermore, international mobility has been typical for scientists for centuries, and universities have always been keen to attract the best research talent from around the world.

With the changes that have occurred in the past few decades in the environment of scientific research and in the role of research in society, internationalisation has become an important tool of science and technology policy for governments as well.

3.1 Changes in the operating environment

Societies and economies have become ever more knowledge-intensive: a growing proportion of their wealth is spent on research and development and on education. At the same time, the wealth and welfare of nations is increasingly dependent on their investment in R&D and education. Today, 0.5-0.75 percentage points of the potential growth in European economies is attributable to this investment. In the United States, up to 75 per cent of productivity growth over the past 50 years has become through investment in education, research and development (European Commission 2007).

Globalisation has significantly increased the mobility of goods, capital, labour, knowledge, technology and ideas. Advances in information technology have allowed for the rapid dissemination of ideas, information and knowledge around the world and facilitated the creation of global networks of cooperation. All this has changed the scene of international cooperation in science, too. The globalisation of business has greatly boosted the demand for researchers and experts even outside advanced OECD countries, effectively creating a global job market for scientists and researchers. With the continuing ageing of the population in advanced countries, steps are needed to address the labour shortfalls in jobs that require scientific qualifications, including research.

European cooperation is continuing to deepen and expand in the field of scientific research. The strategic development of the European Research Area (ERA) is aiming to take international cooperation to a whole new level. This cooperation will significantly intensify the use of national resources and form an advanced platform for the shared use of mutually complementary skills and competencies.

The main policy tools adopted for this purpose are joint programming, more efficient knowledge sharing and transfer, European infrastructure policy, an internal market for science, and international science and technology cooperation (Green Paper 2007). If the ERA reaches its full potential, it would make Europe the world's most competitive and attractive environment for scientific research and technology development.

3.2 The changing geography of science

In the aftermath of the Second World War, the main locus of scientific research shifted from Britain and Germany across the Atlantic to the United States. The United States has remained the world's leading science power to the present day. However, ongoing processes are now shifting the regional and country balance significantly.

In 1995, the United States accounted for 38.4 per cent of world R&D expenditure; ten years later in 2005, this figures was down to 34.4 per cent. During this same period, Europe's share dropped from 30.8 to 26.7 per cent, while the figure for Asia was up from 23.8 to 31.1 per cent. Although Japan saw a drop of around 3 percentage points, China's share was up from 3.6 to 12.7 per cent and Korea's from 2.9 to 3.5 per cent. The figure for the whole of Africa is just 0.6 per cent, which is smaller than Finland's contribution. Asia is now emerging as the world's leading R&D centre (European Commission 2007). If the focus is narrowed to investment in civilian research, the United States' share has dropped significantly since 2001, whereas countries like Germany and Canada have caught up with the United States in terms of research intensity.

Europe's changing position is explained by the low level of business investment in R&D, which in Asian countries is very strong. These trends are accentuated further if we look at the number of degrees awarded and the number of researchers in the different regions and countries. The number of researchers in the United States is roughly the same as in EU27 countries, but the composition of research staff is entirely different. Whereas in Europe no more than 3–4 per cent of university students come from foreign countries, and half of those students are from other EU countries, the figure in the United States is 30 per cent. The proportion of foreign nationals among science and engineering PhDs is greater still at over 40 per cent. By far the largest number of them come from Asia. The United States has managed to retain its lead in some key areas of science and technology by relying on foreign labour. The US National Science Board (2008) expects to see the number of students completing a science and engineering degree triple over the period from 2012 to 2020. Given the current lower level of immigration in the United States, the lack of interest shown by young native Americans in science and the mass retirement of the baby boom generation, it is thought that the United States may well be faced with a shortage of researchers in the next few years ahead (European Commission 2007).

At the same time, Asian countries – which have seen a substantial outflow of researchers to Germany, the UK and other European countries but above all to the United States – are pouring unprecedented levels of investment in scientific education, science and research infrastructures. The number of undergraduate degrees completed in China has already exceeded the figures for the United States, and the number of Chinese PhDs awarded will overtake the United States by around 2010. Ever fewer of the PhD graduates are moving to the United States and Europe, and at the same time the demand for foreign scientists is growing.

In conclusion then, competition for scientists and the best research talent in particular is continuing to escalate around the world. The structures of researcher mobility are changing profoundly.

Indicators of publishing and the scientific impact of publications provide a useful insight into the relative position of different regions and countries on the world map of science. From 1995 to 2005, Europe has gained competitiveness vis-à-vis the United States as the world's major producer of peer-reviewed articles (the EU growth rate is around 25% compared to 10% for the United States). However, the most significant structural change is that the overall shares for Europe and the United States have fallen (they now stand at around 38% and 32%), whereas Asia's share has increased from around 18 to 26 per cent (National Science Board 2008, European Commission 2007). Scientific publishing has increased most sharply in China, Korea, India, Brazil and Taiwan.

Comparisons of the impact of scientific papers show that the United States continued to remain almost in a class of its own. It has retained its strong lead for a very long time; the only country that comes even close is Switzerland. The difference to other regions is particularly clear in an examination of the proportion of American publications among the world's most-cited 10 per cent or one per cent of publications. It is even more apparent when we look at the citation statistics for the world's top publishing universities. Among the top 25 universities receiving the most citations, all are American, and among the 76 universities that had a relative citation impact of over 1.5, 67 were American, eight European, and one Asian (European Commission 2007).

Compared to the world average, the United States has sustained a high level of scientific excellence for decades. In the past 20 years, many countries have managed to enhance the scientific impact of their research considerably in relation to the world average and in OECD comparisons have been closing the gap to the United States. These countries include Canada and Australia as well as small EU countries such as the Netherlands, Denmark, Sweden and Finland.

3.3 Science policy takes on the challenges of internationalisation

In today's world of globalising science and technology, governments are seeking to meet the challenges of internationalisation by shifting their policy emphases and by adopting new policy instruments. These can be roughly divided into four groups:

- Internationalisation with a view to promoting excellence
- Increasing the attractiveness of the research system
- Strengthening international research cooperation
- Developing mobility

These policy orientations and instruments are understood as responses to accelerating global competition in research and innovation. The choice of policy tools varies markedly between advanced research systems (e.g. Canada, Sweden and Finland) and low research intensity countries aiming to catch up (e.g. Greece, Portugal and Turkey).

Quality enhancement is a common shared objective in many national science and innovation policy programmes and measures aimed at promoting internationalisation. Examples include Canada, Germany, Norway and Spain (OECD 2008a).

There are various ways in which to enhance the attractiveness of the national research and innovation system. Support for direct investment in R&D (tax reliefs, availability of skilled and competent researchers, availability of high-level infrastructures and direct financial subsidies) is typical of Ireland and Hungary, for example. Research infrastructures have decisive significance in many fields. The absence of high-quality infrastructures invariably makes it harder and often impossible to attract direct foreign investment and the best talent. In many fields infrastructures are the main foundation for creative research environments.

In recent years many countries have worked to enhance the appeal of their national research system by means of structural reforms. Most typically, these have involved the structural development of the university system and the establishment of Centres of Excellence in research and various types of national and strategic clusters and centres by means of public and private funding. EU funding is largely dedicated to making Europe the world's most attractive research area.

International research cooperation, particularly in the form of joint programming, has increased very rapidly. For instance, the most important instruments identified by the German government in its Internationalisation Strategy (OECD 2008a) are to cooperate with global pioneers, to intensify cooperation with developing countries in education, research and development, and to engage in international research and innovation cooperation in responding to global challenges (climate change, natural resources, health, security and migration). Cooperation with emerging science powers (China, India, Brazil and Russia) is usually based on joint research programmes; this is also the route chosen by Finland. There is also an increasingly strong regional element in cooperation. Japan, China and Korea organised their first high-level meeting aimed at strengthening science and technology cooperation in 2008. Within the ERA, there is some movement towards closer regional cooperation among the Nordic countries (NordForsk), on the Iberian Peninsula and under Austrian leadership in Eastern Central Europe.

As research and innovation continue to become more internationalised, so it becomes increasingly important to establish links with other countries' information sources that are most crucial to one's own national research system. This has led to the creation of networks of international innovation centres that are based in partners countries that in each case are considered most important. Denmark and Finland are good example. The Finnish FinNode network has offices in Japan, the United States, Russia and China, and a new office is being opened in India. Jointly administered by the Academy of Finland, Tekes, VTT Finland, the Finnish Innovation Fund, Finpro and the Ministry for Foreign Affairs, FinNode serves as a network of outposts for the Finnish research and innovation system.

Measures designed to promote researcher mobility are among the most important instruments in the ERA toolbox. Many countries have followed the example set by Canada that has launched a dedicated programme to facilitate the immigration of international-level researchers. Finland's FiDiPro programme is a case in point. Some countries have formulated their own mobility strategies in a bid to respond to the global competition for talent (OECD 2008b). The UK and Japan have the most advanced strategies, and Canada has made most headway in putting its mobility instruments to use. Within the context of the ERA project, the EU mobility strategy provides a framework for the development of national strategies by EU Member States.

3.4 The internationalisation of Finnish science

For reasons that have to do with the small size of Finland's national research system and its earlier tendency of inwardness, Finnish science policy has for decades underscored the importance of international engagement in science and research. The OECD has drawn attention to what is described as the Finnish paradox: whereas business and industry in Finland is highly internationalised, business sector R&D, funding for R&D and the whole national research system are distinctly national in nature and orientation (OECD 2008a). In view of its overall resources and general development, the Finnish research system remains exceptionally immature in terms of its internationalisation.

Among researchers, there is broad recognition and acceptance of the importance of international engagement. More than 90 per cent of the heads of university departments believe that research cooperation contributes to enhancing the quality of research (Hakala et al. 2003). Although research excellence does not by definition require international exchange and cooperation, in practice this link is very strong indeed.

The following discusses the internationalisation of science and research in Finland from three points of view (Ahonen et al. 2009):

- Foreign funding
- Mobility and networking
- International scientific publishing and co-publishing

Foreign funding

Researchers and research teams aim to secure the funding they need from different sources, based among other things on their research strategies and needs. International funding is an indication of

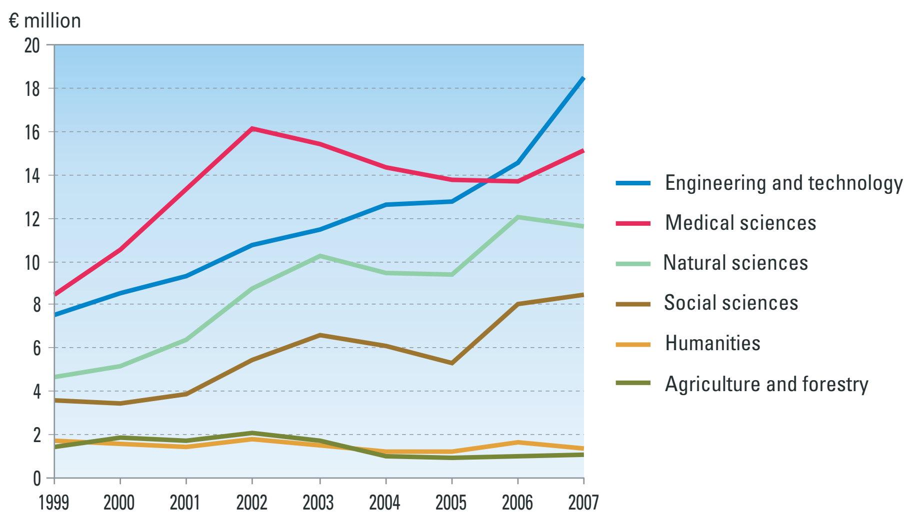

Figure 1. Foreign funding for university research* by field of science in 1999–2007.
Source: Kota database, Ministry of Education.

* Includes funding from EU sources, foreign businesses and other foreign funding.

ongoing international research cooperation or the start-up of a joint international project. Furthermore, primarily in the case of funding received from the business sector, it may mean that the information and knowledge produced has potential applicability.

In 2007 engineering fields received the most foreign funding at close to 18.5 million euros (Figure 1). The sharpest growth in foreign funding from 1999 to 2007 is recorded for the natural sciences at 150 per cent. Engineering fields and social sciences have also seen a sharp increase in the amount of foreign funding.

The EU is by far the most important source of external funding: in engineering it accounts for more than 90 per cent, in the natural sciences and social sciences for 85–90 per cent. The most noteworthy exception is the field of medical sciences, where EU funding accounts for around 45 per cent and foreign business funding for just over 30 per cent of total funding.

Mobility and networking

The development of a global job market for researchers has led to a sharp increase in the international mobility of students, researchers and other professionals with a science degree.

A good indication of the level and openness of each country's research system is provided by the extent to which the country attracts foreign students and researchers and on the other hand by the extent to which researchers from the country have the opportunity to work in high-level research units abroad.

Mobility – as indeed international cooperation more generally – is particularly important to small countries in that it brings diversity and new knowledge into the national research system. It is a key factor in developing creative research environments, in promoting research careers and in building networks.

In 2006, no more than 3 per cent of the country's research personnel were foreign-born, compared to the 10 per cent average for EU27 and more than 10 per cent in countries that in many respects are closely similar to Finland: Ireland, Sweden, Austria and the Netherlands (Figure 2). Finnish researchers work abroad significantly more often, although that too is at a rather low level compared to other similar countries.

The largest number of visits was made in the engineering field, where the figures grew throughout the period under review (Figure 3). This is explained entirely by the visits of foreign

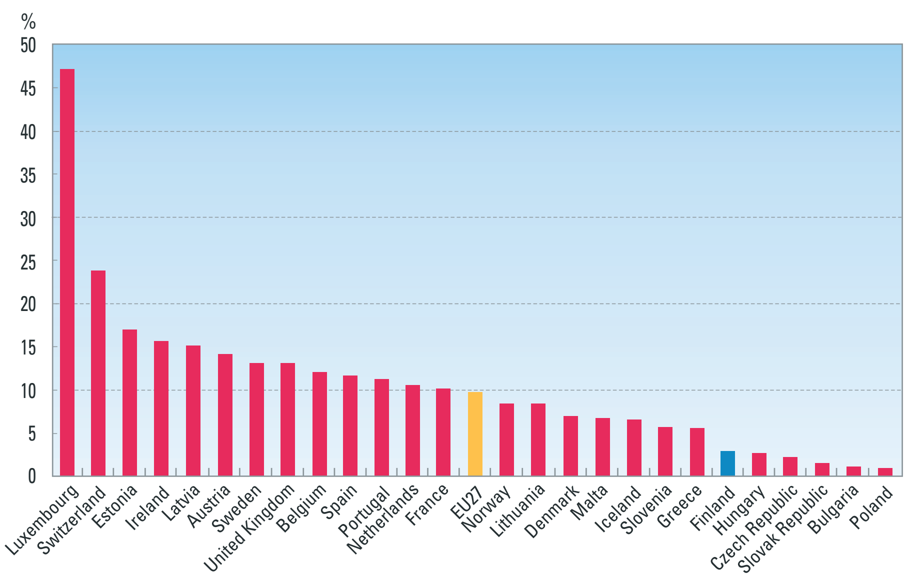

Figure 2. Foreign-born nationals as a proportion of R&D personnel aged 25–64 in EU27 and selected countries in 2006. *Source: OECD 2008d.*

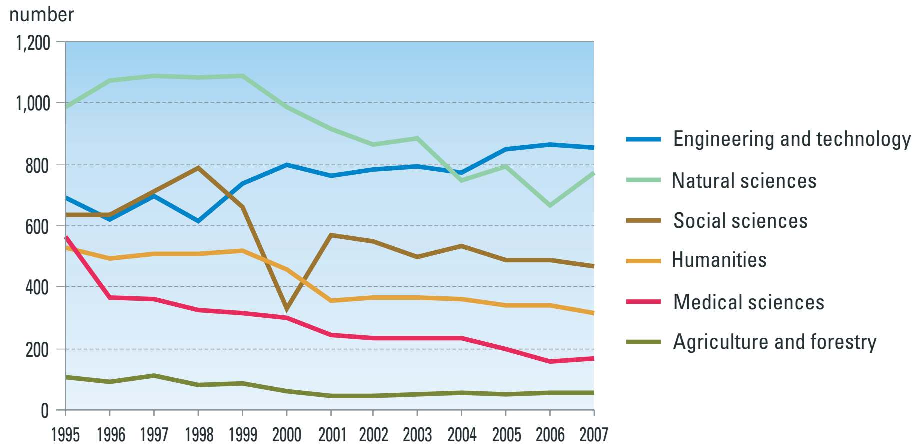

Figure 3. International university teacher and researcher visits in 1995–2007.
Source: Kota database, Ministry of Education.

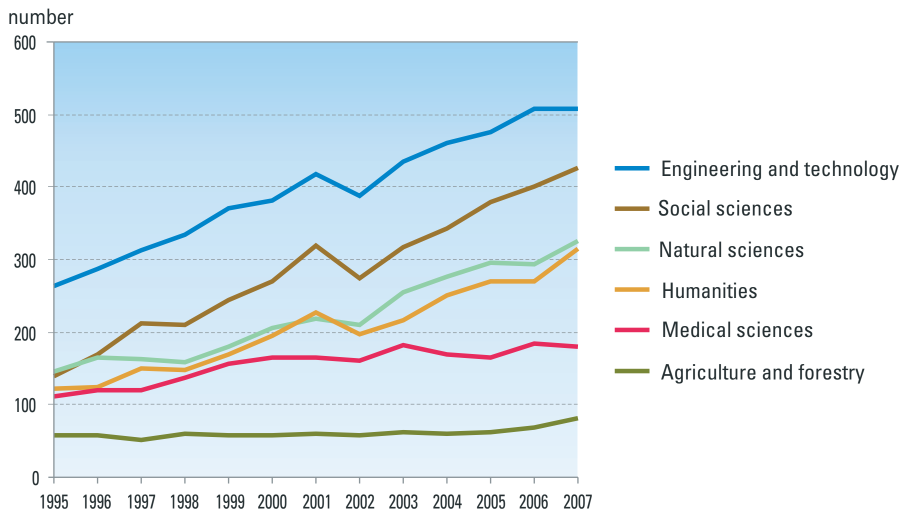

Figure 4. Foreign postgraduate students at Finnish universities in 1995–2007.
Source: Kota database, Ministry of Education.

researchers to Finnish universities (Ahonen et al. 2009). This Figure illustrates how visits in different disciplines have increased, in some instances very sharply, up to the mid-1990s, and since then begun to plateau and decline. In medical sciences and agriculture and forestry, the number of visits in 2007 is at a markedly lower level than in 1990.

The number of foreign postgraduate students has increased in all disciplines in 1991–2007 (Figure 4). In the humanities, natural sciences and social sciences, the numbers have more than quadrupled, in engineering approximately tripled. Agricultural sciences and medical sciences show only moderate increases in the 2000s.

No detailed information is available on the time spent by Finnish postgraduate students in other countries. Experiences and data collected from funding agencies (including the Academy of Finland) and doctoral students themselves indicate that studying abroad has decreased significantly since the early 2000s, following a period of relatively strong growth since the early 1980s.

International scientific publishing and co-publishing

The publication of research results and the peer review system has been and will continue to remain one of the major foundations of science and research. International publishing is the most visible output and demonstration of a genuinely international scientific research endeavour. The diversification of information sources and knowledge sharing seems to be particularly important in such multidisciplinary frontier fields as nanosciences and biosciences (OECD 2007).

As late as the mid-1980s international co-publishing was still relatively rare in natural sciences: no more than around seven per cent of all publications in this field were the outcome of international collaboration. The proportion of co-publications tripled by 2005 (OECD 2007). There are very marked country differences: in France, Germany, the UK and in Canada, 40–50 per cent of all science papers in 2005 were international co-publications, while the figures for the United States and Asia are much lower. In a comparison that covers all fields of research, the number of international co-publications as a proportion of all publications in the Nordic countries has increased (Figure 5).

The significance of EU cooperation is very clearly in evidence in Finnish researchers' international co-publications in all fields. From 1995 to 2004, international co-publications with EU25 researchers increased by 85 per cent, standing at 55 per cent of all co-publications, while the corresponding figure for co-publications with colleagues from the United States was only 14 per cent (Lehvo & Nuutinen, 2006). During the same period the number of co-publications in the natural sciences and medical sciences doubled with many European science countries, while with the United States the figures were up by 35–40 per cent. Science cooperation with European colleagues, and Nordic colleagues in particular, has played a very important part in Finnish researchers' international co-publications (see Figure 6).

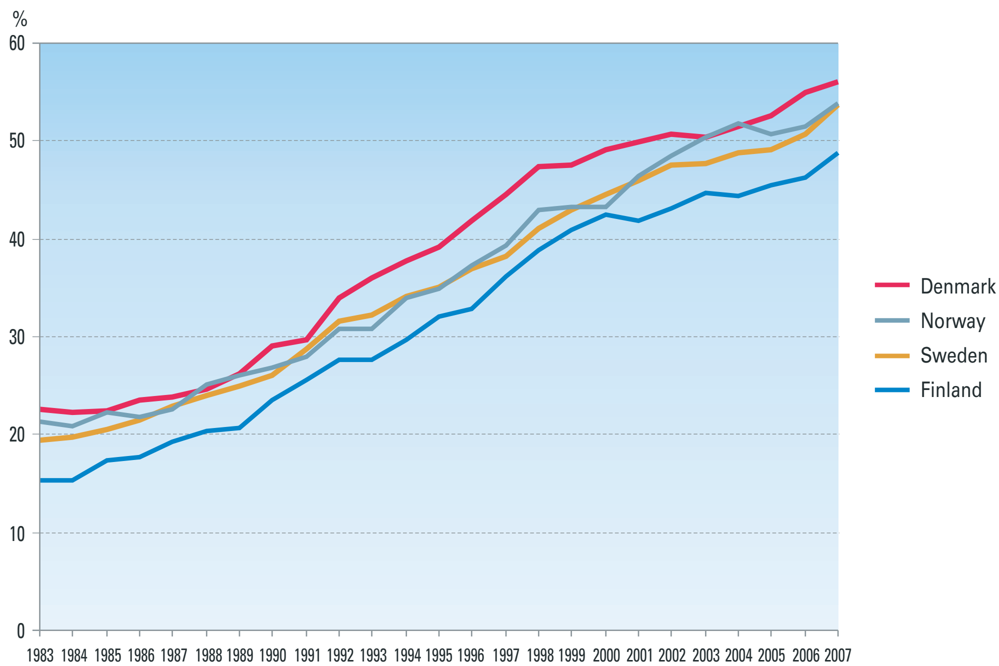

Figure 5. International co-publications in Finland and the other Nordic countries as a proportion of all international publications in 1983–2007. *Sources: Thomson Reuters databases; Swedish Research Council 2009; see also International Research Cooperation in the Nordic Countries. Report 2 from NORIA-net Nordic Bibliometrics Network (in print).*

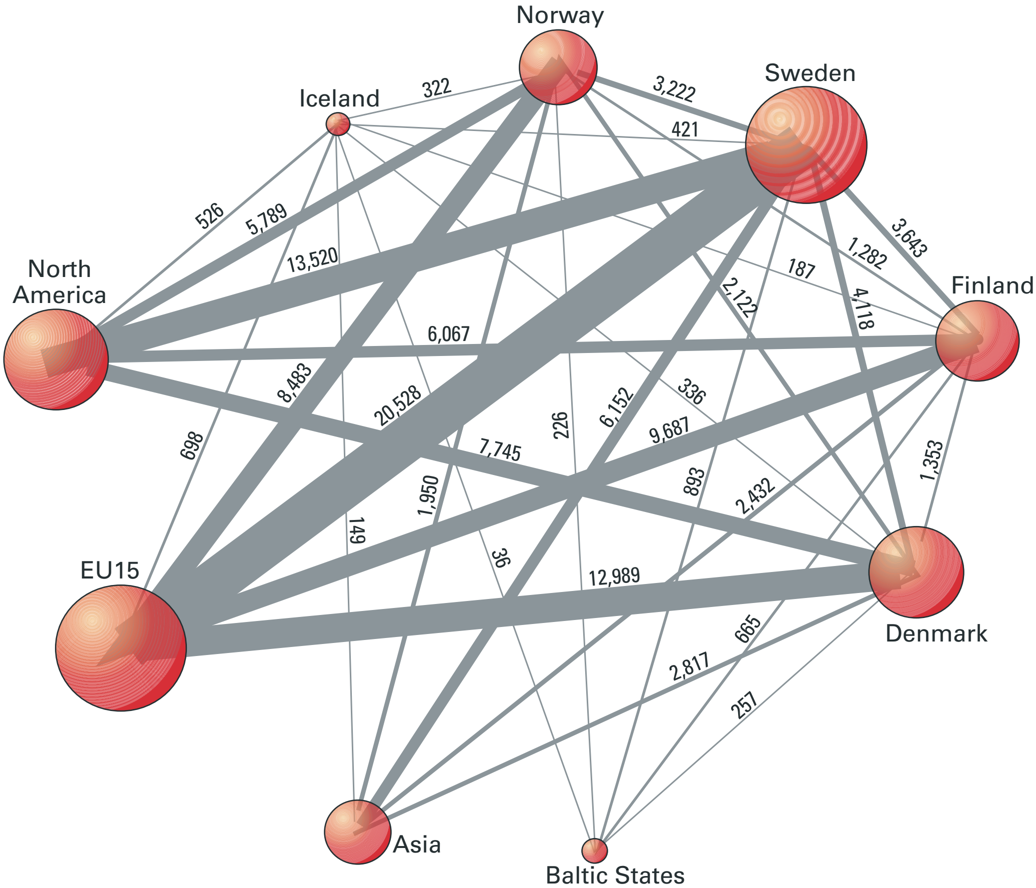

Figure 6. Number of Nordic co-publications during 2003–2007. Data processed using Pajek and Inkscape software.
Sources: Thomson Reuters databases; Swedish Research Council 2009; International Research Cooperation in the Nordic Countries. Report 2 from NORIA-net Nordic Bibliometrics Network (in print).

3.5 Finnish participation in European cooperation

As has been discussed above, Finland's membership of the European Union and the access that this provided to European funding instruments contributed significantly to the internationalisation of Finnish research. Figure 7 shows the frequency of European participations in coordinated funding instruments over the past few years.

The frequency of participation is highest in the smaller countries and in Eastern and Southern European countries. Finland, Sweden and Denmark are clear exceptions to this pattern: participations here are at a low level even though they are all small, research-intensive countries. Finland's relatively low level of participation in EU Framework Programmes for Research is particularly noteworthy.

Looking at the funding situation for FP7 (2007–2013) at year-end 2008, we find that Finland ranked 11th among the EU27 countries in terms of funding agreed and 9th in terms of framework programme success rate.

In the European Research Council's first two calls in 2007 (starting researchers) and 2008 (advanced investigators), Finland had better than average success with nine successful applications in both cases. Relative to national R&D investment, Finland is the most successful of all Nordic

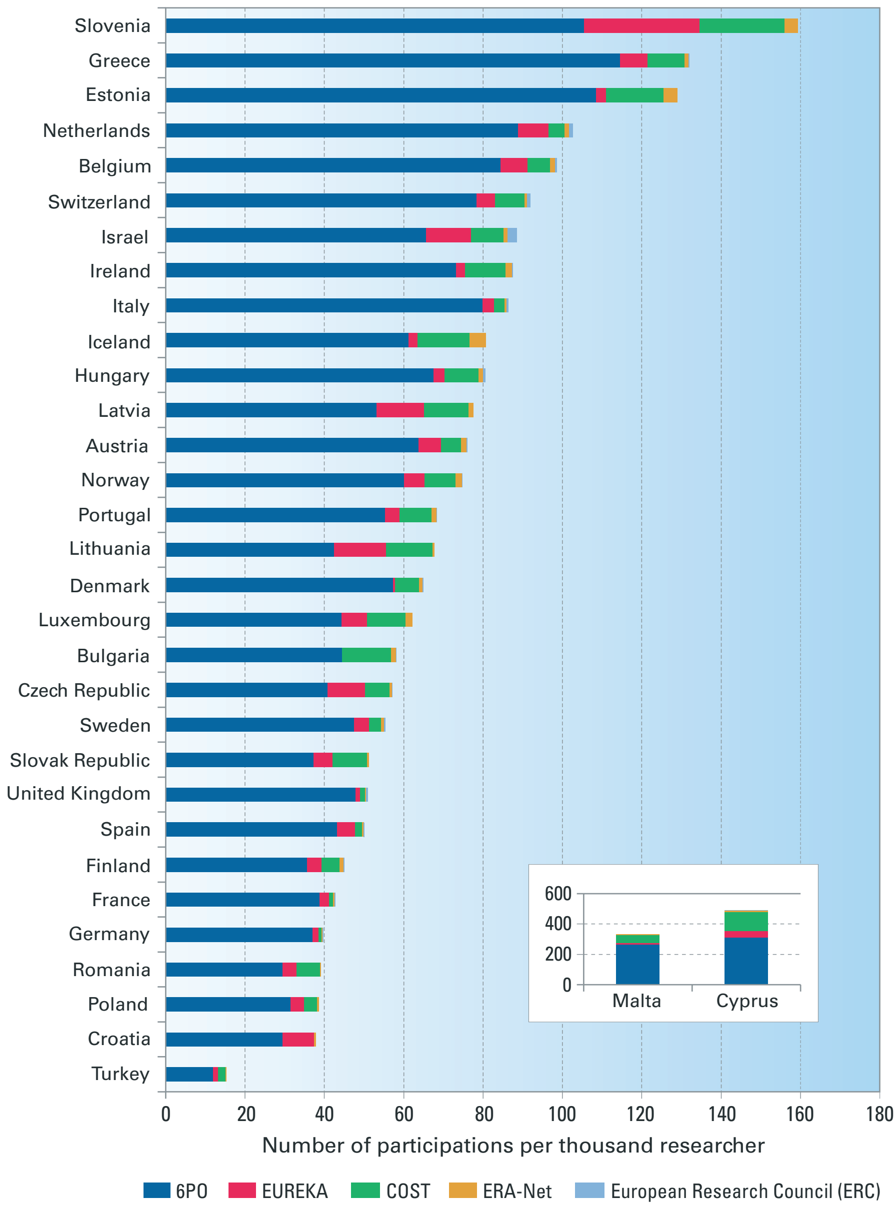

Figure 7. Participation in EU programmes (participations per thousand researchers).
Source: European Commission 2008.

countries (with the exception of Iceland in the case of advanced investigators: one Icelandic researcher received an Advanced Investigator Grant, but is not working in Iceland).

Measured in terms of network contacts, Finland is located outside the centre but not in the periphery, which is occupied by Eastern and Southern European countries. The most important networks are located within the triangle formed by the UK, Sweden and Austria, i.e. also including Germany, Denmark and the Netherlands (for the university situation, see European Commission 2008, pp. 99–100).

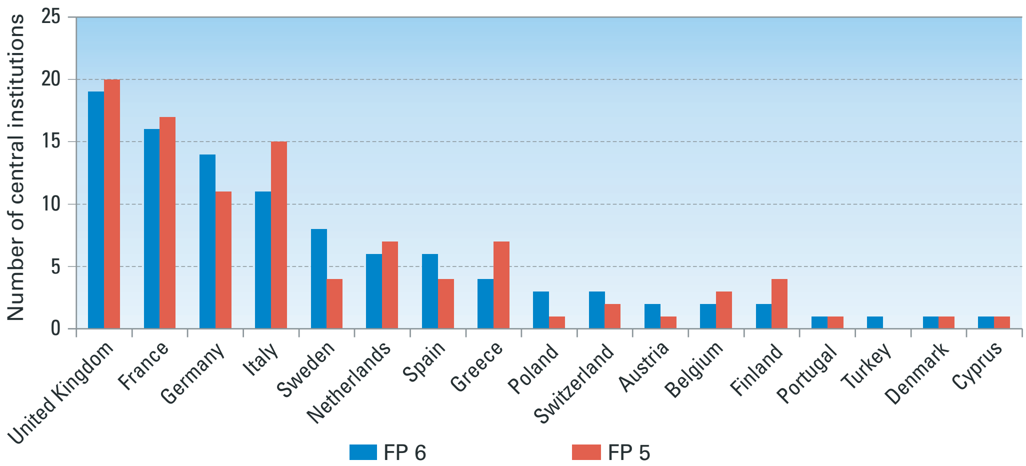

Figure 8. Distribution by country of the 100 most central organisations in FP5 and FP6.
Source: European Commission 2008.

For the organisations involved in EU Framework Programmes, these provide first and foremost an opportunity for networking. From a networking point of view the organisation is important if it has a central role in the network. That is determined on the basis of the number of projects in which the organisation is involved and the relative position of partner organisations in their own networks.

The participation of EU countries in FP5 and FP6 can be assessed by reference to the number of participating organisations that have a central role in those programmes. Figure 8 shows the country breakdown for the 100 most central organisations. Finland had two organisations among the 100 most central FP6 organisations.

The drivers of international cooperation in the humanities and social sciences are somewhat different from those of cooperation in the natural sciences, for example. Their research interests are more often national by nature, and because of their role in driving national socio-cultural development, they publish more often in national languages.

From this vantage-point it is interesting to study European research cooperation in these fields and Finland's role in that cooperation in the light of publishing data (Gingras & Heilbron 2009). This examination shows that European cooperation with Asian and Australian partners has been increasing, whereas cooperation with North America is on the decline. Over 80 per cent of EU cooperation takes place between the big four in these fields (UK, Germany, Netherlands and France, in this order). Together with Spain, Sweden and Norway, Finland is one of the countries that has greatly strengthened its position in European publishing cooperation.

European cooperation by Finnish researchers in the humanities and social sciences has diversified enormously over the past 15 years. In 1980–1993, Finnish researchers published more than 25 articles in collaboration with Swedish and British colleagues. An examination of European publishing cooperation (more than 50 publications) in 1994–2006 showed that in addition to Sweden and the UK, Finnish researchers also collaborated with colleagues from Denmark, Norway, Switzerland, Spain, France, Italy, Germany and the Netherlands (Gingras & Heilbron 2009).

3.6 Indicators of internationalisation

The indicators available for the measurement of internationalisation in Finland are relatively crude. This has caused some divergence of opinion and complicated the task of monitoring the extent, avenues and level of internationalisation in the Finnish research system, and by the same token hampered science policy planning. The Academy has recently commissioned a study (Ahonen et al. 2009) to identify possible indicators for these purposes.

Indicators of internationalisation can be divided into four thematic groups:

- Internationalisation of scientific publishing
- International mobility and visits
- International science funding
- Other international networking

It is important that the indicators chosen for the examination of publishing, international funding or international contacts or networking, for instance, also allow for an analysis of the quality of research.

Useful indicators of the output and extent of scientific activity include the number of Finnish publications in international series, conference proceedings and the number of articles co-authored with colleagues from other countries. One relative quality indicator for comparisons with a relevant reference group is the number of citations received by Finnish publications as a ratio to the average for all OECD countries.

Finland's scientific appeal is described by the number of one-month or longer visits to Finland by foreign senior researchers and by the number of foreign professors and postgraduate students in Finland. One-month or longer visits to other countries by Finnish senior researchers also describe the internationalisation of Finnish research.

The number of international co-funded scientific projects describes global networking, while the amount of EU Framework Programme funding describes the European networking of Finnish research. The quality of Finnish research is described by the amount of foreign competitive funding available for basic research in Finnish organisations. The number of foreign reviewers of doctoral theses could provide an important measure of international networking in certain fields.

3.7 Future changes in internationalisation

The landscape of international engagement in science and research is quite different today compared to the situation just 15 years ago. Existing economic and political structures provide support and encouragement for internationalisation, and the funding available has accordingly increased several times over. In the allocation of research funding, precedence is given to internationally merited researchers. International engagement is a natural part of the research profession from the very earliest stages. The emphasis in research funding has accordingly shifted increasingly from individual instruments towards structural measures to promote internationalisation.

Within the research community itself, internationalisation is increasingly recognized as a fundamental research tool. The needs in different fields of science are continuing to diversify, but in virtually all fields networking within science communities is continuing to gain in importance: this is seen as a crucial way of securing access to sources of information and a method of distributing knowledge. The role of tacit knowledge is also keenly recognized: that increases researchers' prospects of getting the funding they need as that is more and more often provided through programmes.

A growing science policy concern for countries and science institutions is to increase their international appeal. Immigration policy is continuing to gain in importance as it has to cut across various administrative branches for reasons of harmonisation. Researcher mobility is facilitated and mobility strategies are developed in several countries as the global demand for high-level researchers continues to rise. The EU is set to gain a stronger role in determining the rules of the game as well as in funding.

The availability and level of research infrastructures are increasingly important to the appeal of different countries and institutions. International cooperation in the development and use of infrastructures is set to increase. Countries and different groups of countries will work more closely with one another in developing infrastructure policy. The most significant trends from a Finnish point of view are the intensification of European Union cooperation and Nordic collaboration.

Research programmes based on international cooperation are set to gain an increasingly prominent role. The role of research and university cooperation in development policy will continue to grow, particularly at EU level and in EU Member States. Global and regional cooperation in research concerned with common global challenges, such as climate change, the environment, energy, population movements, health and security, will gather momentum especially as the United States returns actively to the international science and technology policy scene. BRIC countries (Brazil, Russia, India and China) will continue to strengthen their presence in international research cooperation and in science and technology in general.

3.8 Conclusions

R&D investment in the United States and Europe has been declining as a proportion of total world investment, whereas figures for Asian countries and China in particular have risen sharply. The number of undergraduate degrees in China has already exceeded and the number of doctorates is about to exceed the figures for the United States. In the United States the offspring of science is heavily dependent on Asian students in particular, and there is also substantial demand in Europe. It is expected that the number of Asian students moving to the United States will continue to fall, at the same time as the demand for researchers in the US is set to rise sharply over the next decade. In the current global labour market, competition for the best expertise is continuing to grow and patterns of researcher mobility are changing considerably. Increasing effort is devoted to making national research systems more attractive.

In terms of scientific impact the United States continues to remain strong and almost in a class of its own; the only country that comes even close is Switzerland. However, in the past 20 years many other countries, particularly Australia and Canada as well as the Netherlands, Denmark, Sweden and Finland, have been closing the gap to the United States.

Governments are seeking to meet the challenges of internationalisation by shifting their policy emphases and by adopting new policy instruments. The most important measures are the promotion of scientific excellence, increasing the appeal of the research system, strengthening international research cooperation and developing mobility.

In view of its resources and overall level of development, the Finnish research system remains exceptionally immature in terms of its internationalisation. Internationalisation is examined from three perspectives: foreign funding, mobility and networking, and scientific publishing.

The European Union is by far the most important source of external funding. In engineering it accounts for more than 90 per cent, in the natural sciences and social sciences for 85–90 per cent.

Mobility, and international cooperation in general, is particularly important to small countries like Finland. In 2006, no more than 3 per cent of the country's research personnel were foreign-born, compared to the 10 per cent average for EU27 and more than 10 per cent in countries that in many respects are closely similar to Finland: Ireland, Sweden, Austria and the Netherlands. International teacher and researcher exchange between universities increased throughout the 1990s, but since the turn of the decade it has continued to decrease.

The number of foreign postgraduate students has increased steadily over the past 15 years. No detailed information is available on periods spent abroad by Finnish postgraduate students, but experiences and data collected from funding agencies and doctoral students indicate that studying abroad has decreased significantly since the early 2000s.

The significance of EU cooperation is clearly reflected in Finnish researchers' co-publications. Co-publications with EU25 researchers account for 55 per cent of all co-publications, compared to just 14 per cent for co-publications with colleagues from the United States.

EU cooperation has huge significance in all fields of science. It has greatly diversified the range of partner countries for Finnish researchers. From this point of view it is noteworthy that Finnish participations in EU coordinated programmes (e.g. Framework Programmes and COST) is at a very low level when compared to the number of researchers in Finland and to other EU countries.

Indicators of internationalisation in Finland are relatively crude, which effectively hampers monitoring and science policy planning. The Academy has commissioned a survey of these indicators, which are divided into four groups: internationalisation of scientific publishing, international mobility and visits, international science funding, and other international networking.

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4 Science in Society

The role of science in society has changed and strengthened essentially over the past decades. A significant number of countries around the world have adopted knowledge-based strategies for economic development. In these countries economic growth and productivity are increasingly dependent on high-level education and science and on the development of new technologies and their innovative application. In international competitiveness comparisons, Finland's key strengths include its excellent education system, its highly qualified and competent researchers, and strong technological development in certain fields.

The significance of an excellent education system to the advancement of scientific research is clearly illustrated in Figure 1. There is of course no direct causal link between the science skills of 15-year-old schoolchildren and the country's researcher intensity, but the Figure does certainly demonstrate that scientific research is held in high regard in Finnish society.

Finland has so far not experienced the kinds of problems in recruiting young people into science and research that have been reported in many other European countries and the United States and Japan, for instance. However, the recruitment base may now be changing.

In 2009 these young people are aged 18–19 and now making their career choices. Even though Finland's PISA results are outstanding, the proportion of Finnish students who expect to have a science-related career when they are 30 is lower than in the OECD countries on average (Figure 2). A closer examination of the number of students

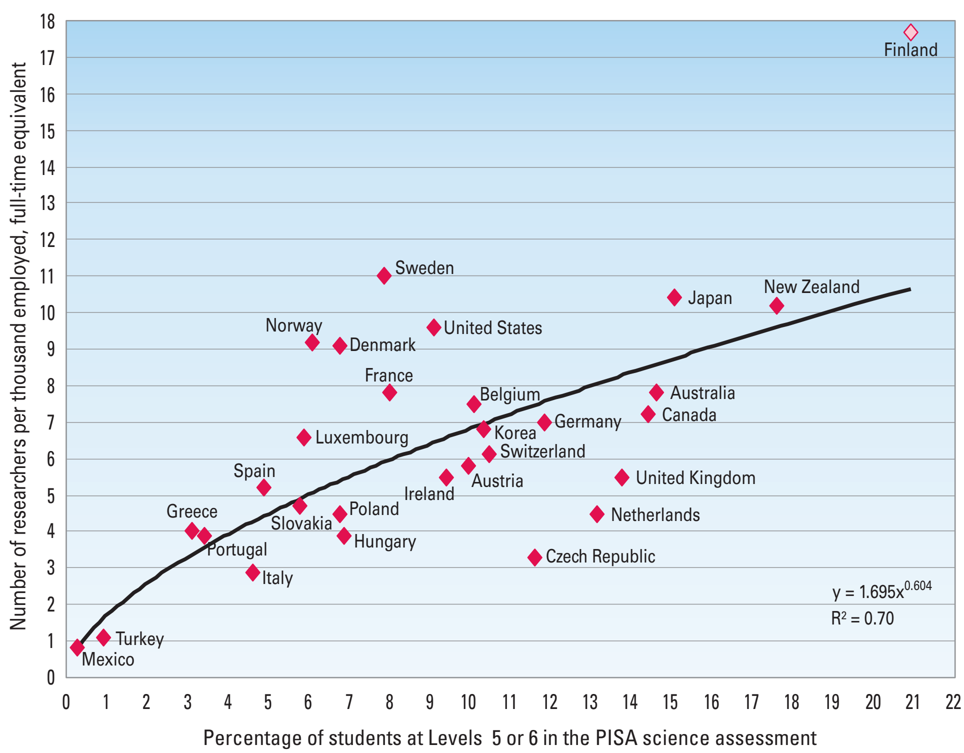

Figure 1. Top-performing students in PISA survey and number of researchers per one thousand employed persons in OECD countries. *Source: OECD 2008.*

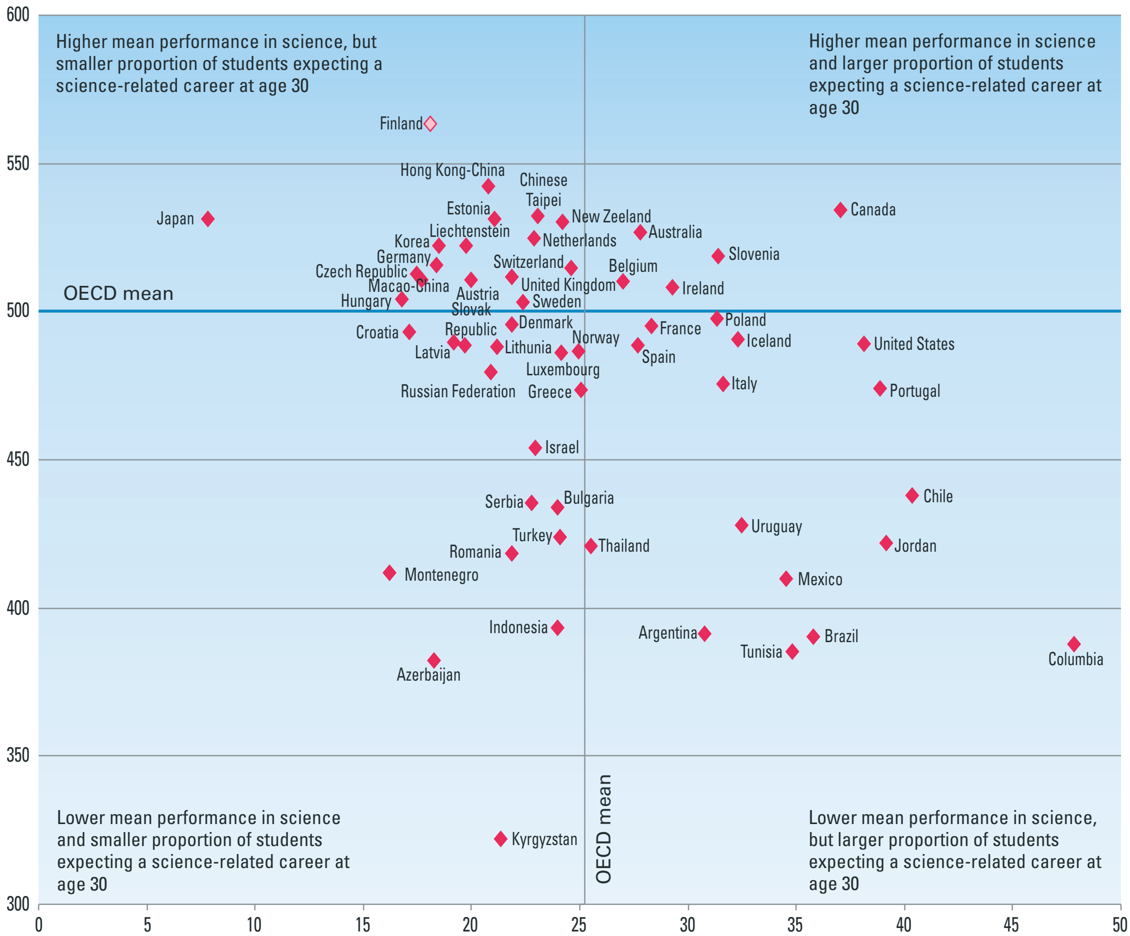

Figure 2. PISA results for lower secondary students and proportion of those who expect to have a science-related career at age 30. *Sources: PISA 2006, OECD 2008.*

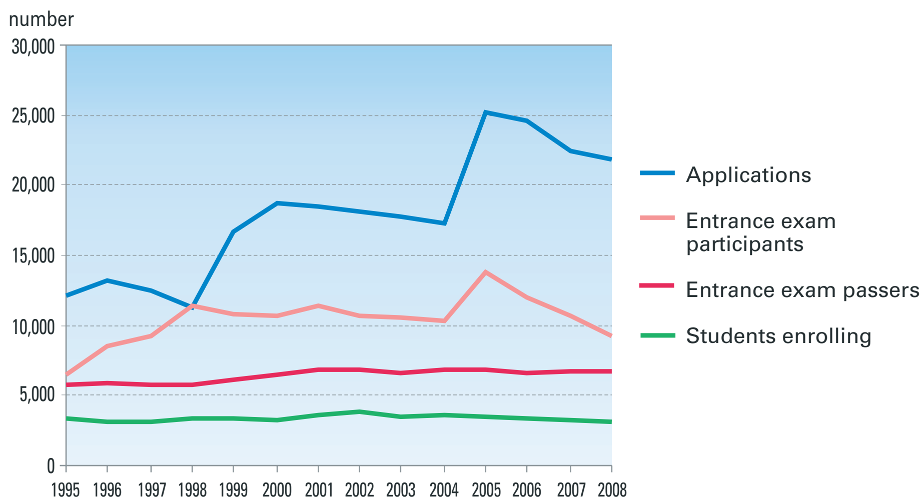

Figure 3. Students applying to and enrolled in university science programmes and number of new students starting their studies in 1995–2008. *Source: Kota database, Ministry of Education.*

applying to natural science programmes at university, the numbers enrolled and the numbers who have started their studies (Figure 3) shows that the number of new students has fallen. In 2002 the figure was almost 3,900, in 2008 it was down to around 2,800: the number of new students has decreased by around 28 per cent.

In a world of increasing interdependencies, there is growing demand not only for technological and economic expertise but also and particularly for cultural literacy and social development management. The role of science and research in evidence-based policy-making has continued to grow in all areas of society: the only viable basis for sustainable decision-making in such fields as economic policy, health policy, social policy, environmental policy and energy and climate policy is provided by sound knowledge grounded in scientific research (for recent development efforts, see DIUS 2008 and Royal Society 2008).

The following discusses the role of science and research in Finnish society from three perspectives:

- Public access to and understanding of science (scientific literacy)
- Scientific research in evidence-based policies
- Impact of scientific research.

4.1 Public opinion and attitudes to science

People in Finland traditionally have strong belief in the importance of knowledge and learning to individual citizens and to the nation as a whole. There have never been any cultural or religious elements that would have actively opposed the acquisition of scientific information or denounced it as inferior to other forms of knowledge.

On the contrary, the research evidence suggests that especially since the national enlightenment project 150 years ago, scientific education and research and its results have formed an integral part of the Finnish concept of culture and education. This is true not only of the elite, but from the very outset this concept has had a strong resonance in popular education, too. Major cornerstones in this development have included widespread literacy and the active application of knowledge in nation and state building.

Despite the broad acceptance and strong position of scientifically tested and verified knowledge today, it is also faced with perhaps more intense competition than ever before from opinions and attitudes that are clothed in the guise of knowledge. Information networks have opened the floodgates of instantly accessible information. However, those networks no longer serve simply as tools for the retrieval of information, but they have become increasingly reliable sources of knowledge, even though they are still far from uniform and consistent. This is a source of some ethical difficulty in science education and in the presentation of scientific evidence.

A comparison of European views on science and technology and the associations of those views with people's values (European Commission 2005a, 2005b and 2007) shows that together with the other Nordic countries and the Netherlands, Finland is in a group of countries whose citizens are best informed about the basics of science. People in Finland have a very positive perception of the research profession and of how research can contribute to the development of technology and industry. People in Finland (64%) believe more often than Europeans on average (50%) that basic research is important to the development of technology. A somewhat higher proportion in Finland (80%) also believe that science and technology will improve the life of future generations.

Finnish people have great confidence in experts. They believe more often than Europeans on average that politicians should listen more closely to the scientists' advice. People in Finland (83%) take the view that decisions on the future course of science and technology should be based on scientists' rather than ordinary citizens' views and assessments of benefits and risks. They have strong belief in the freedom of research, but expect that scientists conform to prescribed ethical standards.

Finnish people take a much keener interest than Europeans on average in science news (Finland: 43%, EU27: 31%). According to the Finnish science barometer, up to 72 per cent of the interviewees were very or rather interested to follow science and research issues (Science Barometer 2007). It seems that people in Finland are more satisfied than anywhere else in Europe in their media access to news about scientific research (European Commission 2007). Newspapers are the main source of information about science in Finland, where a much larger proportion of people than anywhere else in the EU get their science news from newspapers.

People in Finland have extraordinarily high confidence in science as an institution, as is shown in Figure 4.

Confidence in all science and research institutions (universities, science and the scientific community, Academy of Finland, VTT Finland and Tekes) has continued to increase since the beginning of the 2000s. In 2007, the numbers who believed that science can resolve major social problems (such as energy, the environment, climate change, food production and pandemics) were much higher than in 2001.

People in Finland take a very positive view on the public funding of scientific research and are convinced that it pays high dividends to society. Almost two in three people are in favour of funding scientific research from purse.

Young people's attitudes to science were recently canvassed in a European survey

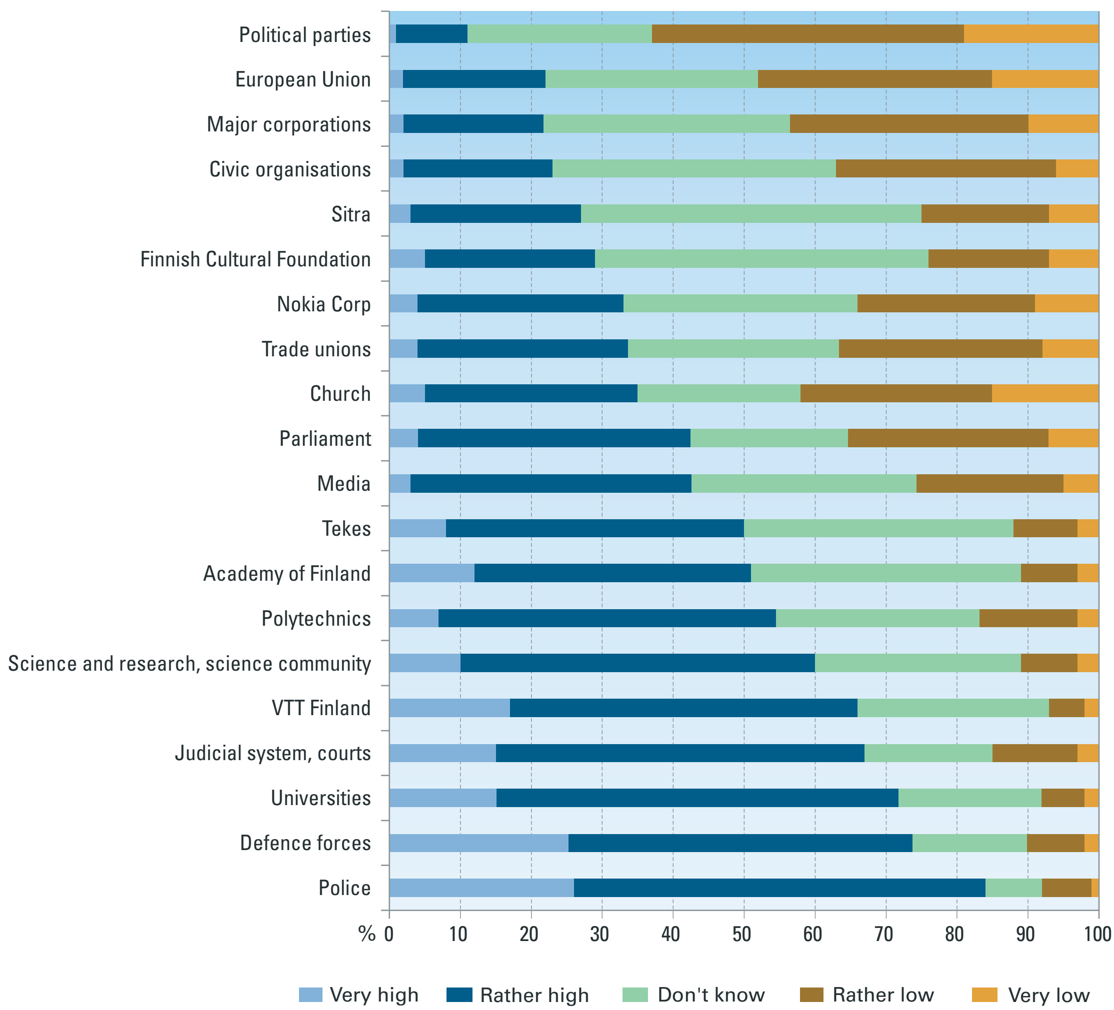

Figure 4. Degrees of trust felt for given institutions within society (%). Questionnaire survey among Finnish people in 2007. *Source: Science barometer 2007.*

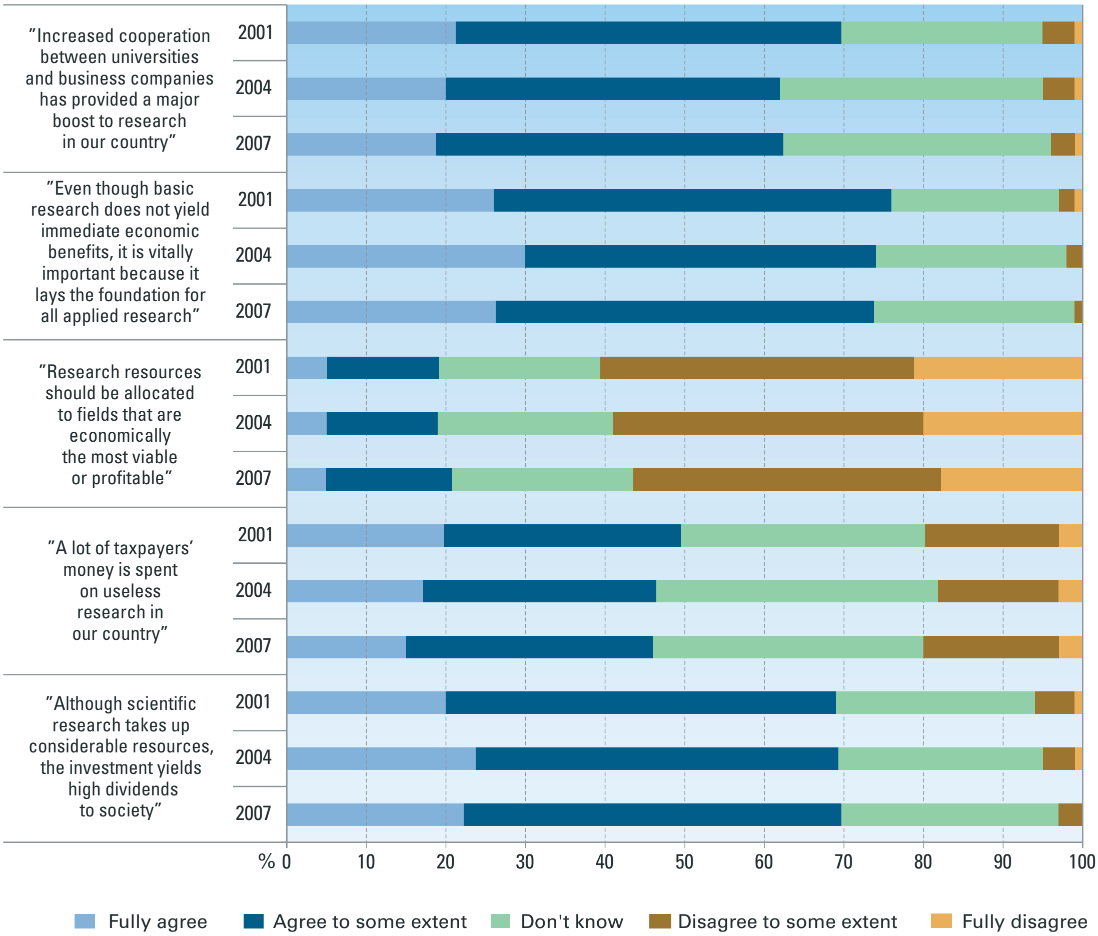

Figure 5. Attitudes to statements concerning the funding of science and its allocation. Questionnaire survey among Finnish people in 2007. *Source: Science barometer 2007.*

(European Commission 2005a). In some respects young people in Finland differ significantly from their peers in EU27 countries. Young people in Finland are more convinced than others that the benefits of science outweigh its harms. Furthermore, they believe much more often than others that scientists are dedicated to serving the best interests of humankind and cause no risk to society. They also have much stronger belief than others that science and technology can help to eradicate world poverty and hunger and to resolve some of the major problems facing humankind. By contrast they believe much less often than other Europeans that science should serve the goals of economic development, business companies or the advancement of knowledge in general. As regards the benefits and risks of scientific and technological innovations, young people in Finland believe they have the most benefits and the least risks.

People in Finland are better informed about science and they show a much more positive attitude to science and technology and the opportunities they offer than Europeans and Americans on average (see National Science Board 2008). Key reasons for this presumably include the high level of general education in Finland, the country's education system that is sympathetic towards scientific knowledge and the relative scarcity of cultural and religious obstacles to the public acceptance of science.

However, there remain significant challenges for the future in this respect. Although there is still room for improvement in information about science, those challenges cannot be met simply by increasing information and popularisation. Indeed, Finland has now moved on to the next stage, which is best described as a process of dialogue between science and citizens. In this process individual citizens can engage in discussion and debate with scientists about questions that involve strong scientific elements (such as reproductive biology and medicine, nanotechnology and many environmental questions). Research and development around these questions often involve ethical issues in which citizens may be just as competent and knowledgeable as scientists in forging sustainable joint solutions.

There are also early indications of an even more advanced system of interaction and exchange developing between scientists and citizens within the Finnish research system. Citizens and various organised groups – particularly those groups most directly affected by the questions concerned – are actively involved in developing research agendas and in research processes. This interaction is relatively permanent and it fosters mutual confidence and common learning. A good example is provided by the role of patient groups and organisations in medical research, another by the role of consumer groups in many fields.

4.2 Research evidence in policy decision-making

It is reasonable to assume that all important decisions in society are made on the strength of sound information, that the people making those decisions are as well informed as possible. The problem, however, is that practical information, expert knowledge, research evidence and the views of citizens and politicians may often differ from each other, even radically so.

We know from both EU and Finnish science barometers that 70–80 per cent of the population would want to see research-based evidence figure more centrally in political decision-making. These expectations are mainly focused on technologies that can help to improve health and life in general as well as on major global problems such as energy, the environment, climate changes, hunger, pandemics and poverty.

The relationship between political decision-making and the research field has varied over time. In Finland, the situation has moved from an elitist research system 50 years ago through a period of policy planning in the 1970s to an era of technology-driven growth in the 1990s. Today, this relationship is very much in transition, with the focus of attention on such issues as climate change, energy, welfare services, competence, and the environment. Research is now understood first and foremost as a strategic resource rather than as a way of resolving policy problems. In any event the need for research evidence is well recognized, as is the need for new organisational solutions and new kinds of strategies.

In Finland, committee institution was long the main procedure for evidence-based policy-making. Committees were the platform of choice to make expert assessments of the relevance of the existing research evidence and to judge the need for new studies and surveys: in preparation of policy reforms, leading scientists would be invited to serve as expert members on committees. At the same time, the discussions at committee meetings provided policymakers with the opportunity to familiarise themselves with the relevant research. It is possible and indeed likely that the discontinuation of the committee institution has resulted in a decrease in the use of research evidence in decision-making.

The aim of evidence-based policy-making is to achieve better and more sustainable policy reforms. All policy reforms are based on some kind of evidence. In evidence-based policy, this evidence is of the highest possible quality, helping to avoid unsustainable solutions generated by short-term political or administrative pressures.

Evidence-based policy is based on the following core elements (see UK Cabinet Office 2001):

- Evaluation of the existing research evidence
- Collection of new research evidence
- Consultation of experts and stakeholders
- Creation of alternative policy measures and their evidence-based evaluation.

In recent years the relationship between policy preparation and policy-making has been primarily approached as an administrative or structural issue. It has been considered to comprise Ministry funding for sectoral research, government research institutes and more recently the structural development of universities.

From a policy development point of view the key is that policy planning has access at the right time to scientifically validated research evidence that is relevant to the issue at hand. To ensure that this is the case, it is necessary to have a functional development process whereby the government adopts the principles and practices of evidence-based policy-making as the basis for its policy preparation process.

To guarantee the quality of the policy preparation process, it is essential that the organisations serving as the primary suppliers of research evidence have adequate scientific skills and competencies. The policy planning issues that have to be addressed in all countries – climate change, energy, the population, competence and health – require the highest possible standard of scientific expertise and the strongest possible knowledge base.

4.3 Impact of research and research funding

In recent years the science and technology policies of advanced countries have placed increasing focus on the requirements of efficiency and impact. The methodological and practical problems involved in the demonstration of impact are addressed from an international vantage-point and based on the needs of different countries (OECD 2008, Kanninen & Lemola 2006).

The most typically recognized socio-economic impacts of science, technology and innovations can be summarized as follows (OECD 2008):

- Economic impacts
- Cultural impacts: public understanding of science, intellectual skills, attitudes, values, beliefs and interests
- Social impacts: behaviour, practices, consumption, work, well-being
- Impacts on political decision-making: decision-making mechanisms, evidence-based policies, production of alternative practices and policies
- Organisational impacts: improving and increasing the efficiency of operations, work processes and the use of human resources
- Impacts on health: lifetime, prevention and treatment of diseases, health care systems and practices
- Impacts on the environment: use of natural resources, environmental protection, improving the state of the environment
- Impacts on education: quantity and quality of trained labour force, teaching methods, pedagogics.

For purposes of providing a coherent assessment and analysis of the impact of science, technology and innovation, the Academy of Finland and Tekes have developed a tool known as the *impact framework* (Lemola et al. 2008). Within this framework the focus of assessment is on core areas of society, providing valuable information with which to monitor the achievement of social policy objectives.

Impact framework analysis proceeds from impacts to inputs, addressing the question of what kinds of impacts science, technology and innovations are expected to produce. As such it provides an opportunity to analyse impacts as part of the strategic development of science, technology and innovation policy.

The impacts of science, technology and innovation are studied within core areas of society that are called *impact areas*. Within each of these areas, data on inputs, outputs, activities, processes and socio-economic impacts are examined as indicators.

There are numerous potential impact areas, and in democratic society individual impact areas can be weighted and analysed in many different ways. Development efforts start out from four impact areas:

- *Economy and renewal:* This impact area describes the economic impacts of science, technology and innovations, such as economic growth,

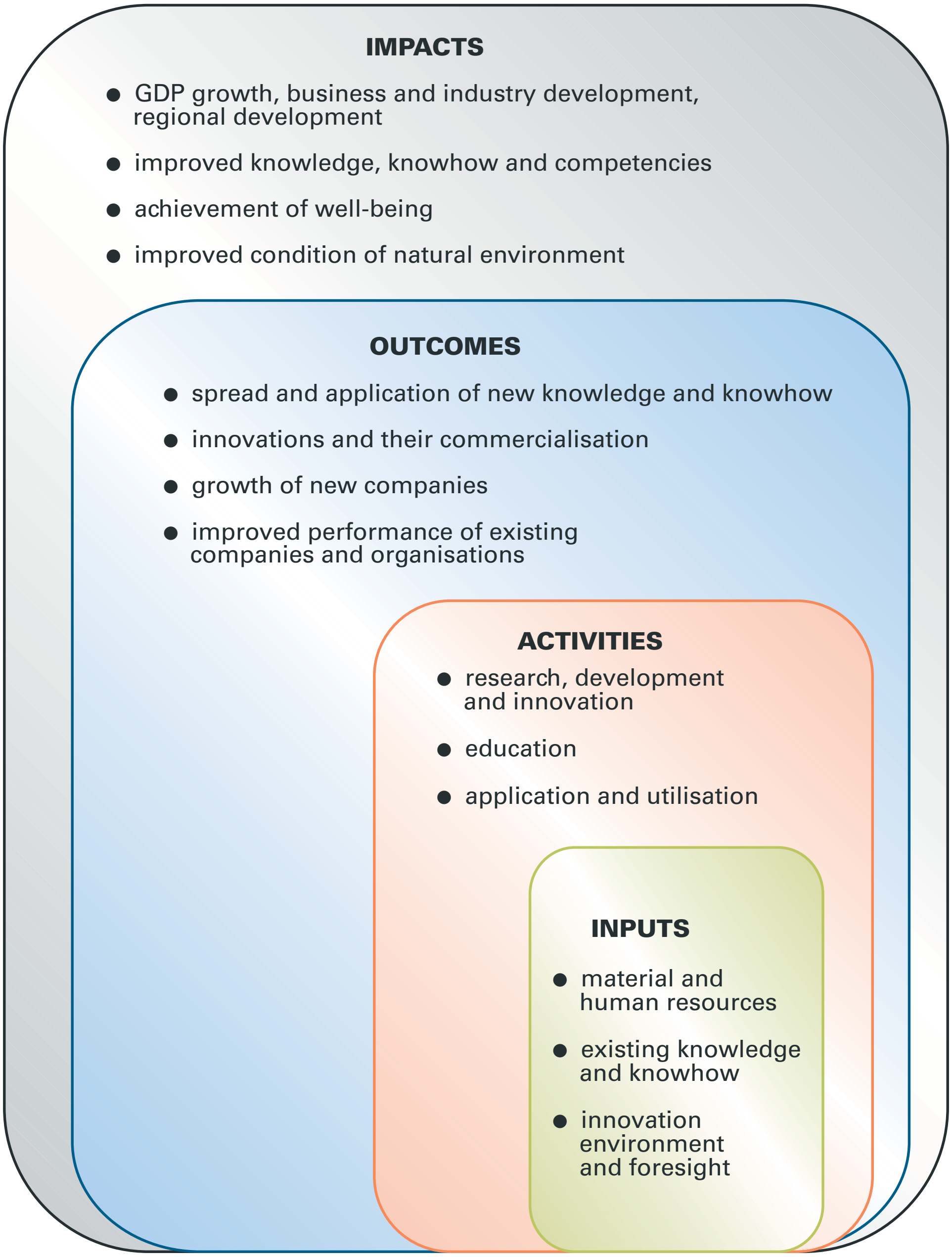

Figure 6. The impact framework. *Source: Lemola et al. 2008.*

productivity, international competitiveness, reform of the production structure, consumption and purchasing power, and employment.

- *Learning, knowledge and culture:* This impact area revolves around those science, technology and innovation resources and other factors that create the necessary conditions for other impacts. Key issues with regard to impact are the quality of the education and research system and its success in creating the skills and knowledge foundation necessary for the growth and development of Finnish society.

- *Finnish welfare and well-being:* The concepts of welfare and well-being are complex and multidimensional. Factors of objective well-being, such as health, living conditions and income, and factors of subjective well-being, such as social relations, self-realisation and happiness, constitute a challenging research problem. The fundamental interest is with the question of how science, technology and innovation have contributed to well-being and welfare in Finland.
- *Environment:* The main problems related to the state of the environment can be traced to those activities in society that have had a significant impact on the state and function of natural systems. It is commonly thought that scientific information concerning the environment and technological and other environmental innovations are part of the solution to the problem. It is also thought that solutions to environmental problems open up valuable new opportunities for innovative business.

There is some overlap between the different impact areas, and they are also tied together by various interactions and interdependencies. These are given special attention in indicator development. The next indicator report on Finnish science, technology and innovation will be completed in 2010.

Impact of national Centres of Excellence in research

Research funded by the Academy of Finland has different dimensions of impact. The following provides examples of the different potential modes and routes of impact of two different Academy funding instruments, i.e. the Centre of Excellence (CoE) programme and research programmes. The injection of additional research funding by the government in 1997–2000 paved the way to the adoption of the Centre of Excellence strategy in 1997. One of the main objectives of this strategy has been to develop creative research environments in which internationally competitive research is combined with high-level researcher training.

The Academy has completed assessments of the first two Centre of Excellence programmes in 2000–2005 and 2002–2007 (Academy of Finland 2009a).

CoE programmes have two main dimensions of impact:

- impact on the research and innovation system; and
- the societal impact of research.

For research itself, major impacts have included the opportunity to open up completely new lines of research inquiry and to take calculated scientific risks.

CoE research teams have been in the position to develop genuine research strategies and to pursue those strategies on multidisciplinary platforms and within diverse networks of cooperation both at home and internationally. Research has shown much improved capacity for renewal.

It is noteworthy that research teams have become far more attractive to PhD students, senior researchers and postdoctoral students. CoEs play a prominent role in the graduate school system and produce a larger number of PhD graduates than graduate schools on average. However, their major contribution from a research career point of view is that they can give young postdoctoral researchers much more independence than is normally the case. CoEs have a significant role in the internationalisation of the Finnish research system: they attract a slightly larger number of foreign postgraduate students than graduate schools on average, and a significantly larger number of postdoctoral and senior researchers. As global competition for talented researchers and experts continues to intensify (see Chapter IV), so national attractiveness will gain increasing importance in the innovation system: CoEs are Finland's most important visiting card to the world, on both a global and European scale.

Two important parallel processes are ongoing in CoEs that are crucially important to the future of the research and innovation system: on the one hand the process where stakeholders in the system are creating a profile for themselves, and on the other hand the process where those stakeholders are enhancing their national and international networking. The creation of a distinctive profile is strategically important to universities in particular, and indeed they have identified this as perhaps the most important contribution of CoEs to their own activities.

Networking is another important avenue of social impact apart from the division of labour in research and the development of organisational profiles. Research collaboration at CoEs involves working closely with the world's best researchers and research teams. Through CoEs, therefore, not only Finnish researchers but scientists from other countries can also gain access to these channels of cooperation.

The extensive networking of CoEs and their cooperation with government research institutes and with government authorities is also important to the achievement of social impact and to the structural development of the research system more generally. The results of research cooperation are put to use in central government. Cooperation has also taken the shape of joint data collection and the appointment of researchers to expert assignments in various positions of central government.

Networking with business companies is one important and effective channel of social impact. Businesses have made clear that they expect a high-quality input from science and research. In most cases networking means that business companies are in the position to influence the focus of research and to discuss its results in the course of the research process.

From a business point of view, one of the most important mechanisms for the transfer of social impact is the recruitment of new experts from the world of research.

The breakdown in Figure 7 is closely consistent with the breakdown of graduate school graduates, which is understandable in view of the prominent role of CoEs in the graduate school system. In 2002–2007 a total of some 1,000 PhDs and licentiates graduated from CoEs. Indeed, CoEs can be said to have an absolutely critical role in securing the nation's knowledge and skills base. Around 20–25 per cent of them took up employment in the private business sector, and 16–18 per cent in public administration and organisations.

CoEs have close links of contact with all sections of society. Their cooperation with government research institutes as well as with government offices and agencies was already discussed earlier. CoE researchers have a wide range of personal responsibilities from participation in parliamentary inquiries, committees, commissions and working groups as well as international expert assignments. Science popularisation is another important aspect of social impact.

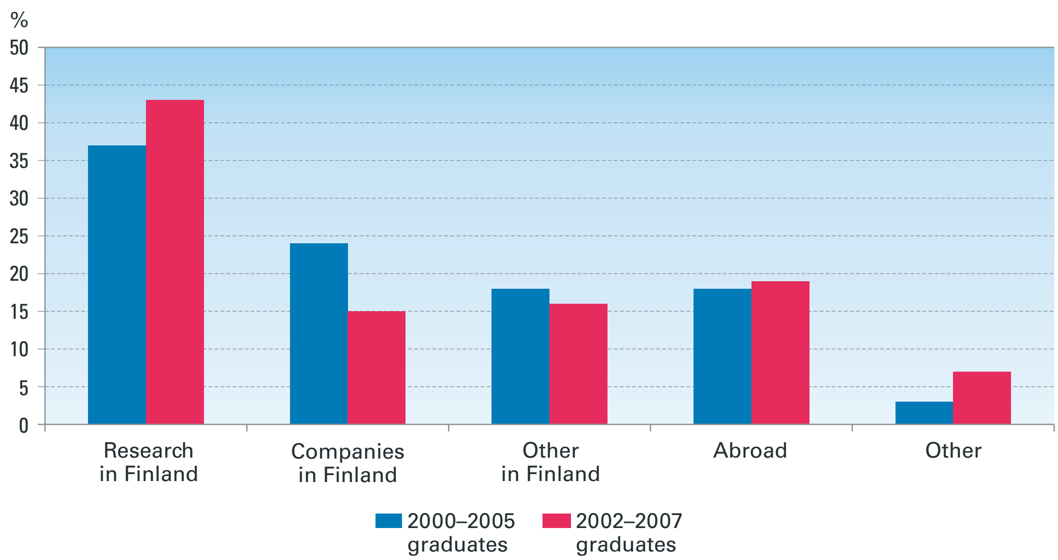

Figure 7. Placement of PhDs and Licentiates graduating from Centres of Excellence, in 2008.
Source: Academy of Finland 2009a.

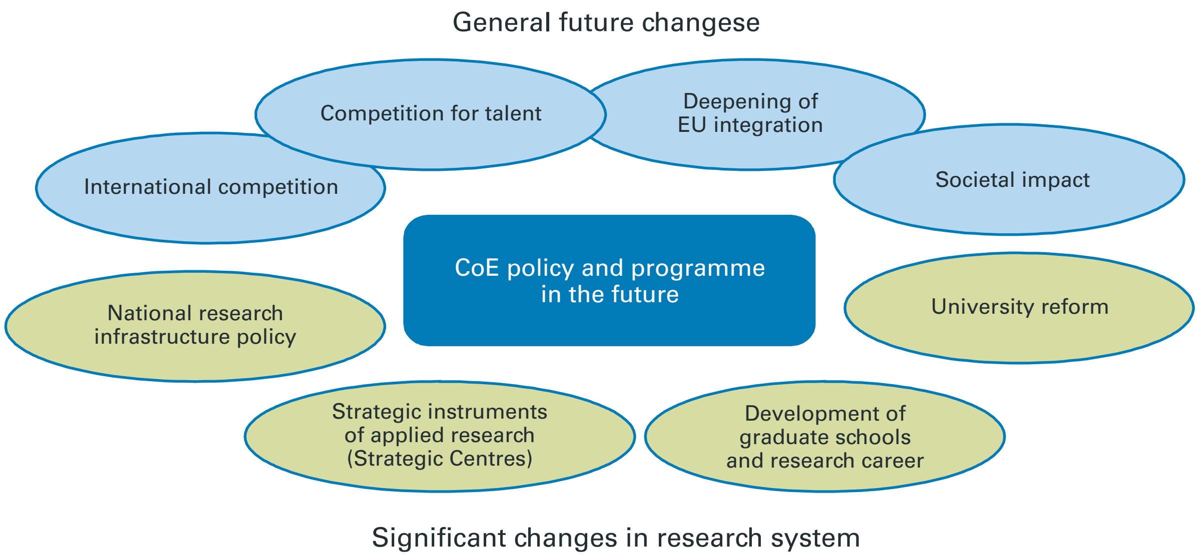

Figure 8. Factors impacting the future formulation of Centre of Excellence policy. *Source: Academy of Finland, 2009a.*

Impact through research problems

Academy research programmes play an important role in reforming scientific research, upgrading scientific skills and competencies, and generating new information about specific research themes or problems. They are a major forum of national and international researchers in different disciplines, users of research knowledge and research funding agencies (Academy of Finland 2009b). Their aim is to combine scientific excellence and long-term scientific and social impact. Research programmes are an important avenue through which the Academy can contribute to public debate in society.

More and more often today, research programmes involve aspects and challenges related to the connections of science to society. Social impact is a fundamental premise of every research programme. This underscores the importance of closer networks of cooperation with the potential end-users of research. Furthermore, research programmes often involve various forms of public debate. In many rapidly developing fields of research and new applications such as biosciences and nanosciences, research programmes also deal with ethical aspects of science. As research programmes today more and more often are international ventures, national and cultural contexts also assume increasing importance.

At the end of this chapter are five cases that illustrate the impacts that Academy research programmes have had on society.

4.4 Conclusions

In an international comparison of science competitiveness, Finland's key strengths are its education system, the availability of researchers and technological development in certain fields.

So far there has been little difficulty in Finland in motivating young people to choose a career in research. PISA surveys have shown that the science skills of children aged 15 in Finland are among the best in the world. However, the latest figures suggest that at least in the science field, this situation is dramatically changing. International comparisons suggest that young people in Finland are less interested in a science career than many others, and the number of new students in science programmes has dropped alarmingly.

Questionnaire results from EU Member States indicate that people in Finland are very well informed about the basics of sciences and that they take a far more positive attitude than average to the research professions and to the impacts of research. Finnish people take a much keener interest than Europeans on average in science news.

People in Finland have very high confidence in science institutions, and they believe that funding for research pays high dividends to society.

Finland is also relatively advanced in terms of communicating science to citizens, and steps have been taken to further improve the dialogue between scientists and citizens. Furthermore, there are indications of even deeper exchange and interaction developing between science and citizens.

Science barometers have shown that 70–80 per cent of the Finnish population would want to see research-based evidence figure more prominently in political decision-making. There is reason to believe that the discontinuation of the committee institution has undermined the use of research evidence in decision-making.

Evidence-based policy-making is continuing to gain in significance. This is partly in consequence of structural reforms (e.g. in sectoral research), but partly it is attributable to public administration being willing and able to make better use of scientific research. The Academy of Finland and Tekes have together developed a tool known as the impact framework to analyse the impacts of science, technology and innovation in core areas of society, i.e. the economy and renewal, learning and skills, well-being and welfare, and the environment.

The Academy's research programmes and Centre of Excellence programmes are significant instruments both in terms of social impact and in terms of impact on the research and innovation system. In both these programmes research and researchers are well networked both at home and internationally. The extensive networking of CoEs and their cooperation with government research institutes and with government authorities provides a bridge from research to decision-making. In most cases networking means that business companies are in the position to influence the focus of research and to discuss its results in the course of the research process. There is much recruitment of experts from CoEs to business companies.

Research programmes are a major forum of national and international cooperation for scientists and researchers in different disciplines, users of research knowledge and research funding agencies. Social impact is a fundamental premise of every research programme. Networks of cooperation with the potential end-users of research are therefore of central importance. In many rapidly developing fields of research and new applications such as biosciences and nanosciences, research programmes also deal with ethical aspects of science.

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Baltic Sea research programmes

Kaisa Kononen, Baltic Organisations Network for Funding Science EEIG

In 2002, the Academy of Finland and three ministries (Ministry of the Environment, Ministry of Transport and Communications, Ministry of Agriculture and Forestry) launched a three-year Baltic Sea Research Programme (BIREME). The aim of the programme was to deepen the knowledge base needed for the protection of the Baltic Sea; in this sense it also supported the Finnish Government's Baltic Sea Programme. At the same time, Sweden had three ongoing research programmes related to the protection of the Baltic Sea, and Germany had a more extensive marine research programme. When the ERA-NET call was opened under EU FP6 in 2003, these research programmes came together to form the five-year BONUS ERA-NET project.

BONUS ERA-NET (2004–2008) involved all nine Baltic Sea countries (Latvia, Lithuania, Poland, Germany, Finland, Sweden, Denmark, Russia and Estonia) and 11 funding organisations. The foundation for Russia joining the project had been set during the Finnish BIREME programme under which the two countries had already held a joint call based on the bilateral agreement between the Academy and the Russian Foundation for Basic Research.

BONUS ERA-NET put in place all the administrative, scientific and economic structures required by the joint research programme. In 2005, the EU Commission selected the Baltic Sea Research Programme as one of just four programmes for which the EU Parliament and Commission were ready to propose special status as an Article 169 Programme. The subject of the research programme was considered exceptionally important in that it supports several current EU policy objectives: the Water Framework Directive, EU maritime policy and the related marine environment strategy, the development of the Baltic Sea strategy as well as the Baltic Marine Environment Protection Commission's (HELCOM) Baltic Sea Action Plan.

The Baltic Sea Research Programme under Article 169 differs in several respects from normal framework programme funding. It has a strong integrating effect on national research programmes, their funding and practical application in society. Programme funding comes from a common pot established by national funding agencies and the EU. The programme is administered by a dedicated organisation founded in Helsinki, the Baltic Organisations Network for Funding Science EEIG, to which the EU Commission and national agencies will relinquish administration of their contributions. The EU Parliament will make its decision on the start-up of the programme in November 2009. Programme funding over the 2010–2017 period is estimated to total around 100 million euros.

In practice, the BONUS programme has already started. The programme's first, 22 million euro call was announced during the transitional stage in 2007, and the 16 projects that were approved for funding started up at the beginning of 2009.

The BONUS programme is ambitious and if it succeeds, it will set a benchmark for research cooperation in other territorial seas in Europe. The purpose of Baltic Sea research should be to support decision-making aimed at the sustainable use of goods and services derived from the sea. This research must therefore be multidisciplinary, integrating both natural sciences and socio-economic considerations. As well as generating new information and new tools to support the sustainable use of the marine environment, the programme will aim to enhance communication between research and decision-making.

Nanoscience Research Programme (FinNano)

Anssi Mälkki, Academy of Finland

The Academy of Finland's FinNano Research Programme 2007–2010 covers 15 research projects, ten of which are funded from Academy research programme grants and four from joint funding arrangements. Other partners in the jointly funded projects are the ERA-NET consortium NanoSci-ERA and the Russian Foundation for Basic Research. Overall programme funding totals 10 million euros.

At the time that the programme was launched, nanoscience and nanotechnology research in Finland was already at high level of excellence and therefore in a good position to take advantage of the additional research investment. There are several nanoscience research clusters, with scientists and the research instruments based at different universities and in several different research fields. The decision was taken to promote high-level nanoscience research and to support interdisciplinary approaches by the allocation of additional resources in this field. At the same time, the opportunity was provided to promote the responsible development of nanotechnology and to foster social debate and discussion.

Launched in 2005, the Tekes FinNano technology programme for 2005–2009 was planned in close collaboration with the Academy. The Ministry of Education has subsequently launched a development programme for 2007–2009 to support the Academy and Tekes nano programmes and appointed a national Nanoscience Forum with representatives of all nanoscience stakeholder groups. The Academy's research programme is thus conducted as part of a wider national effort to promote and integrate Finnish nanoscience and nanotechnology. It also has links with two ERA-NETs, i.e. NanoSci-ERA and MATERA, both of which are continuing to move ahead as ERA-NET Plus actions.

Since the launch of the research programme, research on nanoscale phenomena has continued to expand into ever new areas of investigation. The identity of nanoscience itself is clearly in flux as its focus is increasingly shifting from nanophenomena as such to research areas in which nanoscale phenomena are of great significance. None of this has detracted from the currency of nanoscience, however: a clear indication of this is provided by the significant new investments by Russia, the United States and China in nano research.

With the programme now at the halfway point, it is clear that the broader objectives set for the national investment will be achieved. Beyond its scientific results, the FinNano programme has a significant role in a wider national context, too. As well as providing a potential networking link between research teams, the research programme also offers a channel via which the academic research community can contribute to current debates and discussions on the practical application of research results in society and in business and industry, on nanosafety and on the future of nanoresearch and ethical research questions.

Research Programme on Neuroscience (NEURO) 2006–2009

Mika Tirronen, Academy of Finland

The Research Programme on Neuroscience (NEURO) is a four-year programme between Finland, Canada and China, providing funding for cutting-edge neuroscience research in all the participating countries. The programme involves 16 Finnish, four Finnish-Chinese and three Finnish-Canadian research projects. It provides simultaneous, coordinated funding for the projects during 2006–2009. The Academy's contribution is 7.1 million euros. The programme is also aimed at strengthening collaboration with neuroscience research programmes and doctoral programmes in other countries. NEURO is funded by the Academy of Finland, the National Natural Science Foundation of China (NSFC) and the Institute of Neurosciences, Mental Health and Addiction (INMHA) of the Canadian Institutes of Health Research. The programme is coordinated by the Academy of Finland.

Neuroscience has developed very rapidly in recent years, and consequently it has gained an increasing prominence in many areas of society. Neuroscience studies are helping to improve our understanding of the brain and how it works, and they are also paving the way to new treatments for disorders affecting millions of people. By crossing disciplinary boundaries, neuroscience has also created new approaches to the development of smart technologies. Neuroscience research is an inherently multidisciplinary exercise that combines biomedical research, information technology, philosophy and psychology, for example. One of the key challenges in the field is to integrate different areas of research and to work towards a synthesis between those areas. NEURO aims to further this goal by promoting the introduction of new methods, cooperation among different disciplines and supporting researcher training. Ultimately the aim of the programme is to create high-level, cross-border projects in which topical neuroscience issues can be approached on a genuinely multidisciplinary platform. These projects will be working to shed new light on such areas as memory, learning, social interaction, anxiety as well as neurological diseases and their treatment.

Projects under the NEURO umbrella have also sought to explore and unravel some of the ethical, philosophical, legal and social issues related to neuroscience research. The growth of new neuroscience knowledge has thrown up entirely new kinds of questions about research ethics, the use of experimental animals, the improvement of cognitive capacity, consent practices, prognoses based on brain imaging and privacy protection. Neuroscience knowledge also opens up interesting perspectives on the concepts of autonomy and responsibility in human activity. In 2007, a joint neuroethics call was announced under the NEURO umbrella in Finland, Germany and Canada.

The research programme has hosted several international meetings and seminars, including the "Developing Brain, Emerging Mind" seminar in Helsinki in 2007, the Finno-Japanese neuroscience seminar at the RIKEN Institute in Tokyo in 2009, and the seminar on the neurocognitive basis of learning in Moscow in 2009. The programme has partnerships with several European research funding networks. Under ERA-NET Neuron (www.neuron-eranet.eu), two calls have been announced for European research proposals in 2008 and 2009. In addition, through ERA-NET CO-Reach (www.co-reach.org) and the Nordic-Asia NORIA-net (www.aka.fi), the programme is networked with programmes that are aimed at developing funding cooperation between European countries and China.

Another important aspect of the research programme is to contribute to the popularisation of neuroscience research results so that ordinary citizens, policy-makers and health care and education professionals can better appreciate the significance and applicability of those results. The programme has hosted regular information exchange meetings and press conferences for the media, and has had education collaborations with the Adult Education Centre of the City of Helsinki.

NORFACE

Eili Ervelä-Myréen, Academy of Finland

The Academy of Finland is coordinating the cooperation of European research funding agencies through the EU-funded ERA-NET NORFACE (*New Opportunities for Research Funding Cooperation in Europe – A Strategy for Social Sciences*). The aim of NORFACE is to develop new, sustainable forms of collaboration between social science funding organisations and to increase funding cooperation between national funding bodies. The NORFACE network involves 14 European funding agencies and Canada. The European partners include social science funding bodies from all the Nordic countries, the UK, Ireland, Germany, the Netherlands, France, Portugal, Estonia and Slovenia.

NORFACE has worked to develop new international funding instruments for multinational research teams. The first of these was the NORFACE seminar series in which calls were announced in three successive years (2005–2007). In 2007 the NORFACE partners funded a joint research programme under the heading *Re-emergence of Religion as a Social Force in Europe*. A total of 5.4 million euros was awarded to 10 research projects for a three-year term (2008–2011). In 2008, NORFACE opened the call for its biggest jointly funded programme, *Migration in Europe: Social, Economic, Cultural and Policy Dynamics*. Funding for this four-year programme in 2009–2013 totals 28.6 million euros, 6 million of which comes from ERA-NET Plus sources under EU FP7. Funding decisions on the Migration programme will be made in June 2009. The plan is to provide funding for two or three major projects (at around 3–4 million euros each) and for a larger number of smaller projects (at around 1-2 million euros). All NORFACE seminars and programmes are funded from a common pot, with national contributions determined using an algorithm based on population and GDP per capita. Funding will be made available to projects that are rated as the scientifically most promising projects, regardless of the nationalities of the researchers involved. Both NORFACE programmes also have a scientific coordination body with a professorial level programme director. NORFACE attaches great importance to scientific coordination, which is considered to give scientific and international added value to its projects.

The Migration project is concerned with European immigration and emigration and its aim is to reduce current fragmentation in this area of research. Most European migration research so far has been conducted at the national level. The aim in this programme is to approach questions of migration through multinational, pan-European research projects that deal with migration at a European level. A further objective is to promote theoretical migration research and to raise standards of comparative, multidisciplinary and multi-level migration research in Europe. The programme will facilitate systematic comparison of different structures and different paths of development. The results will provide valuable information for policymakers at national, European and international level.

The programme will contribute to strengthening the European Research Area by increasing European research capacity in the field of migration research. It serves as an example of significant cooperation among national funding organisations, demonstrating that funding agencies are capable of pooling their resources to carry out an extensive jointly funded research programme at pan-European level.

NORFACE has launched important new initiatives in the social science field, which continues to have a relatively marginal role in European research cooperation. Indeed NORFACE is committed precisely to strengthen the role and position of social sciences in the European Research Area by contributing actively to intellectual exchange and debates at both EU and national forums. At the same time, it maintains close contact with both the research community, various stakeholder groups and users of research knowledge.

Science funding organisations are faced with some very difficult challenges brought on by the development of the European Research Area and the globalisation of science. To meet these challenges they will need to show greater flexibility and innovativeness for instance in the international networking and opening of new research programmes and Centres of Excellence.

Power and Society in Finland Research Programme (VALTA)

Petteri Pietikäinen, Academy of Finland

Power and Society in Finland is a four-year (2007–2010) research programme that involves 21 projects and that has a budget of 6.5 million euros. In addition, the programme has three associate projects dealing with closely related themes and funded through general Academy research grants. The programme has no external funding sources. The research programme is intended to explore the impact of administrative and power policy decisions on citizens' everyday life, democracy, the distribution of power and administrative protocol. The themes covered in the programme are the International system and power in Finland; Power in the state and state power; Economy and power; Citizens and civil society; The media and power; and Gender and power.

The research programme is designed to support broad-based research on power and its historical changes in Finland and to produce new empirical evidence on concrete processes of power. The programme starts from the changes that have taken place in Finnish society and its power structures: the European Union, globalisation and the growth of cultural pluralism have directly impacted people's everyday life. Nevertheless, major policy changes have often been pushed through without extensive public debate. While the impacts of these policy changes on people's everyday life, democracy, the distribution of power and administrative protocol have been addressed in individual studies, there is still no comprehensive interpretation of their implications. One of the aims of the research programme is to support broad-based research on power and its historical changes in Finland. Another key goal is to produce new empirical evidence on concrete processes of power, as power is nearly always exercised in concrete ways. Apart from theoretical research on power, the programme encourages interdisciplinary and comparative research and aims to strengthen national and international networking and cooperation among researchers. Special attention is given to the exchange of information and reporting on research results.

In addition to its purely research-driven objectives, the programme also aims to contribute to public debate on networks of power in Finland and to influence decision-makers. One of its research interests concerns gendered power at the municipal level. These research results will be introduced to the authorities and politicians, and in this way the programme also aims to influence legislation. The energy policy project is contributing to the debate on nuclear energy and questions around the increased use of nuclear energy, while the project focused on national minorities and the integration of ethnic groups is aimed at providing new research evidence to support the development of Finnish immigration policy. The programme has also organised two events intended for the general public, one in Mikkeli and one in Kajaani, providing citizens with the opportunity to exchange views with local opinion leaders about power in their local municipality and more generally in Finland. Furthermore, the programme has had cooperation with other Academy research programmes: in 2007 a joint seminar was organised with the Research Programme on Business Know-how and the Social Capital and Networks of Trust programme on corporate social responsibility, and in 2008 a seminar was hosted on the subject of Power and Energy together with the Sustainable Energy and the Sustainable Production and Products programmes. Various publication projects are also underway, and plans are in place to introduce the programme more widely to international audiences (e.g. in Brussels). Together with the Austrian Federal Ministry for Science and Research, the programme has organised a Finno-Austrian seminar on migration in Helsinki. The project's researchers have among other things engaged in public dialogue on the subject of management by fear, written the foreword to the jubilee edition of the Who's Who, and contributed commentaries on the power of the media and the economic stimulus programme. Overall the research programme has very close links with Finnish society.

II The State of Scientific Research in Finland

1 Biosciences and Environmental Research

Contents

1 Biosciences and Environmental Research: Strengths, Weaknesses and Opportunities

The current state of biosciences and environmental research

This, the fifth review by the Research Council of Biosciences and Environment of the state and quality of biosciences and environmental research is based on an extensive canvassing of opinion among scientists and researchers working in the field. This was done in the context of nine half-day workshops in the fields of biochemistry, cell biology and genetics, ecology, evolution and ecophysiology, food science, plant biology, geography and regional studies, agriculture and forestry, microbiology, neuroscience and physiology and environmental sciences. Invitations to these workshops were sent out to leading researchers in these fields, and they met with a positive response. The Research Council's assessment is based on the broad-ranging expertise of the research community at large.

Quality of research

Based on the results of these workshops, it can be concluded that biosciences and environmental research in Finland is of the highest excellence and continuing to develop vigorously. In particular, advances in genomics will in the near future impact the development of many of the fields hosted by the Research Council. Technological advances will also create new opportunities for research, which in turn will pave the way to the development of new technologies. Overall the research conducted under the Research Council's aegis shows a strong international orientation, although the timing of the drive to internationalisation varies to some extent between different fields of research. Many of these fields have developed in close interaction with the global scientific community and are at the very cutting edge of science. Scientists and researchers in different fields work very closely with one another, and interdisciplinary cooperation is an important part of all biosciences and environmental research. Furthermore, there are important points of contact with medical sciences, social sciences, the humanities and natural sciences. One source of difficulty is a certain lack of coherence in both research work and research funding, which has caused unnecessary fragmentation of the research system. This hampers cooperation and makes it harder to achieve synergy benefits. The lack of synergies may adversely affect the efficiency of the research system and reduce the prospects of new scientific discoveries.

Biosciences and environmental research has strong international visibility. Finnish scientists and researchers publish relatively actively in all the Research Council's fields, and publishing trends have developed favourably since the early 1990s. Citation impacts are also high, even though there is some variation from field to field. Some disciplines are at or very close to the international cutting edge, others can be described as internationally competitive.

Research career and PhD education

PhD education at graduate schools in biosciences and environmental research is highly diverse, broad-ranging and systematic. Career training courses at graduate schools have helped to improve the practical workplace skills of graduating PhDs and boosted their employment rates. It is important that as large numbers of PhD students as possible have access to supervised and systematic postgraduate training. Graduate schools are closely networked with one another and with sectoral research institutes, which contributes to stronger networking among PhD students and helps them develop broad-based expertise. So far employment rates for graduating PhDs have been fairly high, although again there is some variation across different fields. In some fields there has been a shortage of people with a PhD education.

Competition is intense at all stages of the academic research career, which also puts the funding system under great pressure. Bottlenecks are easily created at the points of transition between different career stages. On the other hand, competitive selection is an integral part of the research career system. Selection pressures should be evenly and predictably spread out across different stages of the research career so that bottlenecks can be avoided as far as possible. Increased international mobility is to be encouraged throughout the research career, particularly at the postdoctoral stage. Steps are needed to facilitate mobility within the research system.

Infrastructure

The infrastructure for biosciences and environmental research comprises various types of equipment, hardware and laboratories, datasets and libraries, collections, research stations and research vessels as well as staff who are trained in their use and maintenance. The relative importance of infrastructure varies in different fields of research: biochemistry, neurosciences and physiology are examples of equipment-intensive disciplines, whereas environmental research and other fields are more dependent on networks of research stations and time series data. Some of the existing infrastructure is good, although equipment and hardware does tend to age rapidly in the absence of adequate resources for maintenance and replacement. A specific problem in many fields is the perceived shortage of permanent staff specially trained in equipment use. The resources are not available to hire these people.

Societal impact of research

The societal impact of biosciences and environmental research is manifested in many ways. An internationally competitive scientific community is key to tackling and resolving many practical global and local problems and challenges. Climate change and the questions of mitigation and adaptation are important areas of biosciences and environmental research today that require a strong basic research input. The warming of the world's climate is changing plant growing conditions and facilitating the adaptation of new species, but at the same time accelerating the spread of pest species and diseases in the boreal forest zone. Scientists in this field are working to develop means of controlled adaptation to the changing climate conditions. Without a strong research base, it would not be possible to develop cultivars that are better suited to the new conditions. Research funded by the Research Council has a broad multidisciplinary basis and is therefore well placed to address the complex issues of sustainable development, for instance. A good example is provided by Baltic Sea research, which has contributed significantly to curbing eutrophication and to improving protection of the Baltic Sea marine environment. Centres of Excellence have achieved internationally significant results on the strength of their multidisciplinary efforts and good cooperation. Research in the disciplines hosted by the Research Council for Biosciences and Environment also plays an important part in promoting natural biodiversity, health, welfare and environmental protection. The close ties between biosciences and health research add further weight to their welfare policy effects. Environmental research has played a crucial pioneering role in developing new solutions to global and local environmental problems. There is no question that without biosciences and environmental research, many sustainable development challenges would remain unresolved.

Strengths and weaknesses of biosciences and environmental research

The following reviews the main results of the workshops organised by the Research Council in different fields of biosciences and environmental research. Strengths, weaknesses and aspects of internationalisation are discussed separately for each field. The texts are complemented with bibliometric analyses (see Appendix 2 to this report, which provides a detailed description of the bibliometric data and methods), in which the impact of Finnish research is compared with corresponding figures for leading science nations: the UK, Japan, France, Sweden, Germany and the United States. These are at once the countries with which Finnish scientists and researchers have the closest cooperation. Japan is included in these comparisons by virtue of its size and significance. The indicator used for scientific visibility is the number of publications per mean population (Appendix 1). The indicator of scientific impact is the mean number of citations received by publications in different fields (Appendix 2). In addition to these country comparisons, the number of citations received by publications in different disciplines is compared with world averages (Appendix 3). Furthermore, a separate analysis is included of the most-cited 1% of publications in each field of research (Appendix 4).

Biochemistry and biophysics, cell and molecular biology, genetics, bioinformatics

Recent developments and quality of research

This is a very broad and extensive field of research, as is clear from its name. For this reason it is not possible, within the confines of this brief summary, to give the same detailed treatment to its distinctive characteristics as is given to other, narrower disciplines covered in this report. This field of research leans heavily towards experimentation, and therefore its success depends crucially on a first-class infrastructure at different levels (local, national and international) and on constant efforts to upgrade and develop that infrastructure. Research in the field of structural biology was earmarked for intensive development efforts in the 1990s. In the 2000s, priority has been given to the development of functional genomics or systems biology. Resource allocation to bioimaging will be stepped up through the launch of a new research programme this year.

Genomics and systems biology have seen phenomenal progress and development over the past 10 years, which has had a major impact on research in this field. However, it is important to note that even though systems biology approaches are very much in vogue right now, they do not exclude more traditional approaches that allow for more detailed analysis of the molecular mechanisms of biological phenomena. Research in this field, and in systems biology in particular, produces vast amounts of information, and therefore it is crucial that bioinformatics methods are developed for the effective filtering and logical categorisation of that information. Research using the modern techniques available in this field is extremely expensive, and this fact should be borne in mind in the allocation of research funds. Research teams at Biocenter Finland are engaged in important work in this area as well as in molecular medicine, and it is hoped that this centre will become a major driving force in developing the infrastructure and other facilities for research in this field.

There are some very high-level research teams in this field, and all of the top teams have active international cooperation. Many researchers have connections with medicine, which is a major asset for this field. International competition is intense, which further enhances the esteem enjoyed by this line of research in Finland. In recent years the visibility of this field has increased considerably both in Europe and the United States. Increased levels of excellence have brought an increased sense of self-esteem and contributed to diversifying research. However, Finnish scientists and researchers are not yet good enough in marketing their own skills and achievements. One of the reasons for this lies in the difficulty of getting one's observations published, which in turn reflects directly on the researcher's or the research team's visibility. On the other hand, one of the strengths of this field is the high level of basic education among students as well as the effectiveness of the education system. One noteworthy challenge for the future comes from the fact that competition for the best students is set to intensify at all levels.

The bibliometric analysis covers the period from the early 1990s through to the mid-2000s. Publishing activity in this field is rising steadily, and researchers in Finland have increased their visibility to a greater extent than colleagues in many other countries included in the comparison. The number of publications is up by over 40 per cent during the period under review. Finland comes second only to Sweden in terms of publishing activity. In 2003–2005, Finnish researchers published 3.0 articles/10,000 population, while Swedish researchers recorded a rate of 4.0 articles (see Appendix 1a). As in all other countries, Finland's citation impact has notched up slightly. In 2001–

2005, articles published by Finnish researchers in this field received on average 10.3 citations, which comes close to the level in most of the countries examined; it is higher than the figure in Japan but lower than those in the United States (13.8), the UK (13.6) and Germany (12.0). The Finnish citation impact has risen at roughly the same rate as in other countries (see Appendix 2a). Compared to the world citation impact, the strongest period for this field occurred around the mid-1990s. The early 2000s was a somewhat weaker period, but trends have been improving over the past couple of years (see Appendix 3a).

International engagement, mobility and cooperation

Research in this field has long been characterised by strong international cooperation. Networks of cooperation are largely built from the bottom up on the basis of researchers' current needs and interests. This has led to the formation of international, interdisciplinary networks where the skills and competencies of the research teams involved support and complement one another, making it possible to achieve better results than anyone could have achieved on their own. This is a natural avenue to endogenous network formation for long-term and sustainable international cooperation. It is now considered an outdated approach to dictate from above the partners and subjects of cooperation. International mobility is also typical of this field: in addition to researcher exchange programmes within networks of cooperation, graduating PhDs with academic research ambitions have traditionally moved abroad to continue their studies and gain new know-how, which they can then apply in their own research on returning home. Changes in society and in people's attitudes have meant that the threshold is now higher for graduating PhDs to take up postdoctoral positions abroad. One of the underlying factors is that the standard of science in Finland has risen significantly, meaning that new graduates feel they can get a good enough postdoctoral position in one of the top research teams at home. Nonetheless, it is extremely useful to spend periods working with cutting-edge research teams abroad. One way of encouraging graduating PhDs to move abroad could be to guarantee them a four-year postdoctoral term as opposed to the three-year term for those remaining in Finland. Already postdoctoral positions are more readily available for those who move abroad.

Development needs

Research funding in Finland is scarce and short-term. Quality depends largely on the amount of money available, and that in turn depends on publication numbers. It is impossible to take risks unless publication numbers meet the expectations of the research funding bodies. The amount of funding granted by the Research Council for Biosciences and Environment does not correspond with the number and quality of applications submitted. The under-resourcing of bioscience fields is most clearly seen in the number of allocated graduate school positions. Disciplines under the Research Council for Biosciences and Environment account for just 14 per cent of all graduate school positions, whereas the Research Council for Health, the Research Council for Culture and Society and the Research Council for Natural Sciences and Engineering account for 17 per cent, 26 per cent and 43 per cent, respectively. This is not proportionate to PhD placement or to the role of different Research Councils in promoting high-level science. It is difficult for disciplines in this field to gain access to Strategic Centres for Science, Technology and Innovation because there are not yet enough large bioindustry companies in Finland.

Ecology, evolution and ecophysiology

Recent developments and quality of research

Population ecology, population genetics and evolutionary ecology have been at the cutting edge of international research for decades. There is enough critical mass and the disciplines are well placed to retain their current position as long as resource allocation remains on a growth track. Most of the research is focused on animals. Despite the funding made available, there are just a few top researchers in the field of plant ecology. One of the main pillars of biodiversity research, i.e. taxonomy and systematics, has remained very much in the background, but is now showing signs of growth and greater internationalisation. Nevertheless, the development of this field depends on the contribution of just a few individuals. Ecological research on water systems has developed vigorously over the past 5–10 years, adopting a stronger international orientation and more diverse approaches. Ecophysiology has long been an internationally strong field, but the cutting edge of the field remains relatively narrow.

The strengths of ecological, genetic and ecophysiological research derive from the early internationalisation of these fields, their strong conceptual and empirical skills and competencies, and the integration of their approaches. The scientific impact of these fields is impressive indeed, especially following the creation of new conceptual trends and paradigm changes, but publishing and citation statistics are also strong. Taxonomy and systematics have suffered from lack of structure and a scarcity of education. The current growth is driven by strong research, internationalisation and links with graduate schools in the field of ecology. Water research has suffered from the lack of a conceptual, modelling-driven and problem-oriented approach. The current trends of growth and internationalisation are helping to resolve these problems. The 2007 evaluation of water research showed that the funding injected into the field through several research programmes and other activities has produced good results, and water research now stands up to international scrutiny.

Research conducted at the intersection of ecology, evolutionary theory, physiology and genetics, functional genomics in particular, is emerging as a major focus of biological research. Genetic research produces tremendous amounts of genomic information, and the application of that information at individual and population level requires expertise that is in short supply in Finland. Integration of the skills and knowledge acquired in these fields can also contribute to knowledge production in medicine, for example. In the field of conservation biology, the focus has shifted from crisis research to anticipatory approaches on the back of strong mathematical skills. Already the knowledge deriving from this research has been put to practical use in the setting of fishing quota and in the allocation of conservation areas. This field of research is bound to gain even greater currency with the advance of climate change and other environmental threats. Evolutionary ecology is currently a very strong discipline in Finland, and it has many applications in various research environments. It is a conceptually unified discipline with a coherent theoretical framework, which helps to facilitate communication and interaction. Evolutionary ecology is also having increasing impact in practical applications, especially in the human sciences. Water research plays a crucial role in the protection of water systems. The challenge, then, is how to integrate ecology with water research and social research. Water is emerging as an increasingly important political issue, both as a natural resource in its own right and as a source of nutrition.

Publishing activity has been very high in Finland throughout the period under review, and it is continuing to rise. In 1991–1993, Finnish researchers published 0.8 articles per 10,000 population; by 2003–2005, this figure had increased by more than 200 per cent to 2.5. Finland and Sweden stand clearly apart from the rest of the field in terms of their publishing activity throughout the period concerned. Sweden led the way in the 1990s, but in the 2000s it has been overtaken by Finland. Publishing activity has shown a strong upward trend during the whole period. Publishing activity in Finland was three times higher than in the United States and ten times higher than in Japan (see Appendix 1b).

In line with the trend seen in all other countries, the citation impact for ecology has risen in Finland; the latest figure stands at 4.7. The UK and Swedish citation impacts are still somewhat higher than in Finland, whereas the United States citation impact is lower than Finland's. In Finland the citation impact has shown particularly strong growth in the 2000s (see Appendix 2b).

The citations received by publications in ecology have been above the world average throughout the period under review. Citations received by Finnish publications exceeded the world average most notably in the early 1990s, but the figures have remained consistently high, despite growing international competition (see Appendix

3b). A strong cluster of highly cited publications occurred in the early 1990s, when each year the number of these publications clearly exceeded the statistical average. The strongest period was 1991–1994, when up to 3.3 per cent of the ecology articles published by Finnish researchers ranked among the highly cited publications (see Appendix 4b).

International engagement, mobility and cooperation

International engagement is strong in this field of research, both in terms of mobility and cooperation across national borders. Most research teams have several contacts and joint publications with colleagues abroad, often over long periods of time. Furthermore, the main publishing forums are international, and Finnish researchers have a strong representation in various international positions of trust. Early internationalisation has significantly contributed to the growth of ecology, ecophysiology and genetics, and the same trend is evident in other fields that have recently embarked on the path of internationalisation. The main partners in cooperation are based in the strongest science nations, but there is also much collaboration with universities and research institutes in Asia, South America and Russia. The selection of partners is chiefly determined by research subjects or special areas of competence.

The strongest units within this field of research in particular have seen a considerable influx of foreign researchers. Finnish researchers, too, are moving in increasing numbers to work abroad, although there still remain many practical obstacles. The mobility of both newly graduated and more experienced researchers both at home and internationally should be encouraged in connection with funding decisions and through various funding instruments.

Development needs

There is a strong trend internationally to integrate evolutionary and ecological perspectives with developmental biology and genomics. In Finland this trend is hampered primarily by the high costs of obtaining genomic data and by the poor availability of infrastructure, as well as by the lack of bioinformatics experts. The recent decision to close down a major centre for water research and to merge it with other units must not be allowed to jeopardise the maintenance and development of the key resources of water research, i.e. research vessels and other infrastructure. Finland has a uniquely comprehensive network of research stations, helping to take it to the very cutting edge of research in this field. That position of strength can only be retained if there is an ongoing commitment to improve and upgrade the equipment at these stations and to develop these fields of research. Follow-up studies that comprise long time series produce unique information and make it possible to monitor and analyse long-term changes and their consequences. Responsibility for the compilation and maintenance of these time series data rests with museums and other government research institutes. It is crucial that the continuity of time series can be guaranteed and that existing follow-up and other databases can be made available for broader use. This requires the coordination of data storage formats and continued efforts to make them more user-friendly, both for the end-user and for those coding and storing the data.

Food science

Recent developments and quality of research

Food science has broad-ranging responsibility for the safety and healthiness of food that extends from primary production through to human consumption. This requires a multidisciplinary research effort in close collaboration with different players, including the food industry. The overall standard of research in food science is high, and it is highly respected both at home and abroad. The closely related field of nutrition research is very strong, and standards of food safety are exceptionally high (see discipline assessment 2000–2004). There is one Centre of Excellence in the area of microbiological safety, which greatly helps to increase the visibility of research in this field.

The position and future outlook of food research have changed considerably in recent years. The need for research and its perceived importance have continued to grow, in part as a result of the internationalisation of the food industry. Issues of global responsibility, including the adequacy of the food supply worldwide, sustainable food economy, sustainable consumption choices, nutrient loads, environmental issues and climate change, are set to gain increasing importance in the future, which should also be reflected in national education and research in food science. Key areas of future research will include the safety of the food chain and the supply of food. The focus here must be turned to such questions as the impacts of climate change on agriculture (e.g. biodiversity), the use of raw materials (bioprocess technology, gene technology, biotechnology, nanotechnology), food safety (quality, traceability) and the impacts of food and raw material development on rising food prices. The promotion of health through food intake must also remain a priority concern in the allocation of research efforts.

One of the problems in this field is the fragmentation of research, which often makes it difficult to achieve sufficient critical mass. Funding for research comes, among other sources, from several ministries, which only adds to the fragmentation and causes unnecessary overlap. Basic research must also be strengthened in order to catch up with the international forefront in all areas of research. Another difficulty is that despite its close links with the food industry, research lacks the domestic partners that could put its results to practical use.

Publishing activity in food science has doubled during the period under review. Publishing activity in Finland was almost 1.5 times higher than in Sweden, which ranked second throughout this period. Even so the number of publications is no more than 0.6 per 10,000 population. This continues to remain a fairly small and low-visibility field. Publishing activity in Finland is more than twice as high as in the United States and five times higher than in Japan (see Appendix 1c).

Finland's citation impact has shown strong growth during the period under review. The figure for 2001–2005, at 4.9, is higher than in any of the other countries in the comparison. The second highest figure is recorded for the UK at 4.3. The Finnish citation impact is more than twice as high as the Japanese and German figures. Finland has also recorded the fastest growth rate throughout the period under review (see Appendix 2c).

A comparison of the number of citations received by Finnish publications with the world average shows that food science has performed at a consistently high level throughout the period under review. The citation numbers exceed the average for the field of research across the whole period. The strongest years occur just before and after the turn of the millennium. Viewed in these terms, Finnish food science is an internationally very strong field indeed (see Appendix 3c). Measured in terms of the proportion of highly cited publications, food science has performed very strongly since the mid-1990s, particularly during the period from 1998 to 2003. In recent years the proportion of highly cited publications has decreased to some extent (see Appendix 4c).

International engagement, mobility and cooperation

Research in this field has a strong international element. Most research teams collaborate with international groups and institutions either on the strength of EU funding or in the context of Nordic research projects and among other things produce joint publications. The most important research partners are based in Europe and the United States. Finnish expertise in the food sector has a strong representation in organisations such as the European Food Safety Authority (EFSA) and the International Life Sciences (ILSI).

There are excellent PhD education programmes in food science abroad, but the problem is that there are not enough people willing to leave Finland. Indeed, a major priority in the development of postgraduate training must now be to encourage international mobility, bearing in mind that many researchers have family commitments. Finnish research teams have for their part been recruiting increasing numbers of foreign staff (both PhD and postdoctoral researchers), and this trend deserves to be supported. International engagement should also be enhanced by increasing the number of FiDiPro professorships. Continued attention must also be given to increasing domestic mobility, for instance by giving priority in funding decisions to projects in which the researcher switches from one team to another.

Further efforts are needed to improve the cooperation and coordination of food science research teams based at different universities and research institutes. This would help to eliminate unnecessary research overlap and improve the allocation of scarce resources and so support the push towards the international forefront. Interdisciplinary mobility should be encouraged and increased above all in the field of primary production. Multidisciplinary cooperation is particularly important in this field because research in the forest sector, for instance, can deliver useful new innovations for the food sector.

Development needs

Targeted steps are needed to address the problem of fragmentation that often causes overlap in both funding and research. Programme-based research funding can go a long way towards achieving this goal. Joint professorships are another way of increasing efficiency.

Infrastructure maintenance and development calls for closer cooperation among the various players in this field among other reasons so that the necessary pilot level equipment can be acquired (including bioprocess technology).

A review is needed in the food sector to project the demand for PhDs over the next ten years.

Plant biology, plant molecular biology and plant biotechnology

Recent developments and quality of research

In Finland the development of plant biology, plant molecular biology and plant biotechnology got underway at a time when elsewhere the discipline of plant molecular biology was still very much in its infancy. Initially, during the 1980s, researchers in this field moved abroad to learn the methods and gain the necessary qualifications, for instance to Sweden, Belgium and the United States. This also served the purpose of establishing contacts with major international research centres in the field. The development of this field is and will continue to be heavily influenced by the breakthrough of genomics and by the exponential advances in technology. The development and declining costs of sequencing technology and the improved conditions for comparative research are opening up immense research opportunities, some of which are not yet known. Over the next 10 years, the sequencing of the genome of plant species will become increasingly routine in research, and this will pave the way to studies concerned with plant hydrogen production, epigenomics and plant growth. At the same time, the potential will be created for new economic and technological applications; examples include the effective ingredients in medicines and the use of secondary flows in energy generation. The increased flow of data about the genomes of plant species will also increase the amount of bioinformation and in silico research and create growing demand for knowledge and information management competencies.

Finland is known around the world for the strength of its research in the field of plant biology. This strength has also translated into high visibility and a high level of international engagement. There are currently two Academy Professors and two Centres of Excellence in this field, which also has a national graduate school. Postgraduate training is nationally coordinated.

The strength of plant biology in Finland is to some extent obscured by the combined international classification (Plant and Animal Science in Thomson Scientific), with weaker disciplines reflecting adversely on plant biology. Under this classification, part of the production of top-level plant biologists is allocated to other disciplines. For example, research in plant pathology is predominantly classified under agricultural sciences and photosynthesis research under biochemistry. The strength of this field has been achieved through hard work, innovation and generous funding for basic research, which is crucial to retaining the success of any field of research in a small country like Finland. Another source of strength is that research in this field is concentrated in biocentres, which have a sound infrastructure.

The greatest weakness of the field comes from its fragmented structure. Departments and universities are small, and there are signs of fragmentation even within institutions. There are fears that in the future, the number of Finnish students may decline to levels that are not enough to sustain the next generations of researchers. On the other hand, the number of foreign postdoctoral students coming to Finland is high and rising. Another source of future concern is that mobility from Finland to other countries and between universities has decreased far too sharply in recent years, particularly so after PhD graduation. Although the research infrastructure in place is sound and up to date, this may become a critical factor in the future. The growing pressures to engage in innovation and strategic research may represent a threat to the adequacy of funding for basic research. More support is needed for basic research, which is what lays the foundation for applied research. Finland is such a small country that it cannot afford not to do basic research.

Key areas of strength in this field include stress, photosynthesis and signal transduction studies as well as work in the fields of developmental biology and secondary metabolism. Finnish researchers in this field are interested to study not only model organisms, but also other plants such as trees, cereals and other cultivated plants, medical plants and berries, which means that this work is close to practical applications. Basic research with trees is of a particularly high quality and often involves the practical aspect of application. Finland is also well-known for both its basic and applied research in berries.

There is intense pressure to take a more practical and applied approach in research, not only in Finland but internationally. The supply and price of food, renewable energy and climate change present new important (both national and international) research problems, and the expectations of the general public are putting new pressures on plant research. Securing food production and biological energy production are questions of great importance to society, as is the prevention of and adaptation to climate change. The use of plants in the production of chemicals and multiple uses of plants represent new emerging fields of study.

Plant biology has had high international visibility since the early 1990s. Visibility has developed favourably throughout the period under review, and during the 2000s publishing activity has been the highest among the countries included in the comparisons, at practically the same level as in Sweden. Publishing activity in Finland is three or four times higher than in many other countries such as Japan, Germany, France and the United States (see Appendix 1d). Finland's citation impact is lower than in any other country in this comparison during the 2000s, despite rising from 2.8 to 3.8. It seems that in the reference countries, citation impacts have risen more sharply than in Finland (see Appendix 2d). With the exception of a few years in the early 2000s, the number of citations received by Finnish publications are slightly below the world average (see Appendix 3d). The proportion of highly cited publications is consistently below the world average, but there is a clear rising trend from 2001 through to 2007, when the proportion is exactly at the expected value (see Appendix 4d).

International engagement, mobility and cooperation

There are strong pressures now, both nationally and internationally, to move towards more practical and applications-driven research. Work at the newly founded Strategic Centres in the forest, health and energy clusters is well under way, and the field of plant biology has clear points of contact with all of them.

Finland has been closely involved in the strategy work undertaken in European technology platforms (e.g. "Plants for the Future") and contributed to their strategic research agendas (SRA). This has already been reflected in the plant biology calls opened under EU FP7. The decision that now needs to be made is whether, based on the European SRA, Finland too should develop a national plant research strategy to provide guidance and direction for funding agencies.

Most EU funding today goes to applied research. Bioenergy will play a major role in the refocusing of funding. Bioenergy programmes have been launched in a number of European countries, and there is strong demand particularly for interdisciplinary bioenergy research (Science policy brief: European Science Foundation). Finland has been closely involved in this work and steps are now needed to create a third generation (multidisciplinary and interdisciplinary) bioenergy research strategy.

One cause for future concern stems from the reduced mobility of researchers during their doctoral education, especially at the postdoctoral stage, both from Finland to other countries and between universities. There is no shortage of opportunities for exchange, but those opportunities are not being put to the best possible use. Long periods spent abroad help to build up the researcher's independence and ability to take risks, and facilitate new openings and new contacts. People who spend long periods abroad are more likely than others to achieve greater success in their future work. There are also indications that mobility has assumed different forms: students are now moving abroad for shorter periods and are constantly on the move.

Development needs

Research methods in this field are developing very rapidly, which in the future will require the creation of both national and international infrastructure that is readily available. Researchers in the field should have equal access to this infrastructure so that the high costs of the methods required do not become prohibitive. The volume of *in silico* analysis of ready information is set to increase. It is important that the significance of basic research is appreciated regardless of the global and national economic situation, because there can be no applications without the foundation provided by basic research. The major challenges faced by society – food, the price of food, local food, energy, welfare, the environment – can only be properly addressed on the strength of interdisciplinary research. In the best case interdisciplinarity generates added value for research, but this also requires that the evaluation criteria applied in research funding are interdisciplinary. In the future continued efforts are needed to strengthen the impact of scientific research.

Geography and regional studies

Recent developments and quality of research

The main justification for this field of research was long provided by the role of geography and regional studies as a 'national discipline'. Until the 1980s, research results from this discipline were predominantly published in domestic journals. However, with the rapid internationalisation of the Finnish research system from the 1990s onwards, research practices have been changing in the field of geography and regional studies, too. There are now a number of researchers in this field whose career, from the very outset, has been genuinely international. This is seen in the rising quality of research, as evidenced by the excellent reviews received by university units in recent assessments. For example, the units at Tampere, Oulu and Joensuu were ranked among the best performers of their respective universities when their research was compared with international standards. Not all units have as yet been comprehensively reviewed.

Geography and regional studies are characterised by networking across disciplinary boundaries. This has contributed to the growth of several strong lines of research inquiry at the same time. These include environmental research, including studies of the hybridity of nature and society; political geography, including studies focusing on culture, the economy and management; research into regional development and governance, including development studies; cultural geography; the study of urban and rural areas, including urban and rural policy; research on natural resource use; hydrogeography; coastal and flood research; the geomorphology of cold climates and frost research; geoinformatics and regional modelling studies; research in spatial information applications; studies of tourism; and research on geographic methodology.

Through these areas, Finnish scientists and researchers have contributed extensively to international hot spot research on such topics as globalisation, the hybridity of nature and culture as well as society and technology, scale theory, the methodology of topological space and new spatial information methods and applications. There are also multiple interfaces with research in the natural sciences, social sciences and the humanities, creating opportunities for innovative new openings.

Geography and regional studies have always produced information that immediately benefits society. Research in this field has significantly influenced the development of regional policy, for instance. Current research is contributing to a deeper understanding of global environmental issues (research on development, community structure, energy, transport and flood risks), the understanding and management of changes in regional development, the use and protection of natural resources, the development of land use planning and participation, and studies of tourism. Many of the key research issues include the aspect of global-local interaction, such as questions about the changing social and regional structure, the management of climate change, migration, and regional and social divisions.

It is not possible to conduct the same kind of detailed bibliometric analysis for geography as has been done above for other disciplines, for data are only available on how geographic publications compare with world average citations and the proportion of highly cited publications. In this comparison the most significant five-year period comes in the late 1990s. In addition, the figures for the last couple of years of the period under review (2006–2007) clearly exceeded the international reference values (see Appendix 3e). It seems that the proportion of highly cited publications was also highest during this same period. Figures for 1998–2000 are particularly high. In 2006–2007 the proportion of highly cited publications also exceeded the expected value, although not as clearly as in the late 1990s (see Appendix 4e).

International engagement, mobility and cooperation

The internationalisation of geography and regional studies has been clearly reflected in their main areas of strength, but the pronounced national characteristic of this field has remained unaffected. Although some of the research subjects have become internationalised, this field continues to produce information that is directly relevant to society and that could not and would not be produced without the involvement of Finnish researchers. Indeed internationalisation in this field has come about as a result of researcher mobility, research cooperation and the diversification of publishing channels, not because important domestic research subjects have been dropped.

Researchers in this field have good network relations with leading international scholars and research teams. These contacts are formed in various different ways. Important channels of contact include close research collaborations and active involvement in the editorial boards of international journals and other advisory positions (appointments, reviews and evaluations, positions of trust). One indication of just how successful this drive to internationalisation has been is the common assessment that, outside of the English-speaking world, the most interesting research in political geography comes from Finland. Good skills of science communication in the English language are an important asset for researchers in this field. One of their biggest challenges, on the other hand, is how to follow research and developments published in other than the English language.

Development needs

The results of basic research in this field are nowadays widely published in international journals and series. This trend must be further reinforced by supporting international publishing from the earliest stages of PhD education. One of the difficulties is that even though research in this field is very much a team effort, it has a strong tradition of single-author publishing. With the expansion of researcher training, PhD students do much of their basic research under the supervision of senior researchers. Indeed, one way of raising the quality of work in this field is to allocate resources in such a way as to create better framework conditions for senior researchers, too. One concrete way of moving forward would be to increase the number of professorships and so reduce the number of undergraduate and postgraduate students in relation to the number of teaching and research staff.

Another important development need comes from the rapid growth of international research cooperation. It is imperative that international funding as a proportion of total research funding in this field is increased, for that would allow Finnish researchers to tackle internationally significant challenges, such as globalisation, the use of natural resources and the interweaving of ecological and social processes.

Agriculture and forestry

Recent developments and quality of research

Research needs in the field of agricultural sciences have changed rapidly with the emergence of new challenges in primary production and related manufacturing. Rising food prices, the challenges of climate change and advances in production technology have created new research needs in the field of agricultural research, both with regard to content and methods development. The international food market is in greater turmoil than ever since the Second World War, and research must get back to the very basics of food production as both plant production and overall productivity growth have slowed significantly at the same time as the world population is continuing to increase. The forest sector, for its part, is poised for the most dramatic changes it has seen for decades, and research must be able to respond to the needs for change related to both products and frameworks of practice.

In response to the rapid pace of change, the research community is expected to come up with significant new scientific innovations that in turn will trigger other, business-generating innovations. Science and research policy in this field must provide clearer direction to the research community in terms of how research should be targeted. Should climate change be tackled with a view to slowing the process or adapting to it? What action should be taken to try and save the Baltic Sea? Should efforts be made to try and support the viability of businesses? Should the global problems of primary production be tackled and how? It is crucial that the scientific community in a small country like Finland pools its resources and openly addresses questions around the freedom of Finnish science and research and the international division of labour in research.

Cutting-edge research in the field of agriculture and forestry is traditionally, and with good reason, focused on the boreal environment. This line of research has no other option than to address national questions because the northern location of our country means that the results of the extensive field research cannot be tested anywhere else. The length of the day and its relationship to temperatures, the winter and the growing season are all globally unique. For instance, research concerned with plant choices and plant pests is typically in the hands of national researchers. The world-leading forest industry cluster, on the other hand, channels significant international challenges to the Finnish research community. The tropical tree plantations established by the Finnish forest industry represent significant sources for fibre and energy production. Finnish research in this field is well respected, but in view of the current international demand it is clear that greater effort is needed to step up researcher training.

There are a number of areas that produce high-quality and internationally respected research; examples include economics and environmental economics in particular, which are based on the foundations of empirical research that leans on strong theoretical principles and on the use of new numeric techniques. Centres of Excellence in the field of forest ecology are at the international cutting edge. Strong research teams have also developed in the fields of biotechnology and genomics research, which is among the most internationalised of the agricultural sciences. Researchers in this field are working closely with colleagues in Sweden to develop interesting biotechnology and genomics methods for use in forest research.

Major areas of focus over the next few years will include climate change, bioenergy, biotechnology and, in the forest sector, new products and practices. In situations where new research capacity is being created, the Academy has an increasingly prominent role to play in deciding on the allocation of research funding. With the unfolding of climate change, there is growing need for multidisciplinary research in a number of areas from market changes to plant production potential. Market performance and conditions for competition are closely tied up with climate relevant environmental policy. Rather than aiming to support and bolster existing programmes, research in the field of agriculture and forestry must be focused on opening new approaches to the development of future strategy and policy programmes.

Research in the bioenergy field has shown a strong national and practical focus, and there is no hard core basic research. Economics research in this field has the closest links with international basic research. Compared to the investments made in bioenergy research, there is a relative scarcity of work concerned with bioenergy plants and with securing access to raw materials. The connections between food and bioenergy markets present a considerable challenge for multidisciplinary research. Risk management and security of supply as well as weather derivates in the food and energy market are important new areas for future research. The Academy has a significant role to play in developing a strong platform for basic research that can become genuinely competitive and meet the needs of society.

Biotechnology research in the field of agriculture and forestry has developed very rapidly. In the future, it will be expected to address and resolve the increasingly complex problems around the development of primary production and processing. The global forest sector needs international biotechnology expertise that can direct research across wide geographical areas. In-depth and innovative biotechnology research is also crucial to developing the new products that are needed in the forest sector. One of the tasks assigned to the Academy of Finland is to safeguard the framework conditions for research at the field stations that are widely used in agriculture and forestry. The network of research stations operated by universities and sectoral research institutes is a major national infrastructure that is used both by national Centres of Excellence and increasingly by international research teams. Continued efforts are needed to ensure and improve the performance of this network as well as its internal division of labour.

Relative publication output in agriculture and forestry research has shown hardly any increase during the period under review. In fact, the number of research publications dipped in the mid-1990s, only to return to its original level. Nevertheless, publishing activity in Finland is higher than in any other reference country throughout this period. In 2003–2005, researchers in Finland published 0.6 articles and their colleagues in Sweden (who ranked second in this comparison) around 0.5 articles per 10,000 population (see Appendix 1e).

In a comparison of citation impacts, Finland comes second only to the United States. Finnish articles have received on average 3.9 citations, while the corresponding figure for US publications is 4.6 citations. Citation impact growth has been strongest of all in Finland, increasing almost threefold during the period under review (see Appendix 2e).

Measured in terms of relative citation impact, the trends for different disciplines in the agricultural sciences have been variable over time. Forestry sciences were very strong in the early 1990s, but since then their relative citation impact has decreased markedly (see Appendix 4fb). In agriculture, the trends have moved in the opposite direction: in the early 1990s the relative citation impact was below the world average, but from the mid-1990s through to 2003 increased quite steadily. The trend for the last couple of years has been rather slower, but even so remains well above the world average (see Appendix 3fa). An analysis of the proportion of highly cited publications produces a very similar picture. Agricultural research has shown particularly strong performance in 2000–2003, and in general it has lived up to expectations. The number of highly cited publications fell short of the statistical expectation value only in the early 1990s. This same period marks the strongest years for the number of highly cited publications in forestry research (see Appendix 4fb).

International engagement, mobility and cooperation

In forestry the growth of international publishing has been faster than average, and both the number of publications and the number of citations received by Finnish publications have increased significantly. Although Finland enjoys a strong international reputation in this field, world-leading researchers have been recruited here to a lesser extent than to its main rival countries. Likewise, only comparatively few Finnish researchers have been recruited to take charge of leading research teams in other countries. The first FiDiPro professor in the field of agriculture and forestry was appointed in 2008.

The number of foreign nationals as a proportion of all postgraduate students has traditionally been higher in agricultural sciences than in other fields, and during the 2000s their number has increased very sharply indeed. By contrast the number of visits by Finnish university researchers to foreign universities and research institutes has dropped and their duration has become shorter as compared to the 1990s.

Development needs

Agriculture and forestry make extensive use of methods from different disciplines, and development needs in this field are similar to those in other disciplines hosted by the Research Council. For agricultural sciences, the nationwide network of research and field stations is important both for domestic research needs and for their rapidly expanding international cooperation. It is also crucial that the resources needed for extensive and long-term field experiments are secured because many of the series of experiments that have been going on for decades are unique and crucially important for future research.

Microbiology

Recent developments and quality of research

Microbiology is well represented in the Finnish science field. It has points of intersection with medicine, food science, biotechnology and environmental sciences. Its major areas of strength include research in microbial pathogenesis, virology, research in lactic acid bacteria, research in yeasts and flagellated molds, water microbiology and environmental microbiology. There are two Centres of Excellence in the microbiology field. There are also long-standing traditions in industrial application. Future development efforts should be focused on improving diagnostics and environmentally sound production (microbes as production and cleaning agents) and on addressing the challenges of climate change. Microbiology is interested to explore life phenomena on multiple scales, which means it is excellently placed to collect megadata on the functioning of the environment. The processing of this data requires highly sophisticated computational methods and mathematical thinking.

The growing world population density and increasing travel are giving rise to new microbial diseases such as zoonoses. Other health threats include plant diseases spreading from the south, water contamination and the health of forest trees as well as new disease-causing bacteria. To resolve the problem of antibiotic resistance, it is necessary to find new medicines that can prevent the effect of virulence factors. Modern methods of intensive production also have the effect of increasing virulence: therefore there is a current need for research on the evolution of virulence and on the arms race between microbe and host.

Research in the field of microbiology is under-resourced, posing a threat to the continuity of high-level basic research. More research posts and professorships are needed. Basic research in microbiology must be stepped up. The foundations of research funding must be shored up with a view to securing access to longer-term funding. The volume of education should be increased and its level raised. There is need for the creation of a top-level teaching unit in microbiology. The Academy and universities must take steps to increase the availability of resources for basic research. Funding for basic research must include some allocations for purposes of applications projects because Tekes (the Finnish Funding Agency for Technology and Innovation) does not provide funding for high-risk research. The point is often made in public debate that basic research is far removed from applications, but in the field of microbiology basic research can in fact lead to applications very quickly. This needs to be advertised more.

Among the perceived weaknesses of this field are its geographical dispersion and the limited number of research staff. In addition, microbiology is fragmented into a large number of areas. There is not enough exchange and interaction between these areas. Indeed, a forum is needed where experts in this field could meet on a regular basis. There is, however, much international and interdisciplinary cooperation, and the training system is well structured.

Publishing activity in microbiology has increased since the early 1990s and now stands at the internationally high level of 1.1 articles per 10,000 population. Only researchers in Sweden (1.3 articles/10,000 population) publish more than their colleagues in Finland. Publishing activity is almost twice as high as in Germany, France and the United States, and almost three times as high as in Japan. Publishing activity has increased by more than 40 per cent during the period under review (see Appendix 1f).

The microbiology citation impact at 6.4 is the second lowest among the reference countries; only Japan has a lower citation impact. The highest citation impact is recorded for the United States. The figures are also high for the other major science nations with the exception of Japan. These countries' lead over Finland has increased during the period under review (see Appendix 2f).

Compared to world average citations, Finnish microbiology was at its strongest in the latter half of the 1990s. In some of the years during this period, citation numbers for Finnish articles exceeded the world average. Otherwise the rate of citations in relation to the world average has been below 1, i.e. Finnish articles have received less citations than world articles on average (see Appendix 3g). Measured in terms of the proportion of highly cited publications, microbiology's strongest years were in 1994–1997, when the figure exceeded the expected rate for the discipline (see Appendix 4g).

International engagement, mobility and cooperation

The field of microbiology has long-standing traditions, and researchers in the field have had ample time and opportunity to form international networks. Scientists and researchers contribute actively to all major international congresses in this field, organise conferences in Finland and continue to establish new contacts of cooperation. They are also actively involved in international organisations. Researcher mobility is considered extremely important, and there is some concern over the fact that younger researchers are not as keen to move abroad for periods of postdoctoral education. This experience in a different research environment would, however, be extremely valuable when researchers return home to set up their own teams – and ideally their own line of research inquiry. There is currently strong international and interdisciplinary cooperation, all of which is researcher-driven – as it should be.

Development needs

Microbiology researchers should seek to publish in more prestigious and higher quality international journals in order to increase the quality and visibility of their work. Efforts are also needed to step up national cooperation and interaction for instance through the organisation of an annual conference and the streamlining of basic studies. Communications must be increased both at home and internationally to generate better publicity.

The amount of time that PhD students work on their doctoral thesis must be reduced to speed up the launch of research careers. A graduate school should be founded to create more effective and more appealing PhD programmes, for which there is a definite demand. Sustainable production and the use of renewable natural resources are expanding the field of biotechnology, where there is a growing demand for experts with a basic education in microbiology. It is hoped that new technology will be created in Finland that can make good use of the know-how in this field. The people working to develop these new technologies and to set up new businesses in the field should have a PhD-level education. Business interest in PhD education should be increased by appointing business representatives to the boards of graduate schools and by increasing the number of training courses oriented to business and industry.

Neuroscience and animal physiology

Recent developments and quality of research

Neuroscience is unquestionably a discipline for the future. A crucial requirement for its success is to take a broad and inclusive view of the field. Optimally, success in this field requires the application of molecular level and (cell) physiological information to dynamic brain imaging in animals or humans and the application of these results to behavioural sciences. Identification of the genes associated with different nervous system functions provides a solid foundation for this endeavour. In addition, it is essential that sufficient critical mass, the necessary research infrastructures and high-level knowledge, skills and competencies are in place in the field of neurosciences. Neuroscience has important technical and clinical applications to offer and it can have a major social impact, but steps are needed to increase awareness of this potential.

Neuroscience is one of the largest disciplines in Finland, but it still does not appear as a separate heading in the Academy's classification, for instance. It is only during the past 5–10 years that neuroscience has been recognized as a distinct discipline. There are currently two major research centres in Finland, one in Helsinki and one in Kuopio, each with a different focus – which can also be regarded as a strength. Education in the field is organised on a regional basis, but research is internationally oriented. The focused research teams should invest greater effort in national cooperation, too. International networking is largely motivated by gaining access to specific infrastructures. The Academy of Finland provides funding for neuroscience research through all four of its Research Councils, and there is recognition now of the need to identify neuroscience as an independent discipline.

Sweden is ahead of Finland in the field of neuroscience research, with the Karolinska Institutet and Lund University representing strong research bases. Sweden's lead is chiefly attributable to its systematic recruitment in the field and to the availability of start-up resources for new incumbents. It is important that the high standards of research are maintained in Finland, for only this can guarantee access to projects at the international cutting edge. There is adequate research potential in Finland, but in view of the resources available the likelihood of significant breakthroughs is greater elsewhere.

An important part of the intellectual tradition and training in the field of neuroscience research is animal physiology (including integrative thinking processes), which has provided a number of useful models for application in neuroscience and other biological disciplines (e.g. *D.melanogaster*, *C. elegans*, *D.rerio*).

Publishing in neuroscience and physiology has increased consistently since the early 1990s. Throughout the period under review, Finland's publishing rates relative to population have been second highest only to Sweden. The gap to Sweden has narrowed during this period. Publishing in Finland has increased by over 50 per cent. The current publishing rate is 2.6 articles per 10,000 population, compared to 3.0 in Sweden. The lowest rate in this comparison is recorded for Japan, with figures consistently below one throughout the period under review. Finland's citation impact for neuroscience and physiology at 6.3 is the second lowest among the reference countries, but lags only marginally behind France. It has grown faster than anywhere else, but this is partly explained by its low initial level (see Appendix 2g). Finnish articles receive less citations than the world average, and the proportion of highly cited publications is lower than the expectation value (see Appendices 3h and 4h).

International exchange, mobility and cooperation

Most research teams in the field have international partnerships and are involved in various EU-funded or Nordic projects, producing joint publications with these projects. The main partners are based in Europe, Japan and the United States. It is important that the high quality of research is maintained in Finland, for only this can guarantee access to projects at the international cutting edge and provide the potential for significant breakthroughs. Finnish business and industry in particular would benefit from significant breakthroughs in Finland. It is also important that there is the necessary expertise in Finland for methods applications and for the practical application of international innovations. There is adequate research potential in Finland, but in view of the resources available the likelihood of significant breakthroughs is greater elsewhere, for instance in Sweden. However, some international breakthroughs have already been achieved in Finland. As in other fields, the main obstacle to mobility is the scarcity of financial resources. The problems are the greatest for researchers returning to Finland with no resources to continue the work they have started abroad. Neuroscience units in Finland have large numbers of foreign scientists, which provides at least some positive indication of the international appeal of the discipline. That appeal could be further enhanced by investing in unique infrastructures and above all in the skills and competencies of leading Finnish researchers. Greater attention should also be paid to the family needs of scientists moving to Finland, such as spouse employment and children's education.

Development needs

Neuroscience must be granted independent status at university level as well as in the classifications applied by the Academy and other funding agencies. 'Neurobiology' might be a useful category for the purposes of the Research Council for Biosciences and Environment.

There continue to remain some difficulties with the process of recruitment into research posts and professorships. Recruitment is slow and concerned only with the relative merits of applicants, without consideration to the positions into which they are being recruited. This is a problem that universities must address.

Vacancies for Academy Research Fellowships are only advertised in Finland, a lost opportunity with regard to attracting international interest. Research themes carry too much weight and the merits of applications too little weight in Academy decision-making on the allocation of research funding. A new Research Council dedicated to the biosciences needs to be created in the Academy so that scientists in this field do not have to compete with environmental researchers. The criteria for environmental research are completely different from those in the biofield. It is important that the selection criteria do not become too one-sided, for that would concentrate existing resources in ever fewer hands. It is imperative that funding is always allocated on the criterion of scientific quality.

To maintain the link between research and infrastructure, reviews of applications for infrastructure funding must also consider the respective applicants' research plans and the success they have had with their applications for research funding. Research infrastructures must be available for common use. Hardware and equipment staff are needed as well as staff to use research infrastructures as both are part of the infrastructure. Neuroscience is a discipline that relies more heavily than most on hardware and equipment, and access to the latest imaging and functional methods is often crucial for the publication of research results.

Funds must be made available for the repatriation of postdoctoral researchers. Universities must contribute to this effort by providing longer-term research posts for returning researchers.

The forthcoming evaluation of the Neuroscience Research Programme could involve a more extensive assessment of research in this field, including research in imaging. It is clear that computational sciences will gain increasing weight and influence within the neurosciences. The main bottleneck in this field is how to translate university innovations into practical applications. There is a shortage of high-quality basic research and good ideas, but on the other hand all good ideas and innovations never stand idle for very long. An independent group is needed to lobby this field of research (e.g. the Brain Foundation of Finland project). Researchers should be encouraged to join this effort in order to spread the burden.

Environmental sciences

Recent developments and quality of research

Research in environmental sciences comprises a large number of different fields and is often a multidisciplinary exercise. There is active work in a number of different areas, including research on the environment and natural resources, environmental sociology and policy, environmental economics, research on sustainable development, research on long-term changes (climate change and paleoecology), corporate environmental management and research on development countries.

Environmental research is a relatively new discipline in Finland, having started mainly during the 1970s. It is not yet fully established in the university system, which is clear from the limited number of teaching and research posts. However, the field has made good progress in recent years and international research cooperation has now got underway. The level of international visibility varies from one area to another in the environmental research field: many areas of natural scientific environmental research have already achieved significant visibility, but in many others these efforts are still in their infancy. There is currently very strong demand for social environmental research because of the growth of global environmental problems, particularly climate change. Indeed, the demand for experts in this field exceeds the supply, and neither universities nor graduate schools have adequate resources to meet existing training demands.

Natural sciences oriented environmental research is of outstanding excellence in Finland, although there are not very many names at the cutting edge. However, the situation is improving in many units. A tide of change is now sweeping the field of social environmental research. In environmental politics and environmental law, for instance, a scarcity of resources has made it necessary to focus investment in teaching, but with the increasing number of graduating PhDs, research is now gaining a stronger footing. There is a substantial need for more experts with an education in environmental policy, economics and law who could contribute to environmental policy drafting, especially in the field of climate policy. The demand for experts is also strong in business and industry.

Multidisciplinary research is one of the key strengths of environmental sciences. Finnish researchers have had the vision to combine different issues and aspects of complex natural resource issues. Multidisciplinary approaches are quite well established within natural scientific environmental research, and interdisciplinary work that integrates natural sciences and social sciences has also been on the increase. Traditionally strong areas of research in natural resources have included the application of economic theory in bioeconomic modelling, for instance in the context of research concerned with the use of fish and forest resources. Multidisciplinary research is not without its problems, however. There is certainly room for improvement in cooperation and coordination across disciplinary boundaries, and the existing scant resources are scattered across small units. National partners often find themselves competing for the same resources, which obviously hampers cooperation. Several units also lack sufficient critical mass, which effectively hampers investment in multidisciplinary research. Multidisciplinary research at the highest level is a truly demanding exercise which requires both skill and knowledge and adequate resources.

Sectoral research institutes play a very significant role in the field of environmental research. The Finnish Environment Institute, MTT Agrifood Research Finland and the Finnish Game and Fisheries Research Institute are all strong players in the field and have substantial staff resources. Every year they recruit large number of PhDs and PhD students, even though the provision of researcher training is not their primary mission. Sectoral research institutes are particularly well placed to promote and develop multidisciplinary research.

In view of its relatively scarce resources, environmental research has achieved good visibility. Because of its resource constraints the field has no choice but to focus on its existing areas of strength and to make strategic prioritisations. It is possible that with the strong growth of demand in the future, additional resources may be forthcoming for the development of research excellence. So far this demand has resulted in increased research activity funded from external sources, and the institutes' core resources have not increased at the same pace.

A bibliometric analysis of research productivity in environmental sciences has to be confined to comparisons with the world average citation rates and the proportion of highly cited publications. In this analysis the strongest period for environmental research was in the early 1990s, when citation rates for a few years clearly exceeded the world average. In the 2000s, the citation rates have been slightly below the world average. The figures for 2006 and 2007 are again above the world average, but still lower than the peak figures recorded in the 1990s (see Appendix 3i). The same pattern is repeated with the highly cited publications: the peak years for environmental research were in the early 1990s, and the number of highly cited publications exceeded the expected value in 2006–2007 (see Appendix 4i).

International exchange, mobility and cooperation

Environmental research has had strong international collaborations in many areas. Several research teams have significant cooperation especially with European partners, and much funding is received through EU framework programmes. International publishing has increased sharply. However, the tradition of domestic focus continues to weigh heavily on some fields of environmental research, such as environmental sociology and environmental history.

International mobility has to some extent been hampered by the lack of suitable funding for the doctoral student stage. Nonetheless, mobility has increased with the increased involvement in international projects, although it could still be at a higher level. It is still comparatively rare for foreign researchers to come and work in Finland. Indeed, research teams should invest greater effort in international recruitment.

Development needs

The main problems recognized with research careers have to do with working conditions: temporary and fixed-term contracts, pay levels and the lack of supervision are all major obstacles to advancement on the research career track. From the very outset of their studies it should be clear to postgraduate students what it is expected of them after they have completed their PhD, i.e. what exactly their training is aimed at. The development of workplace and methodological skills and competencies should be an increasingly integral part of postgraduate studies. The scarcity of teaching and research posts in environmental sciences represents a major impediment to career advancement for researchers, especially after the postdoctoral stage. This presents a significant future challenge for the Finnish scientific community: how to attract Finland's young, talented and internationally merited researchers back into the country.

Electronic datasets are an important part of the environmental research infrastructure that should be accessible to all universities and research institutes. Some research institutes have opened up their datasets to outside users (or are in the process of doing so), but for the most part these materials remain inaccessible to the rest of the scientific community. For instance, national spatial information and statistical datasets are protected and priced out of reach. The administration of research datasets should be nationally organised with a view to increasing the use of these materials. This will require national harmonisation as well as the creation of new user interfaces.

Research stations are important to environmental research, but the partial concentration of resources and facilities would allow for more effective capacity utilisation and support the development of a downsized network. The datasets generated by research stations are hugely valuable and they should be made more readily accessible for common research use. The infrastructures for environmental research included in the Finnish Infrastructure Roadmap – the Finnish Long-Term Socio-Ecological Research network (FinLTSER), Integrated Carbon Observation System (ICOS), Stations for Measuring the Forest Ecosystem - Atmosphere Relationships (SMEAR) and the Pallas-Sodankylä research station – are all high-quality, comprehensive and well-equipped networks for studying environmental interactions, and it is crucial that adequate funding is secured for them.

In the future environmental research will need to have access to new kinds of infrastructures so that it can tackle the challenges emanating from changing attitudes and consumer-driven environmental problems (e.g. climate change). One example of such an infrastructure is a standing national consumer panel. Administration of the panel should be centralised and its use should be based on open competition. The datasets produced by the panel should be accessible to the whole scientific community.

2 PhD Education and the Academic Research Career

PhD education

Graduate schools in the biosciences and environmental research field are extensively networked, and all of them share in common a commitment to international engagement and to providing systematic and high-quality postgraduate training. The graduate school system has contributed significantly to developing and accelerating the PhD process and to clarifying supervisory responsibilities in that process, and made it possible to offer a varied and extensive range of training programmes. The schools provide key skills and competencies that graduates will need in different career paths, and many of those graduates will eventually opt for a career outside academia. The career training provided by graduate schools has helped to give graduating PhDs a clearer understanding of their own skills and in this way helped them to find employment upon graduation.

Graduate schools are a major entry route to an academic career in science and research, and therefore it is crucial that the system is firmly grounded in high-quality research. For purposes of supervised and systematic postgraduate training it is essential that every university offering training in this field is integrated in the graduate school system.

Education

The aim of PhD education is to provide in-depth expertise as well as broad skills and competencies that are relevant not only to research within one's field, but also to other expert assignments. The more the students learn about universal approaches and methods, the easier it will be for them to find employment in both the public and private sector. Therefore a major focus in developing PhD education should be on general skills and knowledge, such as project management, communication and social skills. Scientific work, for its part, contributes to improving problem-solving skills and the ability to manage large projects.

It is nowadays possible to complete the PhD within a reasonably short space of time. Doctoral education provides the graduate with an adequate knowledge and understanding of the field in question as well as the capacities they will need to develop their competencies. Graduate school graduates have a strong methodological foundation, but sometimes they still lack in independence: in order to complete the PhD within the targeted time frame of four years, they will need to rely heavily on the guidance of their supervisor. Indeed, the length of PhD education should no longer be reduced, for students need time to mature. The scope of training in environmental and biosciences is also suitable. Apart from the completion of formal studies, another important aspect of doctoral education is the presentation and publication of research results. Publishing experience is hugely important and one of the key reasons why graduating PhDs in this field are in so much demand for postdoctoral positions abroad. However, it is not the quantity of publications that matters most, but rather the amount of work put into the PhD thesis and its quality. This should also be taken into account in university examination standards.

Graduate schools in the biosciences and environmental research field have significantly contributed to more systematic postgraduate training and to more effective supervision, which in turn has translated into a lower average age at doctorate. To further lower that age, the attention should now be turned to students' average age at university entry and to encouraging completion of the Master's degree and the PhD within the targeted time frame. It is easier for PhDs who graduate at a young age to transfer their skills to new jobs, and they are also internationally competitive. Furthermore, the postponement of graduation may restrict career options.

Cooperation

Graduate schools have close ties of cooperation with one another and with sectoral research institutes, and they are actively involved in international exchange as well. All of this facilitates the networking of PhD students and their growth as experts with broad-ranging skills and knowledge. Graduate schools in the biosciences and environmental field work closely in organising joint courses and meetings, which means that PhD students have good access to the education courses provided by different schools. However, it is important that cooperation among graduate schools is further intensified and that for reasons of economy they pool their resources to provide courses that build up general skills and competencies.

Recruitment of PhD students and pay

Key to the recruitment of PhD students is to have an open call process and a transparent selection process. The system must be so designed that it siphons the best PhD students for a career in science and research, and it is thought that a joint effort by graduate schools and university faculties to develop the selection process is a worthwhile option. To attract the most talented PhDs students, steps are needed to enhance the appeal and awareness of the Finnish graduate school system. The call for students should also be announced abroad, as visibly as possible. It is to be hoped that the Bologna Process will contribute to promoting international mobility and attracting European postgraduate students into Finland.

Low pay levels have detracted from the appeal of PhD education and an academic career in science and research. In order to address this situation and to reduce this inequality, resources must be made available to graduate schools so that they can bring their pay and benefits in line with the central government wage structure. Adequate pay levels must also be provided for graduate school coordinators, for they play a pivotal role in the operation of graduate schools.

The academic research career

Four-tiered research career model

The four-tiered research career model is intended to achieve a more transparent, predictable and egalitarian academic research career system that allows for more flexible movement from one career ladder to another and from one sector to another (Reports of the Ministry of Education 2008:15). The academic research career, according to this model, proceeds from PhD education to the postdoctoral stage, which is followed by Academy and university research fellowships and finally by the positions of Academy Professor, Professor and Research Director.

The Ministry of Education has set very high numerical targets for the completion of new PhD degrees each year. Only a proportion of those graduating each year can or are willing to pursue an academic career, and therefore PhD education programmes today are increasingly geared to providing students with in-depth expertise in order to enhance their competitiveness even outside the academic job market. It is extremely important that at the PhD education stage, students are made more clearly aware of their career options, both within and outside academia. This can be facilitated by appointing private sector or administration representatives to the graduate school's executive committee and by including administrative and business training courses in the graduate school curriculum. In the future, the first step on the research career ladder should increasingly be viewed as a stage that provides students not only with the skills and competencies they will need in their science and research career, but also in other expert assignments, and that the choice between these two options is predominantly made before progressing to the next step of the career ladder. This would help to ease the selection pressures that are currently somewhat unevenly divided between different stages of the academic research career, and at the same time the exit from the academic career can be appropriately timed. A bottleneck is currently developing in the stage following postdoctoral research, as there is a scarcity of Academy and university research fellowships relative to the number of applicants, and the merit requirements are very stringent indeed (the proportion of postdoctoral researchers who are awarded funding is about 30 per cent, compared to just 10 per cent for Academy Research Fellows). This has important implications for the independence of researchers, too: without a research post it is impossible to achieve independence, and it is impossible to gain that post without proof of funding and independence.

A career in science and research must be made a more attractive option in order to encourage the most talented people to seek such a career. This can be done among other things by developing more predictable career paths and longer-term funding instruments and by introducing more competitive pay packages.

International engagement

Finnish-educated PhDs are in high demand for international appointments. The main motive for leaving the country is to learn new knowledge, which in the ideal case is repatriated along with the returning researchers. It is necessary to have concrete incentives to encourage people to return. In addition, steps are needed to increase information about funding options available for returning researchers (the Academy's general research grants, Postdoctoral Researcher's projects, Academy Research Fellowships and various EU funding instruments). It is important to stress to PhD students, from the very outset, that they will need international experience to compete for the highest research posts. It is now possible for PhD students to make research visits lasting up to several months even during their training period, but opportunities for mobility should be improved even further. Long periods spent abroad bring all-round benefits, and it is therefore important that researchers are encouraged to move abroad even during the postdoctoral stage – although that must not be construed as a requirement. There is much more freedom of choice and quality research in Finland than before, and therefore it is no longer considered necessary to move abroad.

Funding instruments for researcher exchange must be further developed to make them attractive and suitable even for postdoctoral researchers and younger senior researchers. Funding for foreign researchers should include additional resources allocated to the host team, for that would help to foster closer collaboration between the visitor and the host team. When foreign researchers are involved in relevant projects and when they get publications to their name through that project, the arrangement has worked and the cooperation is likely to continue after the joint project as well.

Equality

There is a reasonably good gender balance in researcher training today. However, the clear majority of professors in Finland are still men. The situation looks set to improve among both senior researchers and professors as the proportion of women in both undergraduate and postgraduate training programmes today is continuing to increase, but the shift in balance will take some time to filter through with new appointments. It remains particularly difficult for women researchers to move abroad to study, and therefore continued efforts are needed to remove these obstacles.

Demand for PhDs and employment

PhD graduates in environmental and biosciences enjoy high rates of employment in a wide range of different jobs where their knowledge and skills benefit society as a whole. Most typically, PhD graduates are employed in public sector R&D jobs, but large numbers also find employment in the private sector. There remains some prejudice against the PhD in business and industry, although attitudes have already improved and there is increasing enrolment from outside academia in postgraduate training positions. Cross-sectoral funding opportunities are crucially important, and awareness of those opportunities needs to be increased. For example, funding for the completion of the PhD thesis while in gainful employment greatly facilitates postgraduate training, even though it is provided for a short period only.

In some fields of research there is in fact a shortage of PhDs, because of their high demand outside academia. A field-by-field review is needed of the future demand for PhDs, coupled with an in-depth study of the placement of PhDs. Views and opinions on the demand for PhDs should be collected from universities, research institutes and major business companies.

One other reason why graduating PhDs are reluctant to move abroad lies in the appeal of the local labour market: it is easy to pick and select one's job in Finland. The survey conducted in 2007 on internationalisation and the obstacles to internationalisation, on researcher exchange and exchange opportunities for researchers at the senior level should be repeated at regular intervals to assess the impact of existing support mechanisms and to identify new areas of development.

3 Research Infrastructures

Successful research depends on access to an appropriate infrastructure. Infrastructure requirements vary between different areas of biosciences and environmental research. In the biosciences virtually all fields have specific hardware and equipment requirements. In many fields of environmental research, on the other hand, the main infrastructure requirements include a network of research stations, observation systems, laboratories and statistical datasets. In the past 10 years, the need for molecular biology laboratories has increased sharply in environmental research, too, particularly in the fields of ecology, evolution and population genetics. Transgenic animals, equipment clusters and the management of different methods can also be considered important infrastructure. Infrastructure is needed both locally, regionally and internationally, which needs to be borne in mind in infrastructure design and development.

The current state of the research infrastructure in Finland is somewhat problematic and will require investment in the near future. Most of the existing infrastructure is close to research teams, which means that the defects and shortcomings are mainly local by nature. The scarcity of resources means that the local infrastructure is at risk of becoming outdated and remaining without maintenance. The European Molecular Biology Laboratory (EMBL) and other international infrastructures are crucially important to research, for they provide access to hardware and equipment that are beyond national budgets and to methods that have been developed in international cooperation. The EU will gain an increasingly prominent role in the development of international infrastructure, and it is important that Finland can contribute to this development effort as a credible partner.

Human resources

Several fields of biosciences and environmental research are facing a shortage of qualified infrastructure staff. A piece of hardware or equipment does not yet constitute infrastructure: it is also necessary to have trained and competent people to use, service and upgrade that infrastructure and to provide guidance and instruction in its use. The shortage of bioinformationists and other hardware experts is undermining the utility of hardware and equipment and causing them to become outdated prematurely. The lack of human resources in general is slowing down research. It is important, therefore, that not only hardware and software costs but also the costs of hiring qualified and permanent staff are factored into the development and funding of infrastructures. The presence of core units is crucially important to several fields. Indeed, these units are now becoming increasingly widespread, which is facilitating the growth of interdisciplinary research, but at the same time increasing pressure to hire competent and qualified staff.

Equipment and laboratories

The ageing of key hardware and equipment is a problem in a number of fields. At universities, this is already threatening the quality of teaching, and it is crucial that teaching equipment is updated. Neuroscience and many other disciplines are so heavily dependent on hardware and equipment that access to the latest imaging and other functional methods is often necessary for the publication of research results. In virtually all fields it is essential that researchers have access to good laboratories with state-of-the-art equipment. Furthermore, the need for equipment and laboratories is set to continue to increase in a growing number of new fields. Some fields such as physical geography do very little laboratory work themselves, but instead outsource the tests they require to dedicated laboratories. Indeed, high-quality research environments represent the most important physical infrastructures in this field.

It is only rarely that scientists can use the services of commercial laboratories, for their work consists largely of the adaptation of methods rather than mass work based on established practices.

Furthermore, there is only limited opportunity to cluster hardware and equipment, for researchers need to have local access to equipment when they are developing methods for the investigation of new organisms, for instance. Unit laboratories also provide training for experts in the course of routine practical work.

Decisions of infrastructure acquisitions are currently made at institutional level. Many key research infrastructures are very expensive, so it would obviously make sense for universities and polytechnics to pool their resources in acquiring such hardware and equipment that can be shared. In food sciences, for instance, the research units at Jokioinen, Espoo and Viikki could consider joint pilot-level equipment acquisitions, although this does not mean that this equipment has to be installed in one location. All decision-making on new hardware acquisitions must be premised on ensuring that the infrastructure is as widely accessible as possible and that it serves the needs of as many different research fields as possible. For example, possibilities to use Biocenter Finland for other purposes than for the application of model organisms should be studied.

Datasets, libraries and collections

In the fields of bioscience and environmental research it is important that the various research materials are made universally accessible. Significant research materials in these fields include statistical and spatial information datasets, satellite images, software, time series and data from field experiments. For individual researchers the costs of accessing many datasets compiled and produced with funding from the public purse are prohibitive. Another factor complicating resource allocation is that even expensive datasets are not normally regarded as infrastructure that requires special support. For the field as a whole it is paramount that there is in place an effective and comprehensive library system. Plant and animal collections are central to ecological and evolutionary research. Accurate spatial information provides the foundation for monitoring the spread and extinction of organisms due to environmental changes. It also makes possible the analysis of even very old DNA samples, thus allowing for comparisons of the genotype of existing populations with populations that lived earlier in the same area. Collections are also necessary for the teaching of species identification, which in turn lays the foundation for biodiversity research.

Electronic datasets are a central infrastructure in many fields of research that should be accessible to all universities and research institutes. Some research institutes, including the Finnish Environment Institute and the Finnish Meteorological Institute, are currently taking steps to unlock their research datasets for open access, but as a rule the research data compiled by university researchers and research institutes are inaccessible to the rest of the scientific community. The National Land Survey, a major source of spatial information, and Statistics Finland, for instance, protect their data and price them expensively. Centralised administration of the country's research institutes would go a long way towards improving access to these datasets. This will also require harmonisation of the existing datasets and the development of new user interfaces. Furthermore, steps are needed to safeguard not only the datasets collected and maintained by institutions, but also those compiled by amateurs and individual researchers. Improved access to these sources would also serve to increase research opportunities. For reasons of usability and preservation, it is important that datasets are systematically archived. Existing archives should be put to better use and archiving systems improved and developed. Special attention must be given to long-term data.

Certain datasets require mutual coordination and complementation. Strain collections, for instance, are a specific type of infrastructure in the field of microbiology, and coordination is needed to ensure cooperation between different collections. It will also be necessary to collect a national microbe library because the costs of using international libraries are set to rise, and steps are needed to open up individual researchers' collections for shared use. The Finnish Genome Centre under FIMM currently compiles genome information for humans only. These datasets should be complemented with genome data for other organisms, which would broaden horizons for evolutionary research, for instance. Skills and competencies in the use of genome information should also be enhanced.

Research stations, vessels and networks

Systems used for environmental monitoring and observation, such as research vessels and flow measurement stations, are absolutely paramount to research. Finland has an internationally unique network of research stations and a highly effective infrastructure, which has contributed to bolstering research particularly in the ecological, environmental and water fields, in agriculture and forestry, and in geography and regional studies. Research stations and their datasets should be made accessible for common use, and they must be further improved and developed. In the field of ecological research, for instance, it is necessary to create new water and land facilities. In the field of water research, research vessels are crucial to compiling long time series and to research success in general.

The Finnish Long-Term Socio-Ecological Research network (FinLTSER) that is included in the Finnish Infrastructure Roadmap is aimed at creating a well-equipped, nationwide network of research stations or clusters that focus on ecological and socio-ecological interactions. The network is designed to create greater synergy between universities and research stations in the field. Furthermore, the Maritime Centre Vellamo that has been opened in Kotka is aimed at integrating social sciences, history and maritime research.

New infrastructures

Biosciences and environmental research need a new kind of infrastructure. In the field of environmental research, for example, new challenges have emerged alongside existing, traditional infrastructures. New systems will be needed in the future to integrate existing infrastructures and to develop coordinated research platforms and new centralised social infrastructures. One new proposed innovation in the field of environmental research is a standing, national consumer panel, which could address many new challenges emanating from changing attitudes and consumer-driven environmental problems. Administration of the panel should be centralised and its use should be based on open competition. The datasets produced by the panel should be accessible to the whole scientific community.

4 Societal Impact of Research

Current state of impact assessment

Science is a crucial factor in explaining productivity growth in different countries, but work is still continuing to develop models that would describe the associations between R&D funding and economic growth and productivity. Many OECD countries have begun to incorporate R&D investment in their national accounts to provide a new and more reliable source on the impacts of investment on future economic trends.

It has proved rather more difficult to comprehensively assess the other societal impacts of research than it is to evaluate its economic impact. The reason for this, it is thought, lies in the relative ease of measuring economic values, and indeed the impacts of research have primarily been assessed in economic terms. An even greater source of difficulty is that these impacts are often immaterial, diffuse and take a long time to filter through. As yet there exists no systematic method for describing non-economic impacts in any detailed manner, despite sustained efforts. One major challenge to developing new approaches is the persistence of input-output thinking and the linear model of impact generation. In reality, however, the impacts of science are increasingly generated through the interplay of science and practice. In the context of biosciences and environmental research, social impacts are generated through both the linear and the interaction model.

Impact of research

The societal impacts of research refer both to economic and technological impacts, and on the other hand to the changes that are brought about by research and its results in the environment, in culture and for instance in people's health. Sometimes research produces immediate applications, with immediate economic benefits or other effects. On the other hand, in some instances it may take several years for the impacts of research to filter through. Very often the impacts of science are interwoven or mutually supportive: cultural changes may impact people's behaviour in a way that also has environmental impacts, which in turn may either improve or adversely affect people's health. Although there is no systematic and comprehensive framework for impact assessment, it is nonetheless possible to identify a number of cases where biosciences and environmental research has had an obvious impact on society, on people's well-being and on the natural environment's tolerance of human activity. In many fields the distance from research to practical application is very short. Centres of Excellence in the food and energy fields produce information with both scientific and social impact, and with different time spans from discovery to application. The results of food research are used in improving the safety and quality of foods and in developing new types of foods. In the energy field, a major area of interest is to develop new opportunities for green energy production, which in the future might have a decisive impact on the world energy supply. Ecological research has produced various practical applications for the sustainable use and protection of natural organisms. Evolutionary research, for its part, produces new information about human evolution that has important medical application and that can help resolve the problems caused by hospital bacteria, for instance.

Impacts of biosciences and environmental research

Biosciences are set to gain increasing social significance in the future. It has been suggested that within the next 100 years, biotechnology will transform the world as we know it. Indeed, the twenty-first century has already been dubbed the century of biosciences. Medical technology and gene technology, for instance, are making an ever greater contribution to the national economy. It is also important to ensure that there is adequate investment in this field, which is expected to generate significant profits in the future.

Biosciences and environmental research has increased our knowledge and understanding of different organisms and the structure of our environment and thus enabled a more effective response to looming threats. Climate change is one of the challenges that biosciences and environmental research can help to address. Research concerned with climate change and questions of mitigation and adaptation as well as impact assessments have so far been dominated by physical sciences. There is no question that over time, biosciences and environmental research will continue to gain increasing significance in the search for solutions to adapt to climate change. Modelling in the fields of geography and regional studies, for instance, has provided a good basis for predicting the impacts of climate change on different areas and their community structure. The impacts of climate change on agriculture is an issue of great importance in food science. Ecological modelling, for its part, is aimed at answering biological questions associated with temperature changes, such as the effects that will be seen on the occurrence of different organisms. Climate policy research has played a pivotal role in the development of climate policy. Apart from seeking to forecast future trends and to find new ways of adaptation, research in this field has sought to develop methods to mitigate climate change: the concept of emissions trading comes originally from environmental economics. With the advance of climate change, microbes too will be changing.

In addition to the challenges thrown up by climate change, biosciences and environmental research have sought to address other environmental problems, too. Microbiologists, for example, have developed a method for cleaning up contaminated land by using microbes. Important advances have also been made in the diagnostics of borreliosis as well as in the detection and treatment of bovine mastitis. In the field of plant biology, research is ongoing to develop new methods for the full use of plants and for the discovery of new, clean sources of energy. Furthermore, ecology researchers are producing important information that is expected to pave the way to new energy forms. Biosciences and environmental research is expected to find solutions to the food quality and sustainability issues that will worsen with the advance of climate change. One example of a successful breakthrough in the field of agriculture and forestry is the modelling of the strawberry growth chain, which led to a significant increase in berry yield per hectare. In plant biology, the sequencing of plant genomes will become routine research within the next 10 years: this will make it easier for scientists to find out how plants grow and by the same token to increase crop yields. As global catastrophes continue to increase and escalate, it is important that self-sufficiency is increased. On the other hand, intensive farming has contributed to causing increasing microbiological problems (livestock farming, hydroculture, megahospitals) that research needs to tackle. It is also important that mechanisms are in place to cope with the new plant diseases that will be spreading north with climate change. This challenge will be taken up by microbiology. The safety of the food chain and public health issues, for their part, are high on the research agenda for food science.

Not only nutrition-related issues but a host of other health promotion questions are a major focus for biosciences and environmental research. The information gained about the function of different organisms will pave the way to more effective health care. It is expected that biosciences will produce new diagnostic methods for exploring intracellular interactions at atom level. Microbiologists, for their part, are working to understand and find a cure for cancer using virus-based methods. Research in the fields of microbiology and evolutionary biology is also needed to overcome the virulence challenges created by climate change, intensive farming and travel. The achievement of significant social impact does not always require a major innovation. If neurological research could help to reduce the nation's health care bill of 4.5 billion euros by even a fraction, the benefits would be huge.

As well as impacting climate change, the environment, nutrition and health, biosciences and environmental research have an influence on people's world-view and their attitudes. One of the goals of environmental research, for example, is to change both national and international institutions and to promote the use and application of scientific information in political decision-making. Baltic Sea research has helped us gain a clear picture of the state of the Baltic Sea and had a positive influence on public opinion about the protection of the marine environment. It is believed that biosciences will produce a fuller understanding of the natural environment and society. Increased knowledge and understanding inevitably shapes the way people view their environment and themselves as well as their own behaviour – however slow that process might be.

5 Development Needs in Biosciences and Environmental Research

Different fields have reached different stages of development and are accordingly faced with different kinds of challenges; this is clearly reflected in the development proposals submitted above for different fields of research. Nonetheless, it is possible to identify some development needs that are shared in common by all fields of biosciences and environmental research.

The problem with the existing research career system is that it creates unreasonable selection pressure at different stages of the research career. The bottleneck that used to cause problems at the postdoctoral stage is now shifting to a later stage of the research career. The research career system is and must be selective so that the most qualified people are siphoned off at each point of transition. *However, this selection pressure must be predictable at different stages of the research career, and flexible funding mechanisms must be in place to prevent excessive variation in the elimination process between different career stages. Selection pressure should be more clearly taken into account in the allocation of research career resources.* The selection criteria applied at each career stage must be specified with a view to improving quality management across the system. Furthermore, the career system should be developed in such a way that the skills and competencies of researchers oriented to both academic and non-academic careers can be improved as effectively and appropriately as possible. In researcher training, for example, it is essential to pay closer attention at all stages to the skills and knowledge required in other public and business sector jobs and positions. The PhD degree must be recognized as a merit not only for Academy-funded research positions, but in the open job market as well.

Researcher training in the biosciences is under-resourced compared with other disciplines. The fields of research under the Research Council for Biosciences and Environment account for just 14 per cent of all graduate school positions, whereas the Research Council for Health, the Research Council for Culture and Society and the Research Council for Natural Sciences and Engineering account for 17 per cent, 26 per cent and 43 per cent, respectively. This is not proportionate to PhD employment or to relative role of different Research Councils in promoting high-level science.

One of the key priorities in developing the Finnish research system has been to promote its internationalisation and to increase international cooperation. Foreign doctoral students are showing increasing interest in the research work done in Finland, and the prospects of recruiting foreign students are better than before. Mobility from Finland to other countries, on the other hand, is at a worryingly low level. This is no doubt at least in part explained by the significant improvements made over the past 15 years in the national research and postgraduate training systems. *Nonetheless, it would be advisable to require that scientists and researchers also spend periods abroad to improve their skills and competencies, both at the PhD education stage and particularly at the postdoctoral stage.* Today, over one-fifth of all postdoctoral researchers move abroad after completion of their PhD thesis.

As it is, the option of moving abroad does not hold sufficient appeal for researchers. Indeed, funding systems should be developed with a view to increasing the flexibility of practical research work. For example, more support should be made available, where possible, to families in order to promote gender equality. *Special attention must be given to the conditions for the repatriation of researchers.* Fears of demotion on returning from abroad currently represent some disincentive to leave in the first place. Researchers who decide to move abroad should be able to leave in the knowledge that their funding is secure for at least 12 months after returning home. Funding must be allocated to those fields that require special attention. Furthermore, awareness must be increased of the significance of the skills and knowledge acquired abroad. Practice to date shows that almost without exception, it is impossible to achieve appointments to higher scientific positions without experience gained abroad.

There are concerns in a number of fields about the availability of an adequate supply of PhD students. For this reason *steps are needed to promote and facilitate the recruitment of foreign students.* The Finnish research training system must be made internationally more competitive in order to attract the most talented foreign students into Finland. A common deadline for the applications of foreign students would help to speed up and improve the efficiency of student selection. Deadlines could be timed to coincide with key research funding decisions. Centres of Excellence have been one important factor in increasing the attraction of the national research system, and their role and cooperation with graduate schools should be further improved.

Special attention must be given to the quality criteria for PhD theses, with due consideration to EU doctoral education policy. As it is, these criteria differ between Finnish universities. It is important not to put too much weight on the required number of articles; instead *greater attention should be paid to the quality of articles published as part of doctoral theses.* One article reporting a major scientific breakthrough in a highly respected journal is more significant and carries greater scientific impact than a larger number of shorter articles published in less visible forums.

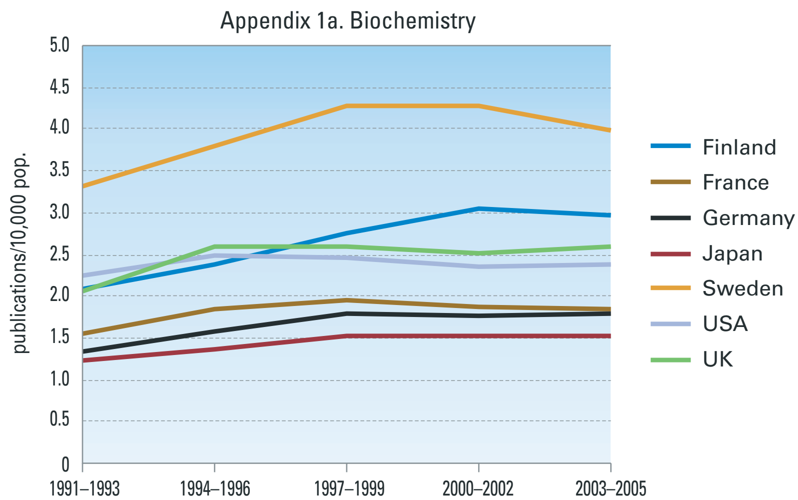
Fragmentation continues to remain a problem in a number of fields. One way of trying to alleviate this problem is through clearer profiling and increased cooperation at national level. Finland is a small country, which effectively limits the size of individual institutions. *The achievement of critical mass will require a strengthening of existing structures of cooperation both within and between universities.* Cooperation must also be stepped up between universities and research institutes. Wherever possible, their operations should be concentrated in joint campuses. Shared laboratory facilities would also contribute to promoting cooperation. Good experiences have been gained from joint professorships between universities and research institutes. Another factor adding to the problem of fragmentation is the lack of consistent and long-term funding. The growth of research has been driven primarily by short-term external funding, which is poorly suited to long-term development projects. Even though the growth of competitive funding has opened up new opportunities for researchers and helped to raise the overall quality of research, it has at once brought increased dependence on short-term funding sources. *It would be extremely important to have a better balance between core resources for research and external funding sources.* In the future, too, a good way of increasing cooperation among researchers and reducing fragmentation is through research programmes that cut across and integrate different fields.

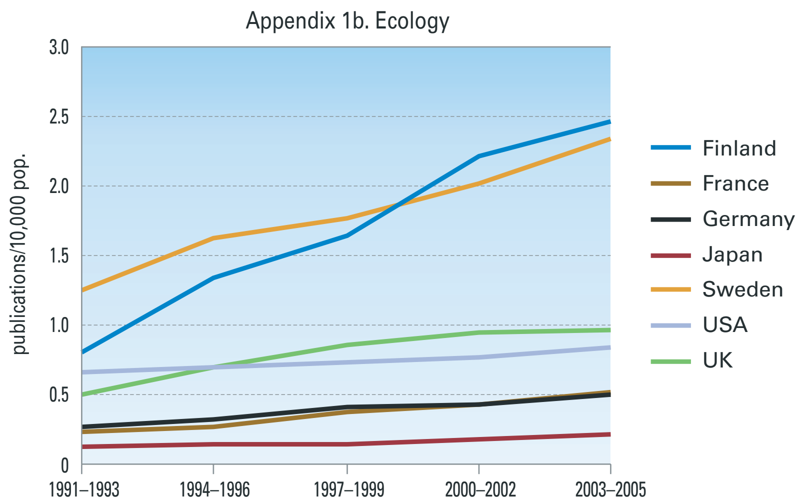
The heavy emphasis placed in recent years on the promotion of internationalisation has detracted somewhat from the development of national cooperation. Many fields continue to lack established structures of cooperation that are aimed at a concerted and active development effort. National science meetings that are now organised in some disciplines could be one way of increasing cooperation within the research system and bolstering the shared identity of scientists and researchers working within that discipline. These could bring together researchers from a certain field in Finland. At the same time, international engagement could be promoted by inviting keynote speakers from abroad. It was also proposed at the workshops hosted by the Academy of Finland in 2008 that these meetings, organised once or twice during the Research Councils' terms, could serve as useful forms for cooperation planning. *It is important to pay attention to the development of forums of cooperation and to the allocation of adequate resources.*

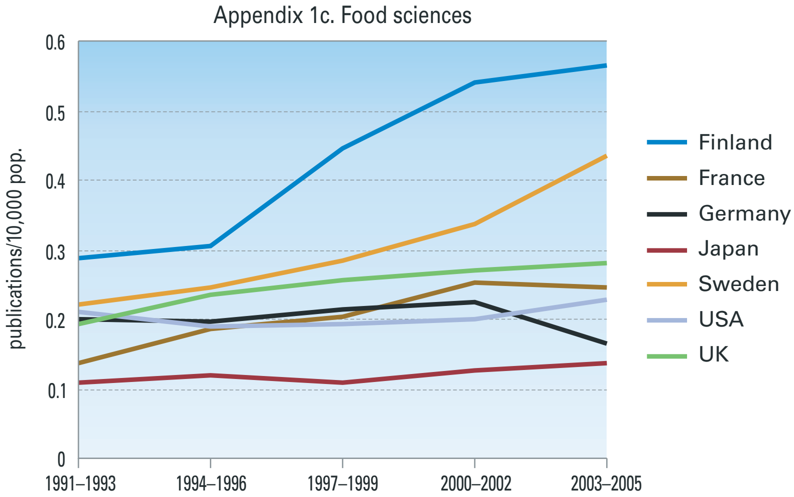
Research infrastructures are pivotal to the whole field of research and its future development. Research conducted under the aegis of the Research Council is broad-ranging and the importance of specific infrastructures varies from one field to the next. One problem that is shared in common by all fields is the scarcity of funding for hiring qualified staff to operate the infrastructure. *Resources must be made available for hiring more permanent staff who have the skills to operate the increasingly complex hardware and equipment.* This is the only way to ensure the efficient use and continuous maintenance and development of research infrastructures. Constant equipment maintenance and upgrading is particularly important in the biosciences. Environmental research, on the other hand, depends most crucially on access to and the continuity of various research datasets and time series. In environmental research and teaching, too, different types of hardware and equipment have gained increasing importance over the past 15 years. The existing network of research stations is a unique strength of the Finnish research network and accessible to scientists and researchers from a number of different fields. *The network of research stations can be enhanced and strengthened by rationally improving their division of labour.*

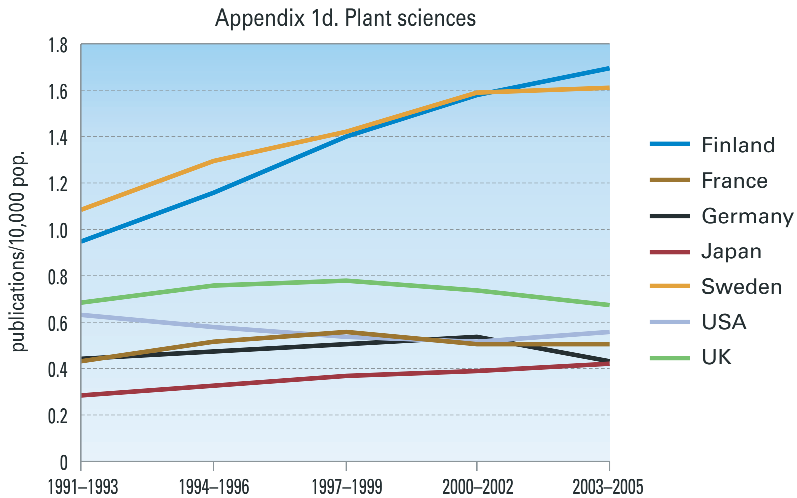
The fields of research hosted by the Research Council play a key role in promoting the sustainable development of society. The Centre of Excellence funding allocated to these fields goes largely to basic research geared to supporting sustainable development. *Steps are needed to further strengthen skills and competencies in fields that promote sustainable production, environmental protection and restoration.* The research challenges addressed in many fields will have long-term impacts most particularly on the future sustainability of our society. Climate change, the diversity of the natural environment, food supply, health and well-being are among the areas of social development where biosciences and environmental research have had a discernible impact. In some areas cooperation through Strategic Centres for Science, Technology and Innovation provides an effective way of focusing research so that sustainable solutions can be found to key problems of basic production and processing. *At the same time it is crucial to ensure continued adequate funding for basic research in the Research Council's fields.* One of the characteristics of research in these fields is that the step from basic research to practical application is often very short. Investment in basic research can often produce information with immediate practical application in a very short pace of time. It is a typical feature of innovative basic research that it is hard to predict what kinds of future applications it will produce. The only way to ensure a continued flow of new scientific inventions and innovations is through broad-ranging enough basic research.

Appendix 1. Publication numbers for different fields of biosciences and environmental research in selected countries






Appendix 1c. Food sciences
publications/10,000 pop.
0.6
0.5
0.4
0.3
0.2
0.1
0
1991–1993
1994–1996
1997–1999
2000–2002
2003–2005
Finland
France
Germany
Japan
Sweden
USA
UK


Appendix 1d. Plant sciences
publications/10,000 pop.
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
1991–1993
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1997–1999
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2003–2005
Finland
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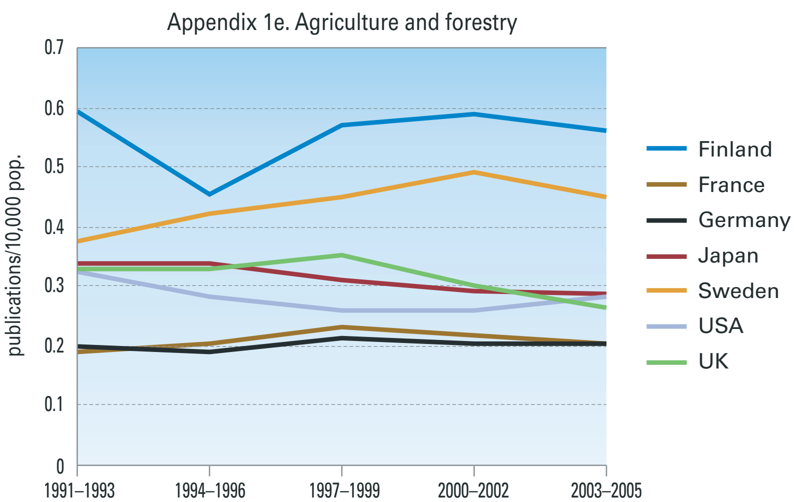
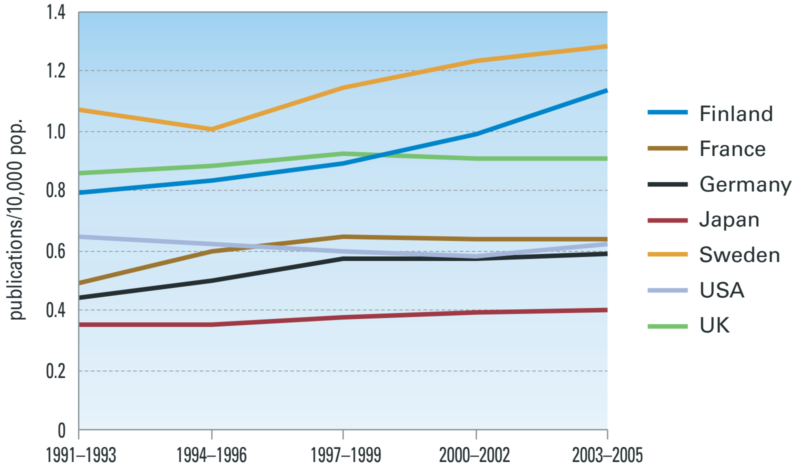
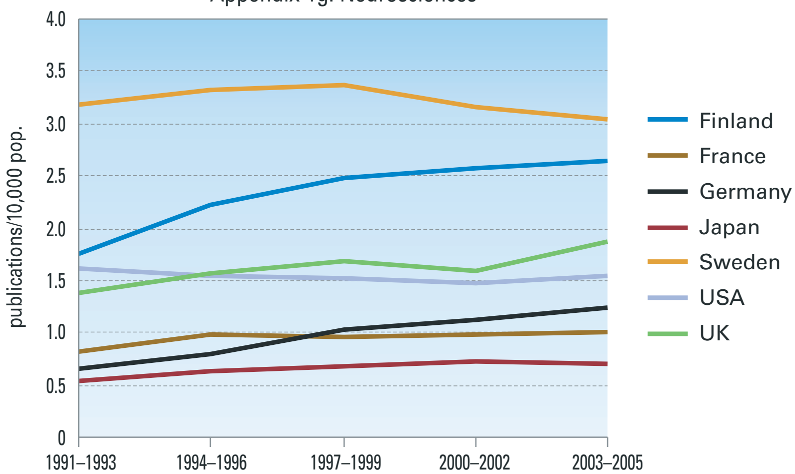
Germany
Japan
Sweden
USA
UK


Appendix 1e. Agriculture and forestry
publications/10,000 pop.
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1991–1993
1994–1996
1997–1999
2000–2002
2003–2005
Finland
France
Germany
Japan
Sweden
USA
UK

Appendix 1f. Microbiology



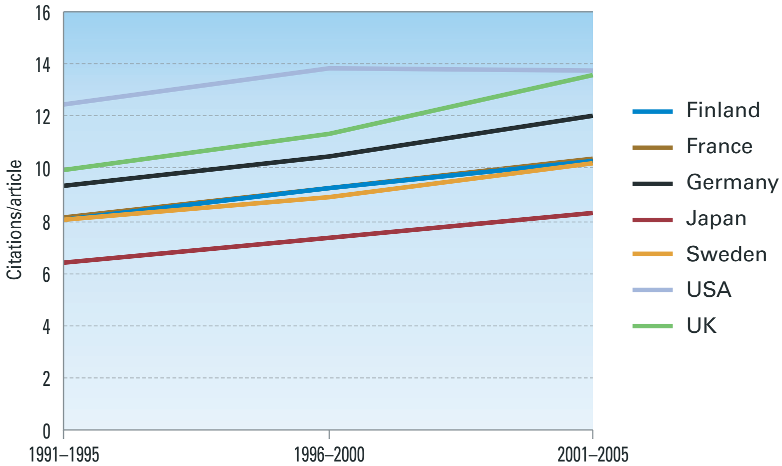
Appendix 1g. Neurosciences



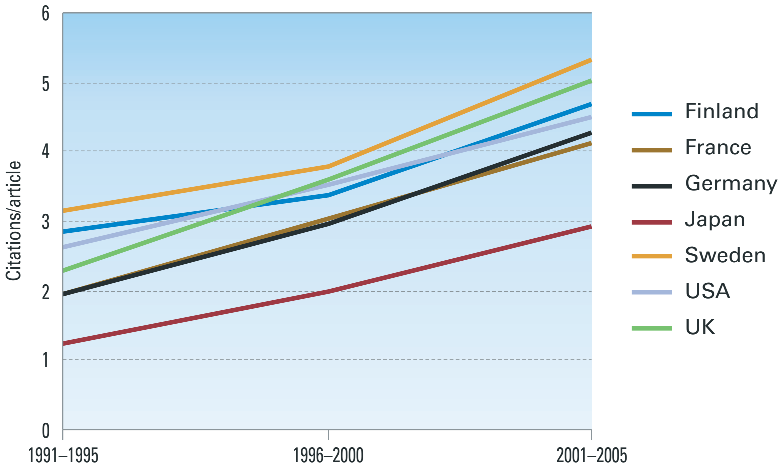
Source: Thomson Scientific, National Science Indicators 1991–2005 (Deluxe).

Appendix 2. Citation impacts for different fields of biosciences and environmental research in selected countries

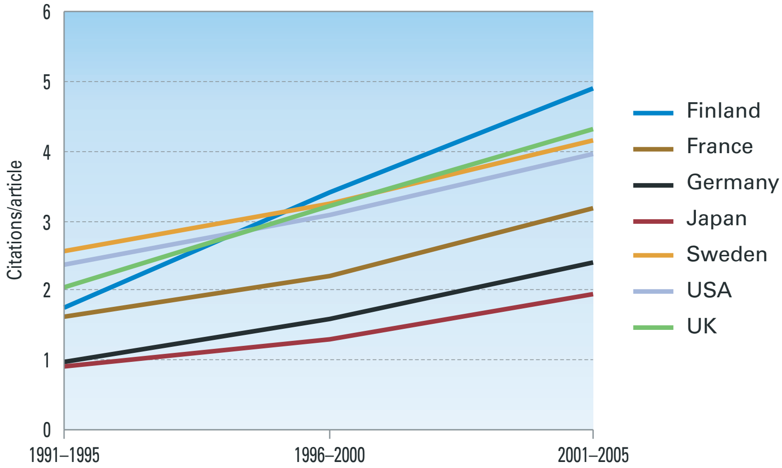
Appendix 2a.Biochemistry



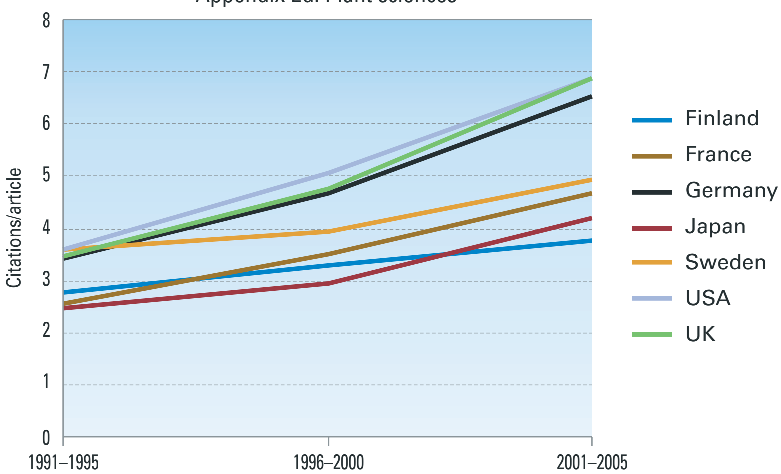
Appendix 2b. Ecology



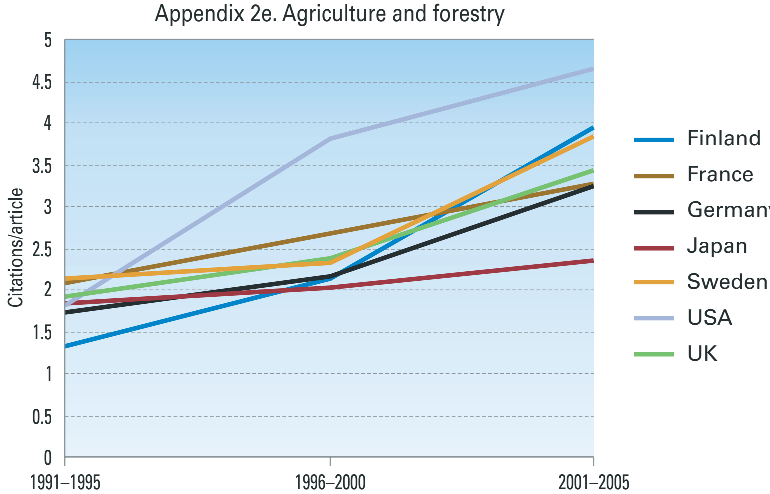
Appendix 2c. Food sciences

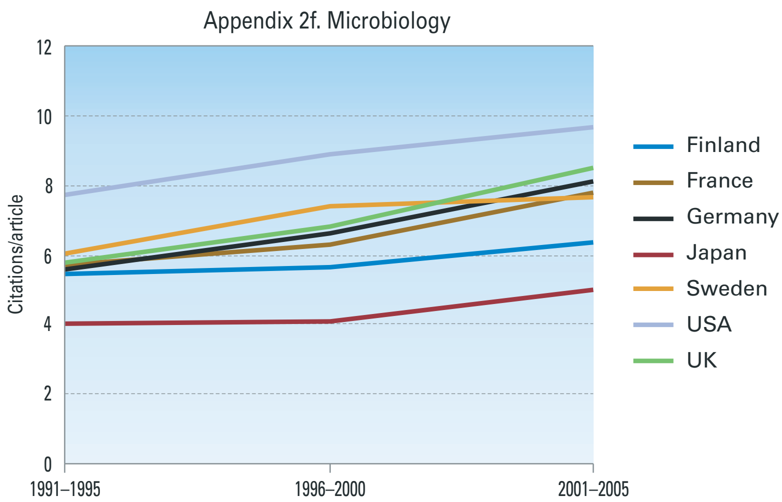


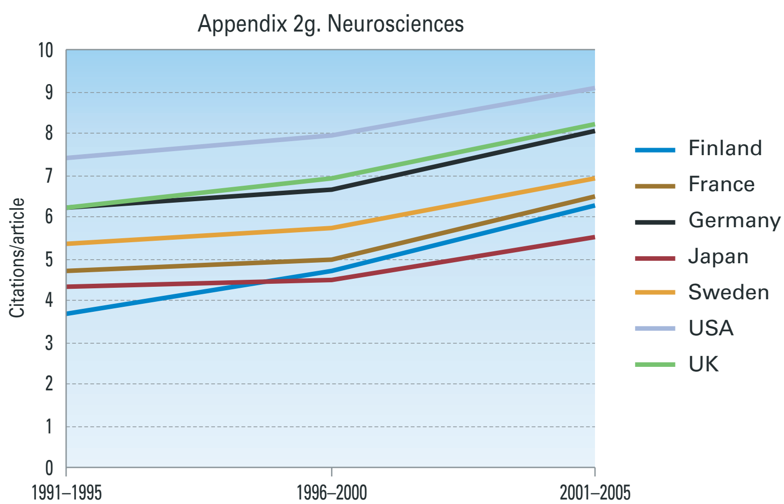
Appendix 2d. Plant sciences



Appendix 2e. Agriculture and forestry



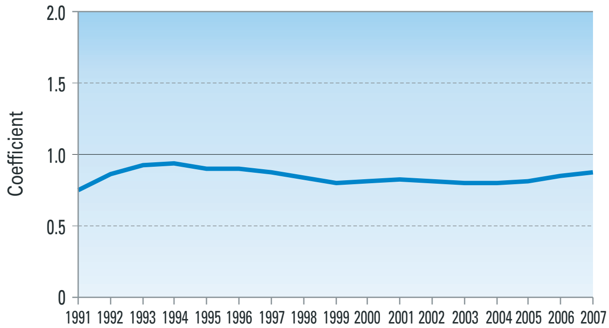




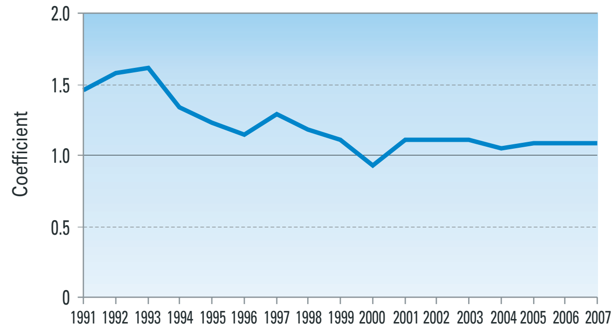
Source: Thomson Scientific, National Science Indicators 1991–2005 (Deluxe).

Appendix 3. Relative citation impacts for different fields of biosciences and environmental research in 1991–2007

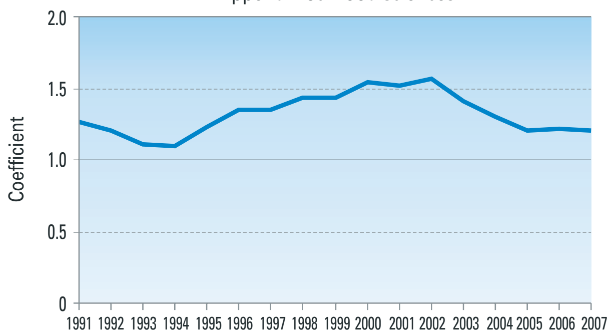
Appendix 3a. Biochemistry



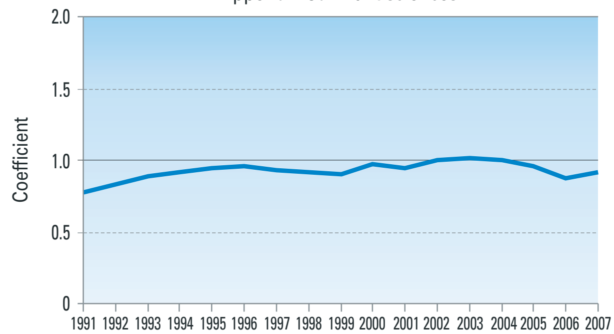
Appendix 3b. Ecology



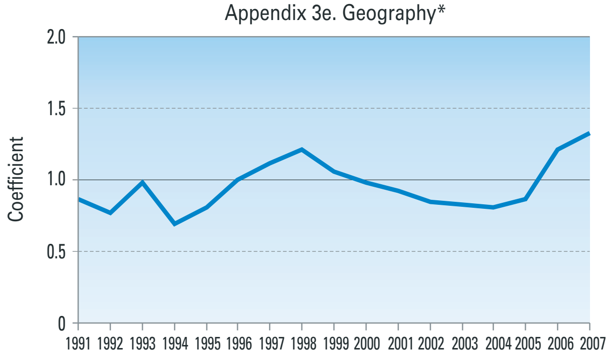
Appendix 3c. Food sciences



Appendix 3d. Plant sciences

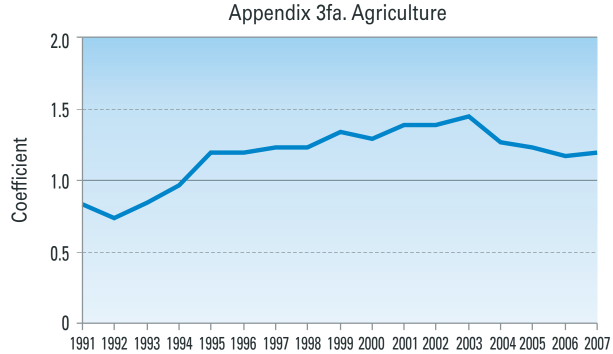


Appendix 3e. Geography*

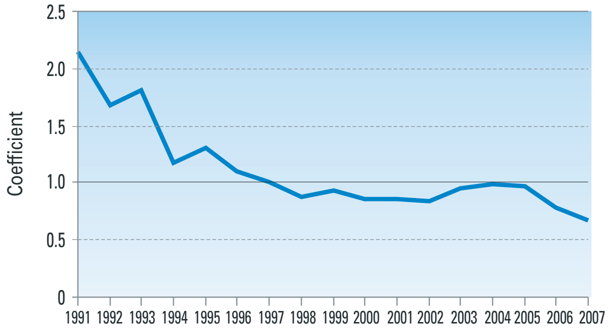


* Results suspect because of the small number of publications in database.

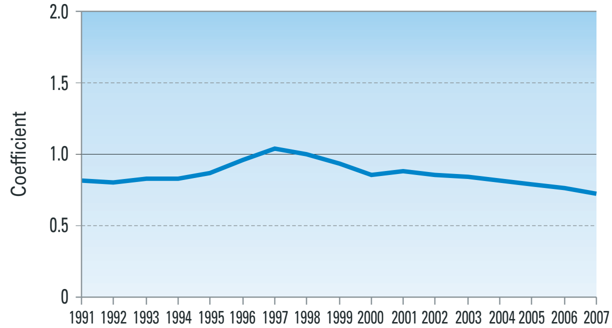
Appendix 3fa. Agriculture



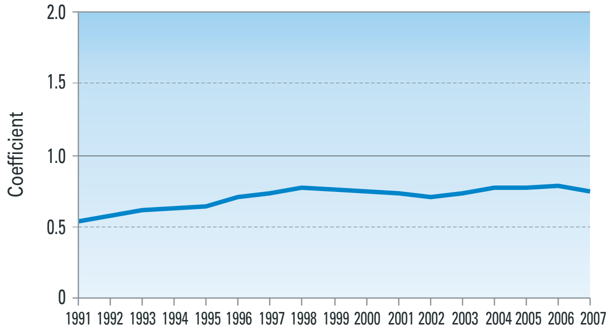
Appendix 3fb. Forestry



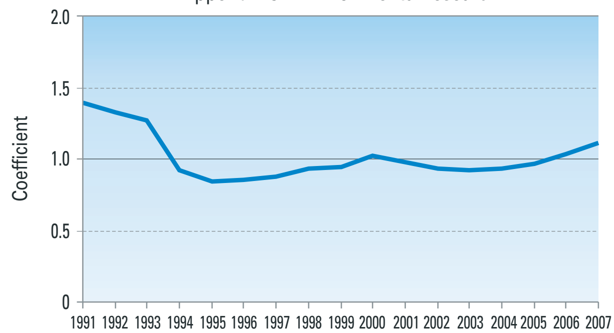
Appendix 3g. Microbiology



Appendix 3h. Neurosciences

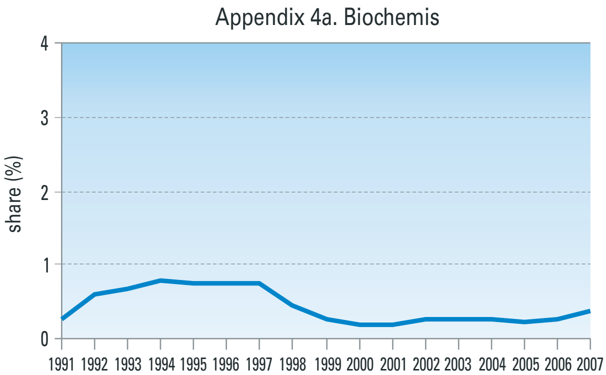


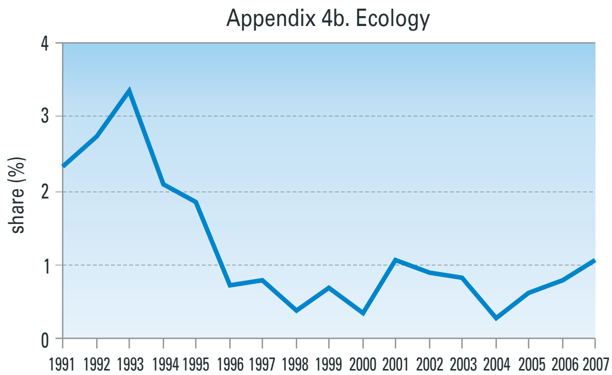
Appendix 3i. Environmental research

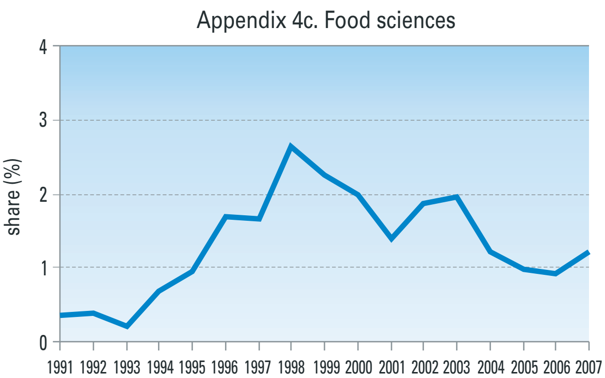


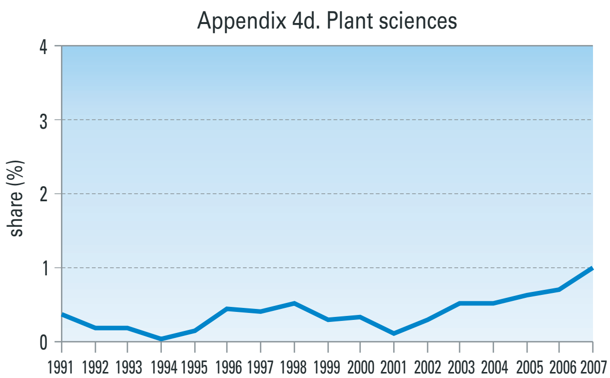
Source: Thomson Reuters Science Citation Index Expanded, Vetenskapsrådet 2009.

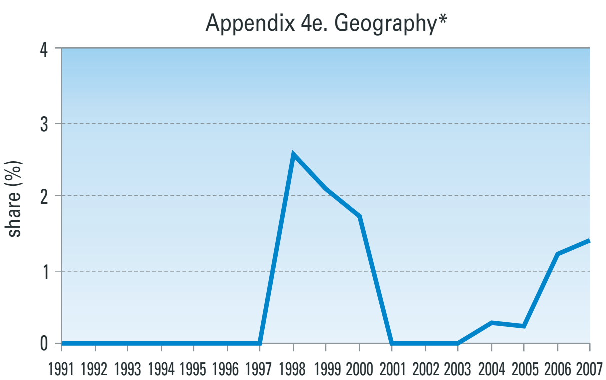
Appendix 4. Highly cited publications in different fields of biosciences and environmental research (most-cited 1% of publications) 1991–2007



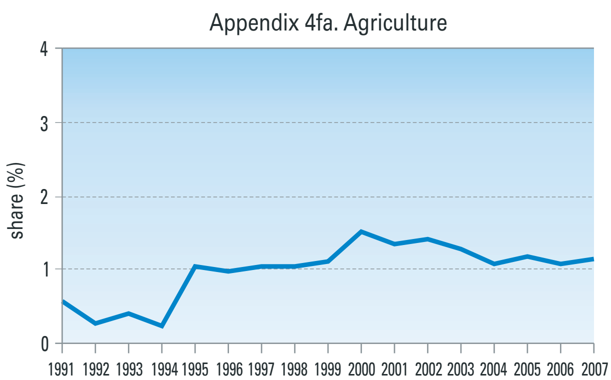




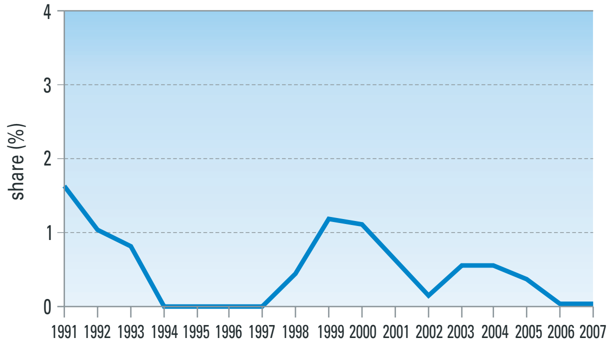




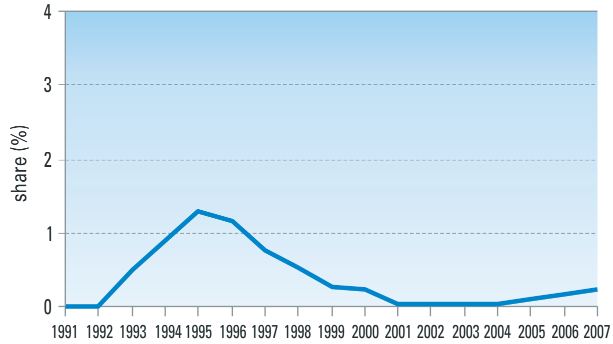
* Results suspect because of small number of publications in database.



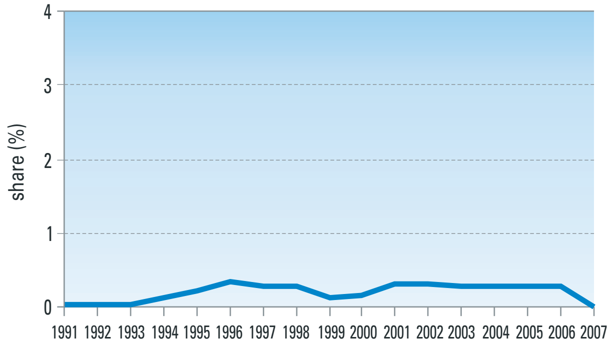
Appendix 4fb. Forestry



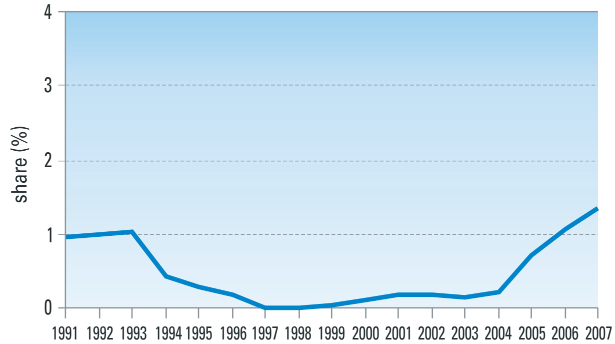
Appendix 4g. Microbiology



Appendix 4h. Neurosciences



Appendix 4i. Environmental research



Source: Thomson Reuters Science Citation Index Expanded, Vetenskapsrådet 2009.

Appendix 5. List of participants in biosciences and environmental research workshops

Ecology, evolution and ecophysiology

Lotta Sundström (chair)	Research Council for Biosciences and Environment, University of Helsinki
Kai Lindström	Åbo Akademi University
Ilkka Hanski	University of Helsinki
Outi Savolainen	University of Oulu
Juha Karjalainen	University of Jyväskylä
Mikko Mönkkönen	University of Jyväskylä
Riitta Julkunen-Tiitto	University of Joensuu
Mikko Nikinmaa	University of Turku
Jyrki Muona	University of Helsinki
Markku Viitasalo	Finnish Institute of Marine Research
Erkki Korpimäki	University of Turku

Regional studies and geography

Jouni Häkli (chair)	Research Council for Biosciences and Environment, University of Tampere
Mari Vaattovaara	University of Helsinki
Jukka Käyhkö	University of Turku
Harri Andersson	University of Turku
Ari Lehtinen	University of Joensuu
Anssi Paasi	University of Oulu
Hannu Katajamäki	University of Vaasa
Päivi Oinas	Turku School of Economics

Environmental sciences

Jyrki Luukkanen (chair)	Research Council for Biosciences and Environment, Turku School of Economics
Juha Kämäri (chair)	Research Council for Biosciences and Environment, Finnish Environment Institute
Pekka Kauppi	University of Helsinki
Anni Huhtala	Agrifood Research Finland
Hanna-Leena Pesonen	University of Jyväskylä
Lea Kauppi	Finnish Environment Institute
Sanna Sorvari	University of Helsinki
Paula Kankaanpää	Arctic Centre
Rauno Sairinen	University of Joensuu
Janne Hukkinen	Helsinki University of Technology
Markku Ollikainen	University of Helsinki

Plant biology, plant molecular biology and plant biotechnology

Hely Häggman (chair)	Research Council for Biosciences and Environment, University of Oulu
Jaakko Kangasjärvi (chair)	Research Council for Biosciences and Environment, University of Helsinki
Eva-Mari Aro	University of Turku
Sirpa Kärenlampi	University of Kuopio
Kirsi-Marja Oksman -Caldentey	VTT Technical Research Centre of Finland, Biotechnology
Tapio Palva	University of Helsinki
Alan H. Schulman	Agrifood Research Finland & Institute of Biotechnology (University of Helsinki)
Teemu Teeri	University of Helsinki

Food science

Marina Heinonen (chair)	Research Council for Biosciences and Environment, University of Helsinki
Vieno Piironen	University of Helsinki
Tapani Alatossava	University of Helsinki
Hannu Korkeala	University of Helsinki
Miia Lindström	University of Helsinki
Seppo Salminen	University of Turku
Johanna Buchert	VTT Technical Research Centre of Finland
Kaisa Poutanen	VTT Technical Research Centre of Finland
Eeva-Liisa Ryhänen	Agrifood Research Finland

Hannu Korhonen	Agrifood Research Finland
Atte von Wright	University of Kuopio

Agriculture and forestry

Paavo Pelkonen (chair)	Research Council for Biosciences and Environment, University of Joensuu
Heikki Hokkanen	University of Helsinki
Risto Tahvonen	Agrifood Research Finland
Katri Kärkkäinen	Finnish Forest Research Centre
Heikki Smolander	Finnish Forest Research Centre
Kyösti Pietola	Agrifood Research Finland
Timo Tokola	University of Joensuu
Laura Höijer	Agrifood Research Finland

Biochemistry and biophysics, cell and molecular biology, genetics, bioinformatics

Reijo Lahti (chair)	Research Council for Biosciences and Environment, University of Turku
Karl Åkerman (chair)	Research Council for Biosciences and Environment, University of Helsinki
Jaana Bamford	Research Council for Biosciences and Environment, University of Jyväskylä
Raili Myllylä	University of Oulu
Arto Annila	University of Helsinki
Pekka Hänninen	University of Turku
Lea Sistonen	Åbo Akademi University
Maria Vartiainen	University of Helsinki
Jari Ylänne	University of Jyväskylä
Liisa Holm	University of Helsinki
Jussi Taipale	University of Helsinki
Markku Kulomaa	University of Tampere
Juha Rouvinen	University of Joensuu

Microbiology

Jaana Bamford (chair)	BY-toimikunta, Research Council for Biosciences and Environment, University of Jyväskylä
Merja Penttilä	VTT Technical Research Centre of Finland
Taina Lundell	University of Helsinki
Tellervo Valtonen	University of Jyväskylä
Veijo Hukkanen	University of Oulu
Kristiina Mäkinen	University of Helsinki
Martin Romantschuk	University of Helsinki
Harri Savilahti	University of Turku
Vesa Kontinen	National Public Health Institute
Merja Roivainen	National Public Health Institute
Per Saris	University of Helsinki
Mikael Skurnik	University of Helsinki
Benita Westerlund-Wikström	University of Helsinki

Neuroscience and animal physiology

Karl Åkerman (chair)	Research Council for Biosciences and Environment, University of Helsinki
Sari Lauri	University of Helsinki
Jari Koistinaho	University of Kuopio
Matti Weckström	University of Oulu
Matti S. Airaksinen	University of Helsinki
Heikki Rauvala	University of Helsinki
Eero Castren	University of Helsinki
Kari Keinänen	University of Helsinki
Pertti Panula	University of Helsinki
Kai Kaila	University of Helsinki
Irma Holopainen	University of Turku
Kristian Donner	University of Helsinki

This report has been compiled by the Research Council for Biosciences and Environment with the assistance of Laura Raaska, Timo Kolu, Laura Valkeasuo, Eeva Sievi and Saana Jukola from the Academy's Biosciences and Environment Research Unit.

Appendix 6 Classification of research fields used in the bibliometric analyses of biosciences and environmental research in appendices 1–4

The classifications used in the bibliometric analyses have been chosen with a view to maximum correspondence with the workshop fields referred to in the text. The classifications of the databases used impose some restrictions in this regard.

Appendices 1 and 2

Research fields	Database classifications
Biochemistry	Biochemistry & Biophysics Cell & Developmental Biology Molecular Biology & Genetics
Ecology	Environment / Ecology
Food sciences	Food Science / Nutrition
Plant sciences	Plant Sciences
Agriculture and forestry	Agricultural chemistry Agriculture / Agronomy
Microbiology	Microbiology
Neurosciences	Neurosciences & Behavior
	Physiology

Database used: Thomson Scientific, National Science Indicators 1981–2005 (Deluxe).

Appendices 3 and 4

Research fields	Science Citation Index Expanded Database: Subject Categories	
Biochemistry	Biochemistry & Molecular Biology Biochemical Research Methods Biophysics Cell Biology	Developmental Biology Genetics & Heredity Mathematical & Computational Biology
Ecology	Biodiversity Conservation Ecology	Evolutionary Biology
Food sciences	Food Science & Technology	Nutrition & Dietetics
Plant sciences	Biotechnology & Applied Microbiology	Plant Sciences
Geography	Geography	Geography, Physical
Agriculture	Agricultural Economics & Policy Agricultural Engineering Agricultural Experiment Station Reports Agriculture, Dairy & Animal Science Agriculture, Multidisciplinary	Agronomy Fisheries Horticulture Soil Science Water Resources
Forestry	Forestry	
Microbiology	Microbiology	Virology
Neurosciences	Neurosciences	Physiology
Environmental research	Environmental Sciences	Environmental Studies

2 Research in Culture and Society

Contents

1 Introduction

The Research Council for Culture and Society has contributed to this overview of the current state of science and research in Finland by reviewing the strengths and weaknesses of the fields of research that come under its purview. Based on its assessments, the Research Council outlines specific recommendations for the development of researcher training and the academic research career, research infrastructures, mobility and internationalisation and discusses the future outlook of science and research in these fields.

In autumn 2008, the Research Council organised three workshops that were attended by more than 50 researchers from the humanities and social sciences fields. The workshops sparked lively debate about questions of researcher training and research careers, networking, mobility and cooperation among researchers, the quality of research in the areas of culture and society, and the renewal and impact of research. These themes were addressed from the point of view of both past and future challenges: what have been the most distinctive characteristics of different fields, which areas have enjoyed the most success and in particular, what are the challenges for the future?

In addition to these workshop discussions, reports by Research Council members and other solicited reviews, the Research Council also consulted a number of evaluations conducted since 2000 of individual disciplines, universities and departments. Other sources used in compiling this report include the series of volumes on *The History of Finnish Science* and the histories of science produced by the Finnish Academy of Science and Letters, which trace the development of different fields and disciplines in Finland.

Although bibliometric analysis has become the tool of choice in assessing the scientific impact of research, they do not provide a sound enough basis for drawing firm conclusions, especially in the humanities and social sciences. There are significant differences in publishing practices between the major fields of science, in every possible aspect. For instance, the humanities and social sciences produce more monographs and edited volumes than other disciplines. Likewise, research in these fields is often motivated by ambitions of social impact, and it has multiple audiences.

The Research Council for Culture and Society has contributed to reviewing the current state of science and research in Finland since 1997. This is the fifth review of its kind. Although the main focuses and perspectives in these reports have varied somewhat, their contents nonetheless constitute a seamless whole. People from different disciplines concerned with culture and society have engaged in a process of dialogue about the place of those disciplines within the broader field of science, analysed the different ways in which scientific impact is manifested and outlined challenges for the future.

2 Research in Culture and Society: Strengths and Challenges

Humanities

Figure 1 shows how university research expenditure (including core budget funding and external funding) has developed in the humanities from 1991 to 2006. During this period, the volume of research funding has increased most sharply in the fields of art and literary studies as well as in cultural studies. Throughout this period the single most important source of external funding has been the Academy of Finland, which has accounted for between 46 and 75 per cent of research expenditure in the humanities (see Figures 2 and 3).

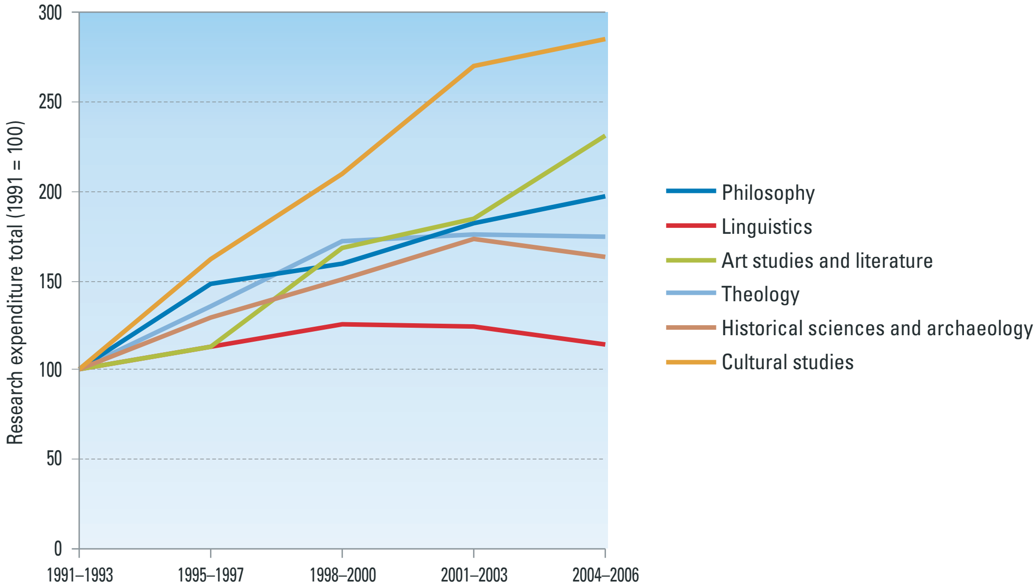


Figure 1. University research expenditure in the humanities in 1991–2006, change.
Source: Statistics Finland and Unit for Science, Technology and Innovation Studies TaSTI, University of Tampere 2008.

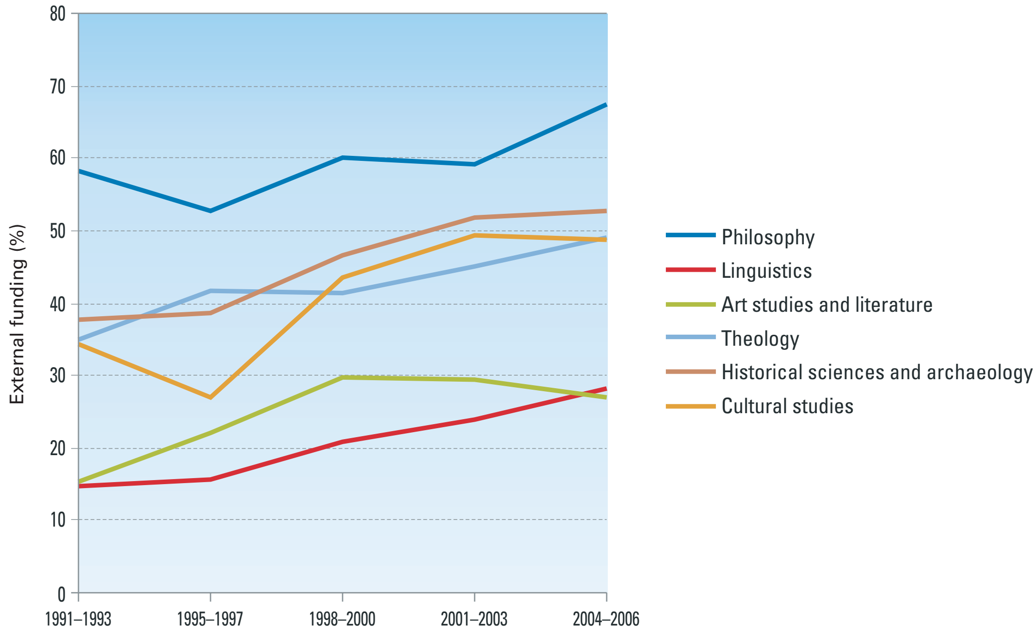


Figure 2. External funding as a proportion of university research expenditure in the humanities.
Source: Statistics Finland and Unit for Science, Technology and Innovation Studies TaSTI, University of Tampere 2008.

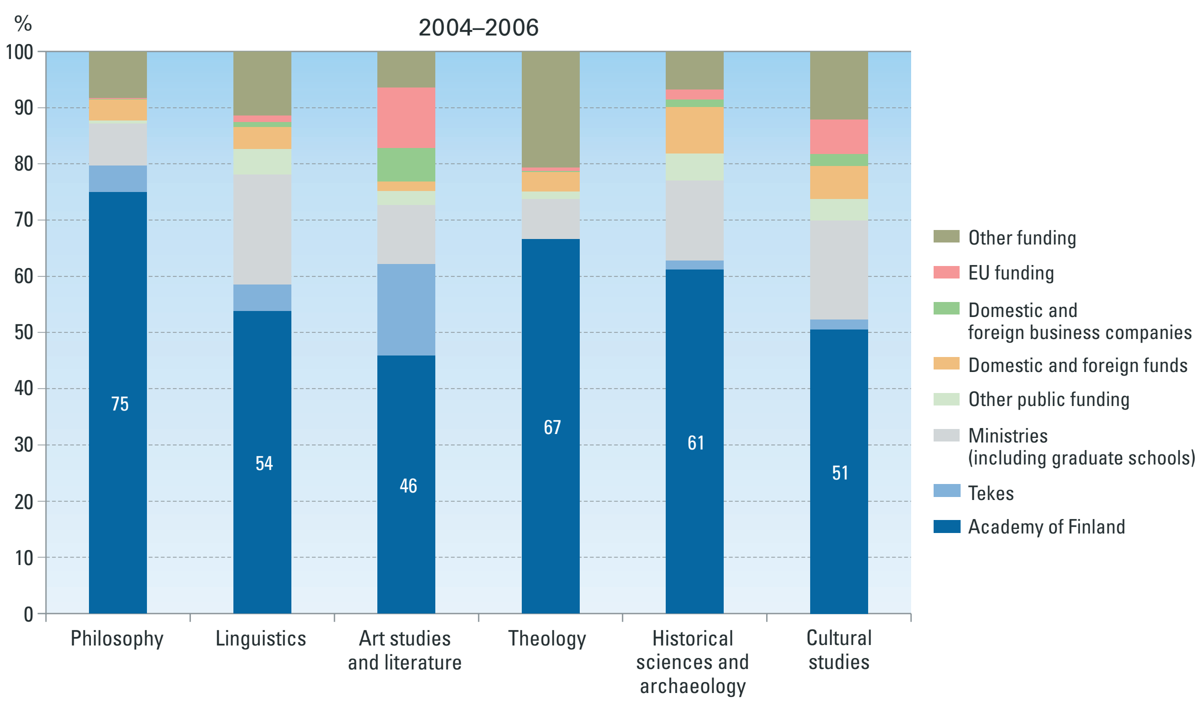


Figure 3. Sources of external funding for university research expenditure in the humanities in 2004–2006.
Source: Statistics Finland and Unit for Science, Technology and Innovation Studies TaSTI, University of Tampere 2008.

Philosophy

- Academy Research Fellow Martina Reuter (University of Helsinki) is studying the philosophy of Enlightenment thinker Mary Wollstonecraft, who has previously been considered a marginal figure in the canonical history of philosophy. Wollstonecraft's work has been taken to reflect an early form of feminism and regarded as a classic of political philosophy, but Reuter expands on this and delves into the history of the philosophy of mind and moral philosophy.

Philosophical research is carried out in most universities in Finland. Some universities have dedicated philosophy departments, others bundle philosophy together with some other disciplines, and there are also philosophers in teaching and research posts in other subjects. Aesthetics, for instance, can just as well be taken to belong to philosophy as to some branch of art research. Philosophy cuts through multidisciplinary subjects such as women's studies and cognition science. Research in logic is conducted in the fields of philosophy, mathematics and computer science. In addition, philosophically oriented research is undertaken in some special sciences.

Finland has for decades produced philosophical research of international excellence. This applies particularly to key areas of the so-called analytic tradition and to fields of logic, the theory of knowledge, the philosophy of science, the history of philosophy and certain areas of ethics, especially applied ethics. In recent years, other areas and traditions of thought have gained increasing international visibility, too.

Virtually all areas and traditions of philosophy have a strong international orientation. However, as well as publishing in prestigious international journals, philosophy researchers are keen to publish domestically. The range of themes covered in international publications is much wider than before, when there were fewer high-profile names in the field. Philosophical research in Finland has earned high praise in recent university evaluations. Special note is made of its achievements in view of the limited resources available. Philosophers have been highly successful with their applications for competitive external funding.

University evaluation reports have drawn attention to problems with resource allocation. Researchers in this field are having to spend time doing jobs for which they should be able to hire auxiliary staff. There is also a lack of consistency in the quality of research, and some fields have regressed. Overall, however, if information from other than these evaluations is also taken into account, the different fields of philosophy are reasonably well covered in Finland.

Philosophical research has changed significantly since the end of the twentieth century both in Finland and elsewhere, as twentieth-century paradigms have progressively given way to a set of new paradigms. This has also opened up new opportunities for cooperation, although new tensions have emerged as well.

The diversity of philosophy and the development of new strands of research present a whole host of new opportunities. At the same time, however, they also present a great challenge: in this situation of constant change, with new paradigms constantly evolving, it is still necessary to establish the criteria for good research. This applies not just to philosophy in Finland, but around the world. Furthermore, philosophy is such a small field that it has to interact and team up with other disciplines. On the other hand, given the high quality of philosophical research, it will certainly be able to retain its nature as basic research and autonomously set the criteria for high-quality research. Another threat to the quality of research comes from the fact that researchers do not have the opportunity to dedicate themselves full time to research. Philosophy would need increased visibility, for example through major research programmes and EU-funded projects.

The field of philosophy has reformed and renewed itself significantly, and this process is still ongoing. Philosophy occupies a strong position in Finnish society and culture, which is also reflected in public debate. The challenge for the future is, first, to ensure that quality standards of basic research in philosophy are not compromised, which will require close communication with researchers in this field. Second, and at the same time, it is necessary that the impact of research is strengthened outside the discipline itself. This requires that researchers invest greater effort in making intelligible their work and their results to researchers in other fields and to the general public. By and large, philosophy has achieved a fairly good balance. In the future, increased efforts are needed to increase and diversify the fruitful interaction between philosophy and special sciences.

Theology

- Academy Research Fellow Mikko Ketola (University of Helsinki) is conducting an historical analysis of the survival of the Evangelical Lutheran Church in Estonia under two different totalitarian systems, the Communist and Fascist, during the Second World War in 1939–1944.

Like many other humanities and social science disciplines, theology is made up of a mixture of different fields. There are three universities in Finland that engage in theological research. Overall the quality of this research has been rated as very high. The Research Team for Biblical Exegetics and The History of Mind Research Unit, both of which are Academy of Finland Centres of Excellence, have produced research of the very highest international excellence. Joint EU-funded projects have increased awareness of Finnish theological research.

The themes covered in theological research have been described as relevant, its research questions as well formulated and its argumentation as intelligent and innovative. Indeed, research in this field is wide ranging, which in some cases may also turn into a weakness.

Finnish theologists have published their work in internationally prestigious series and journals. In some fields researchers may find themselves confronted with the choice between a research subject of domestic interest or importance and one that holds international interest. The experts who conducted an evaluation of the University of Helsinki concluded that it is important for theologists to publish in the Finnish language, too. At the same time, though, theology should publish more work in foreign languages.

It would be important for theology to pool its resources and focus on key research themes within this field. It is expected that increased international mobility will increase job opportunities in the future and at the same time enhance awareness of Finnish research in this field. Most theologists are internationally well networked. One interesting new area in this field is Baltic research and cooperation. The EU's Sixth Framework Programme in particular has contributed to increasing international research cooperation.

Research in the field of theology has good network contacts with adjacent disciplines. Nevertheless, many researchers still continue to go it alone. Within the theology field there is a need for closer cooperation between different areas, among other things to avoid overlap in the choice of research subjects and to gain a more varied picture of research subjects.

The new cognitive approach that has gained ground in the study of religion has even received international recognition. Interdisciplinary and multidisciplinary approaches have also opened up new perspectives in theological research, religious education and the study of church architecture and art. Studies on multiculturalism, ecumenics, social inequality, church diaconical work and voluntary work are examples of new lines of research designed to meet current and changing information needs. A major strength of theological research is its ability to take account of the current social and cultural situation both in Finland and internationally.

One major challenge for future exegetic research is to strengthen archaeological training. As regards research on church history, future challenges in this field include monitoring recent methodological developments and the application of new approaches.

Research evidence has also been widely used outside the academic community, for instance in ethics councils, ecumenical negotiations and various church and state committees. The results of theological research have been reported widely to the general public.

In our globalising world it is important to know more about religion. By tackling issues that are important both to the academic discipline and to society at large, theological research has given those issues greater visibility. New methodological approaches have contributed favourably to the development of this field of research.

Historical sciences and archaeology

- Professor Pirjo Markkola (Åbo Akademi University) is leading a research project called "Male Citizenship and Social Reforms in Finland 1918–1960", which is concerned to explore the construction of maleness within the context of social change. The project will contribute to a new understanding of the meaning of social reforms by studying how they took shape and how they were influenced by representations of maleness.

Historical sciences (including archaeology) are traditionally very strong fields in Finland. There is no dispute about their importance, although interpretations are a source of constant debate. History is part of our national, local and social identity, and it also draws strength from political legitimation and application. Historical research also seeks to problematise this relationship by engaging in debate about history politics and the foundations of historical research.

Historical research has relatively high public visibility and wide acceptance. Much research is done that caters for the interests of the general public, and that work is in strong demand. History researchers have considerable authority, real or imaginary, in the public eye, and they hold important advisory positions. The knowledge gleaned from research filters through to influence teaching and public opinion quite strongly. In general, historical research has a very major impact on public debate. This underscores the importance of academic and free research.

According to the evaluation reports available in this field, the coverage and general quality of historical research is very high, even though Finland still has no high-profile name at the international forefront. In some fields historical research has an international dimension simply by virtue of its subject matter: examples include studies of the history of different countries, the Middle Ages, ancient history as well as ancient and Baltic Sea archaeology. Internationalised fields – even though the research is often exclusively concerned with Finland – include economic history, the history of philosophy, women's history, and to some extent archaeology and cultural history. The verdict of evaluation reports is that compared to the quality of their work, history researchers do not have enough international publications. Too often, it seems that domestic publications define their quality criteria simply by reference to domestic and popular expectations.

Methodological diversity and reflexivity have clearly increased in this field. There are also more high-quality research clusters than before, even though there are no Centres of Excellence dedicated purely to historical research. However, the CoE in the History of Mind and the CoE in Ancient Greek Written Sources, for example, both have history researchers on their faculty. Since there is a relatively scarcity of high-level senior researchers in Finland, research units and organisations in the field tend to remain rather small and scattered – even though the work that is done is of a high quality. In the 2000s, there has been a marked increase in cooperation among historical disciplines as well as in their contacts with other fields.

The mobility and cooperation of history researchers have increased significantly over the past decade both internationally and nationally. Research exchange programmes and the graduate school system have played a major role in this respect. Participation in international conferences is also at a high level, and Finnish researchers have a reasonably strong representation in international organisations. Nonetheless, mobility and cooperation do need to be further strengthened.

There are currently three professorial chairs in the field of archaeology in Finland, which is quite a high number for a field that has some 70 permanent posts. Museums and archaeological companies also engage in archaeological activity.

As most other fields of science and research, archaeological research has been very much influenced in recent decades by the advances of information technology: databases, GPS systems and other applications. The new hardware and software have profoundly changed the nature of field documentation, for instance. One of the outcomes of this development is seen in modelling, which has paved the way to completely new research questions. Multidisciplinary and natural sciences methods will continue to strengthen and develop.

Publishing in archaeology is of very high quality and more international than earlier. There is also significant international networking and project cooperation.

- The research project headed by Professor Jussi-Pekka Taavitsainen (University of Turku) under the title of "Old Things Through New Eyes" follows up on Taavitsainen's long-standing work on the relationship between archaeological objects and the social environment of the past. The project is firmly rooted in, and contributes to, ongoing international theoretical discussions.

Cultural studies

- Postdoctoral Researcher Henri Schildt (University of Helsinki) applies current methods of cultural anthropology and interpretations of sacral architecture in his analysis of the Peruvanam Shiva Mahadeva temple, which is a representative example of Kerala temple architecture and a living temple institution. The scientific challenge is to do interdisciplinary research that takes a new and innovative approach.

Cultural studies is not any one particular discipline or even a clearly defined cluster of disciplines. Demarcations can and have been drawn in very different ways at different universities. The same subjects are taught in different departments and different institutes together with a whole range of arts and historical, cultural and social sciences. In some cases the same subjects are spread across different faculties. Most typically they come under the humanities faculty, but for instance the University of Helsinki differs from the mainstream in that comparative religion comes also under the Faculty of Theology and social and cultural anthropology come under the Faculty of Social Sciences. Cultural studies are also pursued in the field of history as well as in the areas of women's studies, media research, Asian and American studies, development research and rural research, Baltic Sea research and Arctic research. There are also several graduate schools in these fields.

Finnish research in the field of cultural studies is of high international excellence. In some fields, such as Finno-Ugric cultures and northern studies, it is at the cutting edge internationally. An important strength in folklore studies and Finno-Ugric ethnology as well as in studies of Sami and other minority cultures is their international engagement. There is open and far-reaching interdisciplinary cooperation in these areas of strength, and they are also open to theoretical and methodological challenges. These in turn have contributed to creating a sense of currency and pluralism as well as commitment and, in some areas, a strong profile for the field. Research in cultural studies could be described as 'youthful'. The evaluation reports available have drawn positive attention above all to the multiple approaches and perspectives espoused by the discipline, its pluralism in general and to its paradigmatically open and inquisitive attitude.

Networking among researchers in this field is extremely active, although obviously this does vary to some extent between different fields of research. The networks themselves are well established.

Weaknesses in the field of cultural research include the small size of units, the large amount of teaching and administrative tasks and the scarcity of staff resources. The research output of both research and teaching staff falls short of potential. In some cases it is felt that the faculty and department do not enjoy due respect within the academic community. Research in cultural studies has great impact across the board, and its social impact is widely recognized and appreciated. This is reflected in its active contribution to public debate and in the impact of research on the construction, maintenance and recognition of cultural identities, for instance. Also, research in this field has an undisputed impact on political decision-making. In this sense the position of the field is quite rewarding.

Much effort is devoted to popularising cultural studies. For some reason international evaluation panels pay only scant attention to the role and contribution of Finnish folklore studies, ethnography and anthropology to the Finno-Ugric minority populations' struggle for survival.

The field of research in cultural studies is varied and exciting and is now at an expansive stage. In some fields Finnish research is clearly and firmly at the international forefront. The selective focus strategy seems to have paid dividends. The theoretical and methodological acuity within this field is noteworthy. On the other hand, the small size of units and departments and the scarcity of resources are definitely causing problems.

Art studies

- The research project headed by Professor Pauline von Bonsdorff (University of Jyväskylä) provides a critical analysis of the institutional and physical boundary conditions for children's life-world with a view to how those conditions allow children to live and act and create spaces – physical, social, imaginary – according to their own needs and preferences. The results will have direct application in the design and management of children's spaces and institutions as well as in art education at school.

In recent years, some fields of art research have advanced and reached international level. A wide range of subjects are covered, some of which are groundbreaking. Researcher training has also received increasing investment, and this is now beginning to yield results. The biggest problems are the scarcity of resources, the small size of institutions and the lack of cooperation among them.

Overall the quality of research outputs is improving, although not all fields can be described as international cutting edge. However, research on film and literature, for instance, has received excellent reviews, and even in less successful fields, the quality of research outputs is generally rated as above average. Competitive national funding as a proportion of total research funding in the field is excellent.

The research focus is shifting increasingly towards multidisciplinary projects, which is due to the interweaving of the various realms of art and art phenomena and to the increasing mediatisation of art. This is a sign that art researchers are also keeping a keen eye on current art phenomena. The multidisciplinary orientation is reflected not only in the research projects conducted in various art fields, but also in the ever closer links of research themes with both the social sciences, communication sciences and technology sciences.

Although the quality of research outputs in art studies is high, publishing in international journals continues to remain at a low level in all fields of art research. This deserves more attention. One possible reason for the problem lies in the lack of resources available for language revision and translation, as the requirements on style and presentation are exceptionally high in these fields of research. Another big problem is that art research institutions are relatively small units and becoming ever smaller, putting research staff in particular under excessive stress: they are too burdened with teaching and administrative duties to concentrate properly on research.

Many international evaluation teams have drawn attention to the status quo of chronic under-resourcing in arts departments. Since the units are small, they might perhaps benefit from developing a clearer focus on selected areas of specialty. For tenured researchers in particular a major difficulty is the absence of a sabbatical system. Another critical point raised in evaluation reports is that much of the research at arts departments is done in the context of fixed-term research projects, which means fixed-term job contracts – and that is hardly conducive to raising the quality of research. Quality research requires the opportunity for long-term commitment.

Art researchers are frequently asked to explain and comment on their work in the media. Generally speaking there is a good working relationship with the media. Researchers also give talks and lectures at various events intended for the general public. In this sense research in these fields has good impact, at least indirectly. However, there is a surprising paucity of articles intended to popularise art research. Young researchers in particular are keen to focus on advancing their academic career rather than the popularisation of their research results.

The renewal of research depends very much on the younger generation of researchers and their fresh perspectives. Competition for research funding is fierce and there are concerns that in this competitive environment, radical views are at risk of being sidelined.

The recent evaluation commissioned by the Academy of Finland of research in art and design concludes that Finnish research in these fields is of international excellence. The evaluation focused on universities of art and design on the grounds that all of them engage in research that has interaction with artistic work. This kind of research is quite new internationally, and according to the panel of experts Finland is leading the way in some fields. The panel also observes that arts and design significantly contribute to the development of innovations. Research that interacts with doing art was thought to open up new avenues for generating knowledge.

Linguistics

- Adjunct Professor Maria Vilkuna's (Research Institute for the Languages of Finland) research project is concerned with sentence structure phenomena in regional dialects of the Finnish language. The aim is to fill in gaps in knowledge about the Finnish language and to try out new methods for obtaining reliable information about the structural resources of the spoken language. The results will have direct relevance to the theory of natural language syntax. One of the project's goals is to build up a network of researchers interested in the syntax of Finnish dialects and to join the network of dialect syntax researchers that is currently being developed in Scandinavia and other European countries. The project has introduced new uses for old digitised data.

Linguistics is a very heterogeneous field of research. When the Finnish Graduate School in Language Studies (LANGNET) started up in the late 1990s, bringing researchers from a variety of disciplines around the same table, one of the hardest challenges was to find a name for the school that adequately described their common research interests.

Language is studied from many different perspectives. The fields of research include linguistics, phonetics, philology, discourse and conversation analysis, language pedagogics, language psychology, language philosophy, language sociology, research on rhetorics and style, and neurolinguistics. Indeed, linguistics is inherently an interdisciplinary exercise. The general trends in the development of linguistic research have been rather similar to those seen elsewhere, although it is possible to detect some differences in emphasis. General linguistics is an important discipline in the United States and some other countries, and its theories and methods have a strong natural science base.

In Finland, phonetics and research focused on individual languages or language areas are traditionally strong areas (national languages, Anglistics, Germanistics, Romance philology). All these fields of research have strong departments that concentrate on the area of applied language studies, particularly the learning of foreign languages. Other important areas of applied linguistics in Finland include translation, interpretation, logopedics and various communications applications.

Key areas of strength for Finnish language research include conversation analysis, language typology and language history. Other important lines of research include cognitive linguistics, construction grammar and language technology. Discourse analysis, research on minority languages, research on language contacts and research on sign languages are also well respected fields.

Domestic publications are traditionally the main avenue for the publication of research results in linguistics. However, in the past ten years publishing in international refereed journals has sharply increased. LANGNET has been highly instrumental in this regard. It is noteworthy that publishing practice in the other Nordic countries has been very similar to that in Finland, yet during the past 20 years Finnish researchers have received less international exposure than their Nordic colleagues. In the future, greater attention must be paid to ways of developing publishing culture.

The broad scope of linguistics research clearly attests to the importance of this discipline. Linguistics has a major impact on how communities and nations see their own history and identity. Linguistics plays an integral part in the creation and transmission of cultural knowledge.

- Professor Terttu Nevalainen is in charge of the Centre of Excellence for the Study of Variation, Contacts and Change in English at the universities of Helsinki and Jyväskylä. The Centre's main focus of research is on language as a social and discursive phenomenon, processes of language change and typologies of variation. This research cuts across traditional discipline boundaries by incorporating the methods and approaches of social history, culture, learning research and computer science into linguistics.

Social sciences

Figure 4 shows the development of university research expenditure (including core budget funding and external funding) in the social sciences from 1991 to 2006. During this period, the volume of research funding has increased most sharply in economics, political and administrative sciences, communication and information studies, and psychology, where funding allocations have at least doubled. The Academy of Finland has been the most important source of funding in psychology, social sciences, law, political and administrative sciences, and information and communication studies (see Figures 5 and 6). In the field of economics, funding from Tekes (the Finnish Funding Agency for Technology and Innovation) at 25 per cent of the total in 2004–2006, has exceeded the Academy's contribution. The social sciences have also benefited significantly from funding from ministries and from the EU.

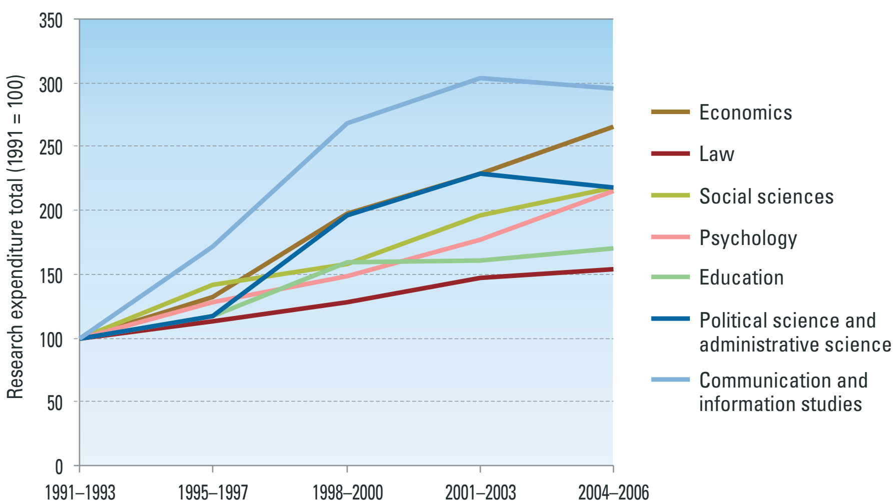


Figure 4. University research expenditure in the social sciences 1991–2006, change.
Source: Statistics Finland and Unit for Science, Technology and Innovation Studies TaSTI, University of Tampere 2008.

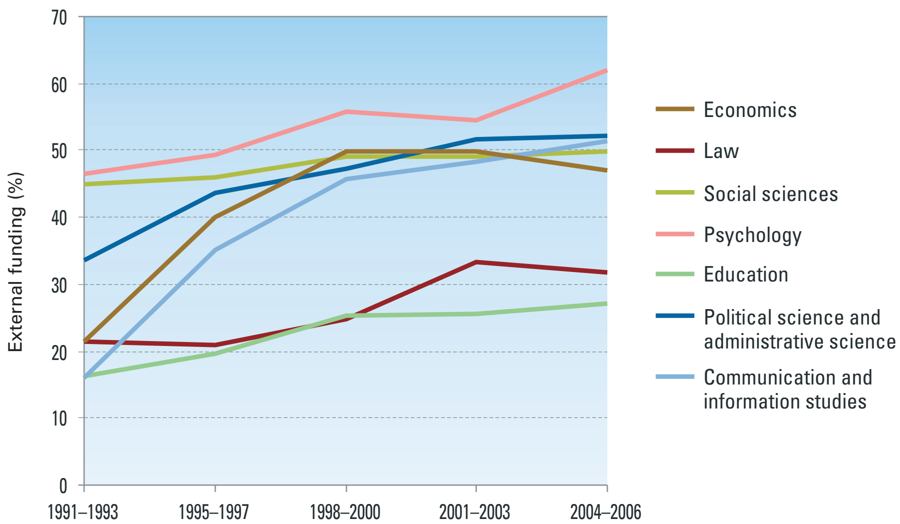


Figure 5. External funding as a proportion of university research expenditure in the social sciences.
Source: Statistics Finland and Unit for Science, Technology and Innovation Studies TaSTI, University of Tampere 2008.

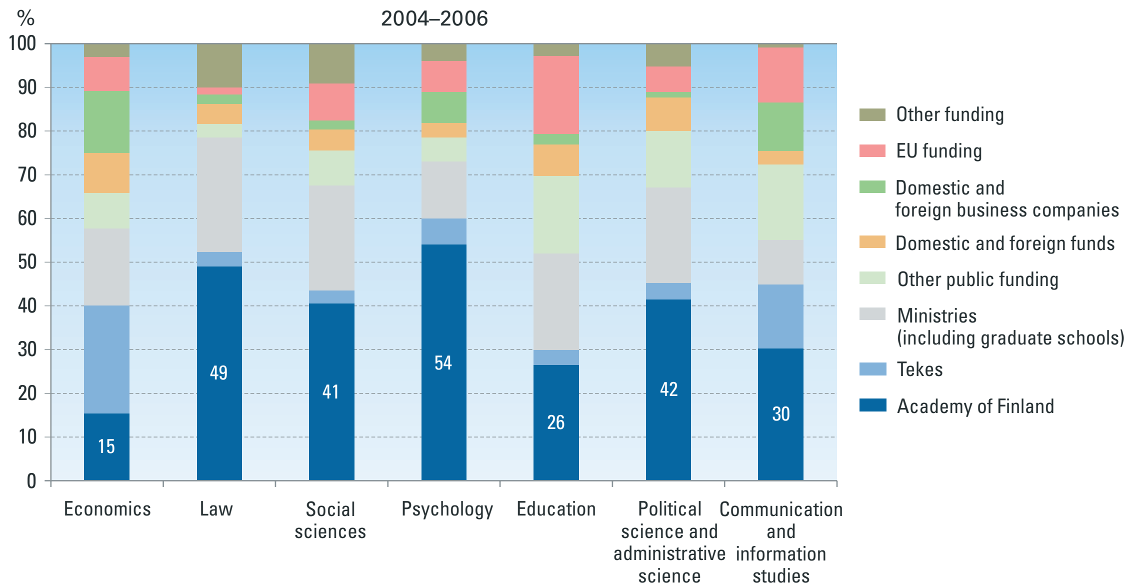


Figure 6. Sources of external funding for university research expenditure in the social sciences in 2004–2006.
Source: Statistics Finland and Unit for Science, Technology and Innovation Studies TaSTI, University of Tampere 2008.

Law

■ Professor Kimmo Nuotio's (University of Helsinki) research project "Security – The End of Criminal Law?" investigates the development of the criminal law system and its interweaving into an increasingly complex security management regime. Legal doctrine is regarded as an indicator of the political pressure upheld by the security regime and of the presence of power. The research combines perspectives from law and the social sciences.

There are three faculties of law in Finland, and the discipline traditionally has a strong practical orientation. There have been no discipline assessments in the field of law, and the Faculty of Law has received an assessment only in connection with the evaluation of research at the University of Helsinki.

The quality of research outputs at the University of Helsinki Faculty of Law is described as lacking in consistency. Research is currently being reorganised into research teams that are oriented to interdisciplinary, comparative and international research. The quality of research varies at all major departments under the Helsinki Faculty of Law from excellent (e.g. general jurisprudence, women's studies, social civil law), through good (criminal law, administrative law, tax law) to satisfactory. For this reason the overall scores for the various departments are mediocre. The only department that received the highest possible score was a small institute that focuses on one of the faculty's key areas of strength (international law).

The three faculties of law in Finland have somewhat different profiles in that Turku, for instance, specialises in research on basic rights. The impression that quality research is concentrated in certain key areas of strength is further reinforced by the fact that since the evaluation of research in Helsinki, Centres of Excellence and other research projects seem to have turned their focus to those research areas that had the best success in the evaluation. Centres of Excellence and other research projects have provided a useful way to overcome the problems associated with departmental divisions and also to alleviate the problems of research focusing on one particular legal doctrine.

The institutional division of legal research into different departments in Helsinki is based, in part, on the traditional distinction between private law and public law. The evaluation concluded that this division is counterproductive in that it hampers rather than facilitates interdisciplinary, comparative and international research. The imbalance between the number of professorships and postdoctoral positions was also seen as a threat. On the one hand, it seems that recruitment into teaching positions from research projects is very difficult, and on the other hand, there is a scarcity of permanent faculty positions in research intensive fields. The problem lies in the allocation of resources within the discipline. Traditionally strong fields are reluctant to lose any of their resources. The law curriculum, too, perpetuates the need to allocate resources to all the various fields of law. Master's programmes are designed to produce lawyers who have a basic knowledge and understanding of all aspects of current law – and this means that tuition must be provided in all those aspects.

The national graduate school, the annual conference of legal studies and research projects that cut across traditional discipline boundaries all serve as good examples of researchers' national networking. The pressures coming from European integration and globalisation are pushing researchers to devote greater attention to internationalisation. In particular, cooperation at European level has become virtually indispensable. Indeed, EU membership has had more direct impact on the field of law than most other disciplines. However, the research field remains deeply divided. Some researchers are firmly committed to national and international cooperation, others take a more traditional approach and rely in their work on data from national legal sources and on national research questions.

The renewal of research in this field is threatened by problems in the academic research career track. The main difficulty, paradoxically, is landing a permanent faculty position from a postgraduate position in high-quality research. In some fields there is also a mismatch between research intensity and the availability of faculty positions. The high demand in the job market for Master's graduates is making it harder to recruit promising talent into doctoral programmes, and the number of doctoral theses published in the field is certainly not too high. What can be called into question is whether the people who are recruited into research really are the most suited to this job. Pay levels for postgraduate research students are considered too low and the long-term security offered by the academic research career inadequate. There are differing views within the law field on whether or not to retain the Licentiate's degree. Although steps have already been taken to make this a vocational postgraduate degree, many doctoral students still choose to complete the Licentiate's degree before taking their PhD, which effectively delays PhD graduation and causes additional financial problems. Many postgraduate students who work while studying aim to complete the Licentiate's degree. The non-academic job market for PhD graduates is reasonably strong, at least if judged by the relative earnings of PhD graduates.

Psychology

■ Academy Research Fellow Mika Koivisto's (University of Turku) research interests lie in the neurocognitive mechanisms of visual consciousness. To clarify the neural foundation of phenomenal consciousness is one of science's most challenging problems: how can the material brain evoke personal, subjective experiences? The methods employed include transcranial magnetic stimulation (TMS) combined with functional magnetic resonance imaging, methods for recording and analysing the brain's electrical activity and behaviour measurements.

Psychology is a strong discipline that produces high-level research in a number of fields, including brain research as well as learning and motivation research. There are two Centres of Excellence in this field, the CoE in Learning and Motivation Research, and the Brain Research Unit. Major strengths in psychological research include longitudinal studies, dyslexia and psychotherapy research. The field also boasts important methodological strengths, and there are many young talented people who are producing high-quality research.

The quality of research outputs in the field has improved significantly over the past ten years. One contributing factor has been the improved quality of researcher training. The role of graduate schools is not just to train new PhDs, but to provide a structure for the networking of senior researchers. Indeed, psychological research is currently in the stage of vigorous renewal. In brain research and physiological research, for instance, new methods and equipment have opened up new vistas and new approaches. 'Old' research questions are now being tackled from fresh angles. For example, the significance of emotions has recently attracted renewed research interest, and there is also strong interest in the associations between genetic and psychological factors. There is an increasing trend in psychology towards modelling processes and individual cases.

One definite weakness in the field of psychology is the lack of cooperation: the same or similar lines of inquiry are pursued in different universities, without much coordination at all. One source of concern is the slowdown of international mobility, which has affected Finnish science and research more generally, even though the international dimension is ever present in modern research. There is without question a need for a sabbatical leave system in the field. Overly fierce competition and the tendency of the field to turn in on itself present the most serious threats for the future.

There is much applied research in the field of psychology that has significant impact. Again, however, the scarcity of resources presents a problem, as does poor cooperation with the media.

Psychology researchers are well networked and they are very internationally minded (e.g. in publishing). An important tool in this regard is the online university network Psykonet. CoE cooperation between different universities is also very important. The University of Jyväskylä and University of Tampere have also set up new mechanisms with a view to promoting cooperation. A good example of a wider than national contact network is provided by the Baltic-Nordic Graduate School Network.

- Professor Jari-Erik Nurmi (University of Jyväskylä) is head of the Centre of Excellence in Learning and Motivation Research, whose aim is to create a new, integrative, research-based view on how learning difficulties develop under the dynamic influence of neurocognitive and motivational factors. This understanding will in turn lay a more solid foundation for the prevention of learning difficulties in both the family and school environment.

Education

- Postdoctoral Researcher Maarit Alasuutari (University of Tampere) is interested to explore how individualised education plans for infants impact day care practices, family life and views on childhood and child upbringing. Her research is an ethnographic case study, the data for which are collected in three day care centres in one municipality.

Research in the education field has received fairly positive evaluations. However, it is less than straightforward to form an overall impression as training in the education field is divided into several units that perform different functions. The framework conditions and quality of research vary depending on whether we are considering early education, teacher training or degree programmes in different disciplines (education, adult education, vocational education and training, special education). For the purposes here, a distinction is made between teacher training and education sciences, with the latter serving as an umbrella for different degree programmes.

A major strength of *teacher training* is the high level of involvement in national and international research networks (including the teacher-researcher network, which has significant social impact). In addition, some researchers have close network contacts with quality units in both the research and teaching field. One weakness of teacher training is that the system of teaching and research posts leans too heavily towards teaching and furthermore is slow to change. The number of quality scientific publications is also low, and only a small proportion of personnel are involved in preparing research publications. Often there is too little interchange and research cooperation between separate units. The same applies to cooperation and exchange between PhD students. In some cases it is clear that the field lacks a coherent research strategy.

One of the strengths of *education sciences* is its multidisciplinary research orientation. There are several research teams in this field that comprise both doctoral students and postdoctoral researchers. In some units there is a strong interest and drive to developing research methodologies. Among the weaknesses of the field are the scarcity and randomness of outside research funding. There are not many postdoctoral researchers, and often departments and units do not have cooperation in researcher training and research projects. The numbers who obtain external funding and produce high-quality articles are also fairly small. It seems that several departments also lack a clear publishing strategy.

Research in the education field has received fairly high evaluations in outside reviews. Education faculties and departments at different universities have developed and followed strategic action plans for several years. They have also produced high-quality international publications, innovative research projects and internationally interesting joint projects. However, international breakthroughs are possibly achieved by just a small minority, and therefore they do not give a true reflection of the whole department's performance and achievements.

There has been a clear increase in multidisciplinary research projects. Researchers in the field have close ties with international networks. Virtually all education units in the country have at least one internationally oriented research project. However, closer attention should be paid to the choice of partners: the key is to select partners that will generate real added value to the research project and its objectives. Rather than going it alone, researchers should invest greater effort in co-producing publications with domestic and foreign colleagues.

In recent years there has been a growing recognition in education sciences of the need for methodological reform. Many of the phenomena addressed in education research are such that they require a mixed method approach. At the same time, there is growing interest in methodological development (e.g. non-linear modelling methods). These efforts have received well deserved praise in outside discipline assessments. A major challenge in the field is to get universities to join forces in a concerted effort to further improve and develop researcher training. The multidisciplinary research projects launched and conducted in recent years have also contributed to the renewal of research in the education field. One of the obstacles hampering the growth of multidisciplinary research is the scarcity of experts in the economy of education.

Research in the education field is often rated as having high impact. However, there still remains a huge challenge in developing methods of measurement and evaluation that provide a true and relevant picture of the impact of scientific research.

Social sciences

- Postdoctoral Researcher Simo Häyrynen (University of Joensuu) uses both social science and cultural studies tools to analyse and explain one of the big issues of modern society, i.e. the public and non-public survival strategies of declining industrial communities. His case is the town of Outokumpu whose mining operations were closed down in 1989.

There are more than ten universities in Finland that conduct research and provide education in social sciences. The main social science disciplines are sociology, social policy, social work, social and public policy and social psychology. In addition, there are certain special fields and multidisciplinary subjects that award PhD degrees.

Social sciences research is an institutionally very large field with extensive research interests that cover a wide range of social phenomena. Social sciences also have a strong presence in various multidisciplinary ventures such as women's studies and cultural studies, but also in such fields as organisation and management.

With just a couple of exceptions, social sciences have received very positive assessments in recent international evaluations. The commitment in the field to international engagement is reflected in its increasing rates of international publishing, the number of people involved in journal editorial posts, the publication of research monographs by international publishers, and in research projects that benefit from both national and international funding.

Evaluations of social science research have drawn attention to some weaknesses that are inherent to the university system and that may be reflected in the overall quality of research. At the University of Helsinki, for example, one of the problems mentioned is the scarcity and uncertainty of funding and postdoctoral research positions. Since the renewal of science requires a constant search for new innovative lines of inquiry, the lack of secure and long-term funding is mentioned by international evaluation panels as a major challenge for the maintenance of high-quality research. Some of the units in this field are small and lack the resources to reach the international forefront. Some of the smallest units publish nationally to a greater extent than internationally.

Social sciences in Finland have a strong international orientation and strong network contacts with the other Nordic countries and the rest of Europe. Most contacts outside of Europe are in the United States and Russia. Social science researchers are involved in numerous EU-funded projects, and their high level of international engagement is also reflected among undergraduate and postgraduate students. Graduate schools have contributed to promoting systematic networking, which has also increased mobility. Furthermore, international conferences and seminars are now organised on a more or less routine basis, another indication of the high level of international engagement in the field.

For small units in particular, lack of resources means that international cooperation as well as networking and mobility require significant effort and input.

Evaluation reports for the units that received the highest overall ratings were unanimous in their praise for the renewal of social sciences. This applied both to research into subjects of current social interest (national context) and to international research following the development of new theoretical and methodological research trends. Multidisciplinary approaches were mentioned as having a beneficial effect on the renewal of research.

In the social sciences, renewal depends crucially on the possibility to commit long-term to doing research. This very rarely is the case in Finnish universities today, as is highlighted by international evaluation reports.

Social sciences research is concerned with society and social phenomena, and therefore it has by default social impact. This impact is diffuse, adding to society's self-understanding in a broad sense. Social policy and social work are the disciplines that most often provide concrete, empirical information about key problems in society and the ways they can be resolved. Basic research in sociology and other social sciences, then, provides theoretical and methodological tools for various other disciplines and expands the set of basic theories that have 'rhizomatic' (Deleuze & Guattari 1992) effects throughout the social sciences.

A major challenge that lies ahead for researchers and research funding agencies is to explore and understand the slow, long-term processes of impact in science and research. This will go some way towards dispelling the current tendency to understand scientific impact in terms of media exposure alone.

Economics

- Professor Markku Tuominen (Lappeenranta University of Technology) is leading the research project "Innovativeness in Russian High-Tech Industries", which is intended to explore the commercialisation of innovations in Russia. The project describes the current state of the Russian innovation environment and analyses the impacts of technology transfer, open innovations and distributed product development on the commercialisation of innovations in Russia.

Economics and business administration are an important part of the university curriculum and academic research. Economics traditionally leans on a social science approach. The business administration tradition is more diverse and varied, consisting typically of accounting, management, marketing and entrepreneurship. The business administration research tradition is younger than the economics tradition, but in recent years its research capacity has overtaken the corresponding capacity of economics.

The Academy of Finland has conducted its own assessment of the discipline of business administration to complement the evaluations undertaken by universities themselves. The national evaluation of economics and business administration comprised nine university units and a total of 65 departments. The aim was to provide an overall assessment of scientific excellence in the field and to weigh the impact of research from a business know-how point of view. The general impression emerging from these evaluations is that all economics units tend to give priority to teaching and that there is a relative scarcity of resources for research. There are no marked quality differences between the university units included in the evaluations. The quality of research outputs is described as high across the board.

National cooperation has clearly increased and is continuing to increase in this field, partly as a result of national changes in the university organisation and structure, including the merger of the Helsinki Center of Economic Research (HECER), the University of Turku and Turku School of Economics, the new Department of Business and Management at the newly formed University of Eastern Finland, and the closer cooperation and coordination between the universities of Jyväskylä and Tampere as well as between the universities of Oulu and Lapland. Nonetheless, researcher mobility both within the country and internationally remains fairly limited.

There are two high-level graduate schools in the economics field, the National Post-graduate Education Programme in Economics (KAVA) and the National Post-graduate Education Programme in the Economic Sciences (KATAJA), and there is broad-based economic cooperation. International research at the leading edge has increased during the 2000s, although there are still relatively few Centre of Excellence units and Academy Professors in the field. Although researcher training has expanded significantly, further steps are needed to increase the appeal of the academic research career and to develop career paths for PhDs both in academia and in business and industry. There is a growing need for research and training both at universities and in business companies.

One of the major challenges that lies ahead in the economics field is to increase the volume of funding available for basic research. Empirically oriented research in particular needs funding in order to collect extensive individual and register datasets. In addition, a programmatic agenda and a stronger multidisciplinary orientation is needed to strengthen research. Multidisciplinary cooperation can help to create critical mass and to promote the social impact of this field.

Globalisation has generated new research challenges, but there is still need for theory-building on a national business and institutional basis. Economists are closely involved in economic policy debates and in various advisory positions. In the future applied research will assume increasing prominence and importance from a social impact point of view.

Political science

- Academy Professor Kari Palonen (University of Jyväskylä) is Director of the Centre of Excellence in Political Thought and Conceptual Change, which describes its mission as thinking, reading and analysing phenomena politically. This method expands the scope of political research to contingent activity. The CoE consists of three interconnected research teams: Political Thought and Conceptual History, Politics of Philosophy and Gender, and Politics and the Arts.

Academic research in the field of political science is undertaken at the universities of Helsinki, Jyväskylä, Tampere and Turku and at Åbo Akademi University. Faculty education is also provided at other universities. In a national analysis key indicators suggest that political science departments have been highly successful in the 2000s. There are Academy-funded Centres of Excellence at political science departments in Helsinki, Jyväskylä and Turku. The Åbo Akademi Department of Political Science has its own CoE that focuses on democracy research. The Department of Political Science and International Relations at the University of Tampere has undertaken to coordinate a major research project on electoral research. The Department also has other major research projects that are funded from external sources. The holders of the chairs of political science at Jyväskylä and Turku are currently appointed as Academy Professors. In general, political science departments have been highly successful in competing for Academy funding.

International engagement and international scientific publishing have continued to increase. While in the late 1990s no more than a handful of authors had signed with an international publisher, today there is at least one such scholar at every political science department in the country. All in all, the European visibility of Finnish political science both at scientific conferences and in the field of PhD education has significantly improved in the 2000s. Finnish names are also seen more frequently on the editorial boards of science journals and even in higher-profile international editorial positions.

Finnish research in the field of political science has shown good momentum in its development over the past ten years, particularly with respect to international engagement. This is reflected both in publishing forums, participation in international projects and in the hosting of international congresses. The main weaknesses in the field are the insecurity of the academic research career; the absence of Finnish contributions to top publications; and the fact that young researchers are less interested than before in making long-term research and teaching visits to other countries.

The ongoing restructuring of universities will help boost the prospects of the academic research career in the competition for the talents best suited to pursue a career in science and research. The first steps have been taken on the road to restructuring, but progress seems slow. Whether political science can succeed in the competition for the best research resources will only be seen once the new Universities Act takes effect. The main threat to the quality of research, both at home and internationally, comes from the fragmentation of the discipline and the lack of consistency in the evaluation criteria applied.

Finnish political science researchers are reasonably well networked, particularly so at the University of Helsinki and Åbo Akademi University. Strangely enough, mobility is on the decline among PhD students and particularly among recent incumbents of postdoctoral positions. This might have to do with the uncertainties of the research career, but social factors are no doubt at play as well. American universities, for instance, are far more sensitive in their recruitment practices to the needs of family members than is the case in Finland.

Networks of cooperation in general are more extensive than ever before. Although in some sense it could be said that EU projects and some other forms of international cooperation are involuntary and imposed, there is nevertheless increasing international cooperation that grows from below, out of necessity.

Finnish research in the field of political science is highly diverse and varied. Renewal takes place through the adoption of new perspectives and research strategies within a certain school of thought rather than through the introduction of whole new paradigms. In this respect Finland is not only a bazaar of great diversity, but also one of fragmented trends. Because of the small size of the research units, renewal may in some instances depend on one single personality. When people leave their position, the new incumbent may bring along an entirely fresh approach. In other countries it is common for universities to specifically recruit experts in a certain field. With the possible exception of Helsinki, this is not normally affordable in Finland.

Although the number of scientific monographs published by Finnish political scientists is on the increase, and although scientific articles are also being published more often in leading international journals, it is still a very small elite of Finnish researchers who publish internationally. Furthermore, the world output of scientific literature is growing at a phenomenal pace, so it is possible that the relative contribution of Finnish researchers to that output has actually declined. Impact is of course always ultimately a matter of quality. In that respect it seems that the situation has remained quite stable over the past ten years.

Communication studies

Professor Maija-Leena Huotari (University of Oulu) is leading the research project "Health Information Practice and Its Impact" in which the focus is on the prevention of metabolic syndrome and obesity. This is an interdisciplinary project at the intersection of information studies, medicine and nursing sciences. The subject is highly topical because according to the WHO Regional Office for Europe, obesity has tripled over the past 20 years.

Research in communication studies consists of both humanities and social sciences oriented work. This is a broad ranging field at the core of which lies the discipline known as media studies, but it also comprises such areas as communication technology, visual communication, speech communication and information sciences. Many of the evaluations conducted in this field are relatively old, and the 2007 report on the Current State of Communication Research in Finland is mainly focused on the situation in the private business sector.

The main strength of communication research lies in its broad scope and its multidisciplinary approach. It is highly international in its focus: for instance the research subjects in the field of speech communication are of great current international interest. Finnish communication research has close contact with its American counterpart.

As for weaknesses, mention needs to be made of the small size of the units in this field and their fragmented research strategies. Furthermore, communication research in Finland is heavily tied to the Finnish language and international publications are scarce. It is traditionally focused on social journalism and on mass communication research. New research interests in the field stem largely from globalisation and media digitisation. For example, subjects of visual communication continue to remain under-resourced compared to their significance.

The university network for communication sciences has for years worked to condense relevant information and to enhance cooperation in the field. There are also several collaborative Nordic research teams and research information centres, such as the Nordic Information Centre for Media and Communication Research (Nordicom) and the Nordlis network. Finnish communication researchers hold high-profile positions, serving for instance as chair and vice-chair of the new collaborative European network for speech communication research. Many departments in the field have long-standing cooperation with US and British researchers.

Communication research (including visual communication, speech communication and information sciences) has close ties with people's everyday life and it has exceptionally high visibility in the media. It also contributes actively to public debate in society.

Funding is also channelled to communication research through certain funds and foundations. This has a major influence on the orientation and focus of research.

Communication research has an empirical focus. There is a strong tradition of qualitative research in the field. Popular research subjects include media and popular culture as well as organisational culture. The impact of research in this field is bolstered by its interdisciplinary and transdisciplinary nature.

Social scientific research places great emphasis on the links between practice and theory, for instance between journalistic practice and research. Many researchers have close and direct contact with the media. Nonetheless, researchers in the communication field face much the same difficulty finding work outside academia as researchers in other fields.

■ Professor Pekka Isotalus (University of Tampere) is leading a research project on "Social Interaction in Interpersonal Professional Relationships", which is concerned to identify communication theories and concepts that are relevant to studying interaction. The project primarily employs a qualitative approach and it uses a number of different methods of data collection, including interviews, observation, questionnaires and essays. The results will have application in speech communication education as well as in developing methods for the evaluation of interaction quality in professional contexts.

3 PhD Education and the Academic Research Career

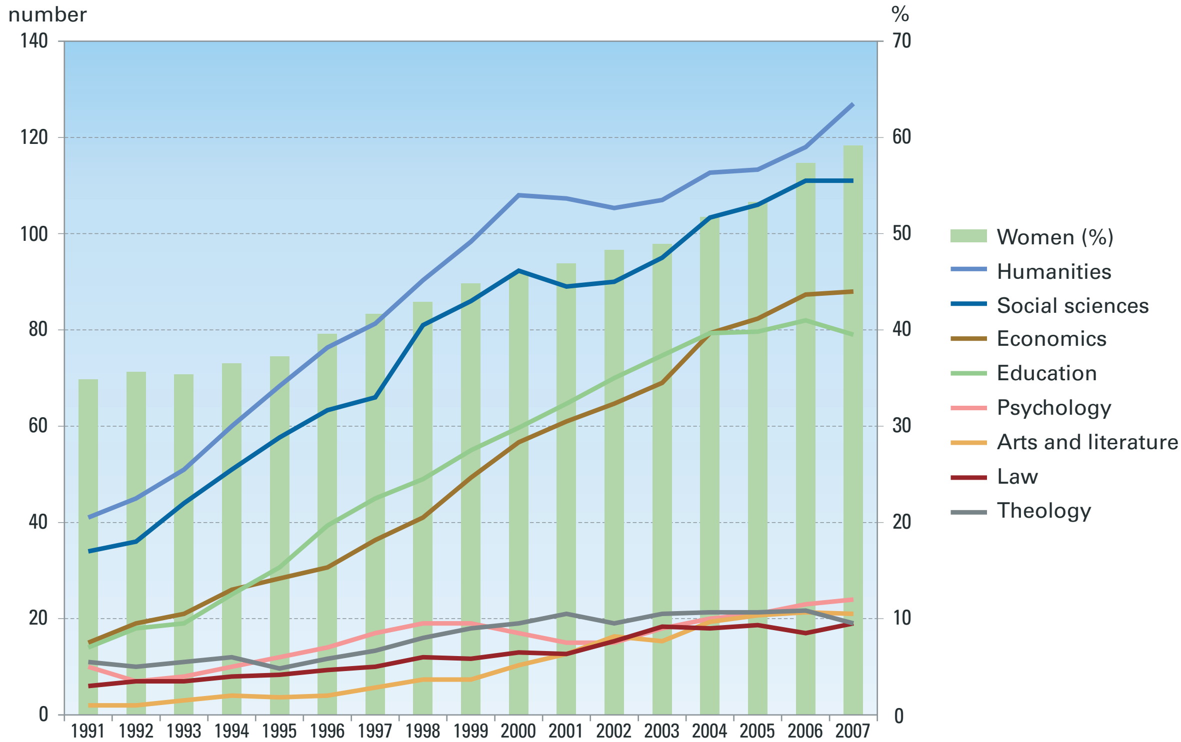


Figure 7. Number of PhDs awarded in disciplines under the Research Council for Culture and Society and women's share of PhDs in 1991–2008, three-year moving averages. *Source: Ministry of Education, Kota database 2009.*

In all fields of research under the Research Council for Culture and Society, the number of PhDs awarded has increased sharply over the past couple of decades. All in all, the number of PhDs completed in 1990–2008 has tripled: the figure for PhDs earned by women has increased fivefold and for those earned by men twofold. In 2008 women accounted for 59 per cent and men for 41 per cent of all PhD students in the fields of study under the Research Council. The proportion of women among new PhD graduates has increased most sharply in the field of business administration, where the figures have increased 11-fold during 1990–2008, and in education sciences, which show an almost 8-fold increase during this period.

A distinct strength in several fields of cultural and social research is their broad-based and diverse researcher training. Theology, history, cultural studies, linguistics, psychology, education sciences, social sciences, economics, political science and communication research all have their own national graduate schools, which have had a major positive impact on the efficiency and quality of researcher training. They have also helped to pool scattered national resources. Interdisciplinary cooperation and openness to new theoretical and methodological perspectives also count among the strengths of these schools. Graduate schools serve as an excellent example of systematic and international PhD education particularly with the adoption of the new researcher training system as set out in the Bologna Agreement.

The main weakness of researcher training in cultural and social studies is the shortage of teaching staff and their heavy workload. There are too many doctoral students relative to the number of supervisors, and this is reflected in the quality of training. Furthermore, departments are too small. These problems have been highlighted in a number of evaluations. Steps are also needed to further increase and intensify national cooperation.

The number of doctoral students in cultural and social studies who complete their PhD outside graduate schools continues to remain high. Private foundations are another important source of funding for PhD students alongside graduate schools. Furthermore, considerable numbers complete their PhD while working full-time, or simply out of personal interest.

The postdoctoral stage has proved to be one of the most problematic in the field of cultural and social studies. Funding is intermittent, and the relative scarcity of permanent research positions further adds to the sense of uncertainty. Indeed, a key challenge for the future is to achieve appropriate balance in the numbers admitted into researcher training programmes. In some disciplines the numbers currently admitted are too high (e.g. history). Indeed, scientific research ought to be more closely tied to basic studies, and the career development of young researchers should be promoted with a view to both their own future prospects and the university's needs.

There is a marked duality about training in linguistics, law, education and some other fields of cultural and social research. On the one hand, there are full-time postgraduate students who benefit from systematic and often internationally oriented training through high-quality graduate schools, Centres of Excellence and research projects. On the other hand, there are also large numbers of postgraduate students in law, for example, who pursue their degree studies on a part-time basis and with variable success.

It is only now that the problems surrounding academic research career prospects have begun to receive attention in science policy planning. The Academy of Finland, universities and foundations should join forces to create mechanisms so that resources could be coordinated and joint national objectives set for doctoral education programmes. The number of PhDs awarded is not an appropriate criterion for the allocation of university funding.

4 Research Infrastructures

Research infrastructures in the fields that come under the Research Council for Culture and Society consist of datasets and registers, data processing methods, associated skills and competencies and computing capacity as well as research equipment.

Libraries and archives are essential resources for researchers in the humanities and social sciences. In these fields research is published in the form of monographs. There is a continuing readership for older research literature, too. It is crucial that these library collections and services are maintained and developed.

There is a large abundance of materials. Memory organisations have well established materials that have national significance and that are in shared research use. Most of these materials, however, are in a format that can only be used *in situ* at the archive or library by manual browsing. Furthermore, several research programmes and projects have accumulated nationally significant datasets that have further application. Individual researchers and departments also have materials and datasets that could have wider research use, but they have not been stored in a readily distributable format. What is more, cultural and social research makes use of many datasets that have not originally been collected for research purposes; examples include parliamentary documents and court records.

It is a key objective in these fields to compile research materials and datasets with a view to more effective utilisation. Apart from the technical side of usability, information is needed on data protection and rights of access. There are two approaches to the development of research materials. One route is to integrate existing scattered datasets, to work systematically to accumulate them and to make them as widely accessible to researchers as possible. Secondly, existing datasets can be digitised so that they can be accessed via the Internet. This is a highly labour-intensive process. The handling and processing of research materials and datasets is currently entrusted in research projects to students, but it would be possible and indeed necessary to have trained, dedicated professionals for this purpose.

The materials needed in cultural and social research are such that they can be used in other contexts as well. The materials and databases of the National Board of Antiquities, the National Library and the Research Institute for the Languages of Finland are widely accessible not only to scientists and researchers, but to other users as well.

Statistics Finland materials are highly useful in many research fields, but their use for research purposes is very expensive as the statistical agency's data pricing is based on the Act on Criteria for Charges Payable to the State.

The Finnish Social Science Data Archive compiles and archives research data in the social sciences. Most humanities research fields, by contrast, have no mechanisms for systematic data archiving. It is crucial that researchers in all fields assume greater responsibility for research data and that they are more keenly aware of development needs in this area. With a view to developing register-based research, a number of institutes have now joined forces to establish the Finnish Information Centre for Register Research.

The effort invested in developing research data and their accessibility have attracted considerable research interest from abroad, too. For instance, Finland's involvement in the European Social Survey provides wide access to research and comparative data on Finland.

Advances in language technology have paved the way to various easy-to-use software tools that facilitate the handling of large datasets. The archiving and use of research data require extensive basic research in language technology and applications development. In addition, there is need for a separate profession who have the necessary skills and competencies in methods development and application. The processing of large datasets requires computing methods, too. Many modelling methods are also very popular: good examples include the computer simulations produced in the fields of history and archaeology of Middle Age villages. E-science is a major focus of development in several fields.

Laboratories are needed in the fields of musicology, psychology and archaeology, for example. There are some clusters and shared laboratories in the field of psychology. There are no laboratory facilities for archaeologists in Finland.

In recent years much effort has been invested in the development of research methods for cultural and social research, and systematic researcher training has helped to improve methodological competencies. Research in these fields employs both qualitative and quantitative data, and several disciplines can apply the same datasets to tackle different research questions. Old research data have assumed new meanings with the evolution of new methods and research questions. For example, philological research and the preparation of critical editions employ language technology applications, and political science researchers can go back to studying old parliamentary documents with fresh sets of questions.

5 Research Council's Development Proposals: "Basic Research, Pluralism, Cooperation"

In its overview of recent developments and current challenges in the fields of research that come under its aegis, the Research Council for Culture and Society has directed its attention to the following observations: Researcher training has become more professional than before and its quality has improved in all fields, which also show a much stronger interdisciplinary and multidisciplinary orientation. Research methods have developed significantly in various fields, which in turn has opened up new research perspectives and contributed to improving the quality of research. Paradoxically, the broad scope and diversity of cultural and social research are indicative both of its fragmentation and its capacity for renewal.

National graduate schools have served to promote both national and international cooperation in the field. However, both mobility and networking should be increased at national and international level. Steps are needed to increase the number of research visits into Finland, and on the other hand Finnish researchers could attend international conferences more often.

The main bottleneck in the academic research career path has moved to the postdoctoral stage. Indeed, the aim should be to encourage mobility both between different sectors in society and more generally. The expertise and research skills of PhDs should be made more readily available and accessible to all sectors of society. Mobility between industry and academia still remains at too low a level, even though this could have great significance to the creation of new jobs and knowledge transfer.

Departments and units in the fields of cultural and social research are often too small and they are characterised by internal fragmentation and a broad spectrum of subjects. On the other hand, there is a very obvious shortage of researchers and auxiliary staff. It is only very rarely that researchers can concentrate full-time on research. Administrative tasks are a constant drain on their time.

There have been some important changes for the better in publishing practices in the field of cultural and social research. For instance, the practice of co-publishing has increased in the social sciences. On the other hand, monographs continue to play a prominent role in the humanities, and it is important that this can be secured for the future.

The role of basic research

Excellence in education and basic research is fundamental to building the future of our research system. The Academy is the single most important player in the basic research field in Finland and the major source of funding for cultural and social research. *The Research Council considers it important that there is adequate competitive research funding.* The allocation of research funding must be based on long-term science policy objectives and national priorities. Universities are clearly under-resourced to conduct basic research at the highest possible level, and funding must be stepped up. This funding vision will only be possible if there is close interaction and collaboration between the scientific community and decision-makers.

Research infrastructure

One of the most important areas of infrastructure development is the digitisation and archiving of research materials to make them more readily accessible to the science and research community. This will also help lower the costs of retrieving research data if they can be accessed online.

Many memory organisations have ongoing digitisation projects, which should be further *improved and stepped up. In addition, mechanisms must be put in place to ensure that new research data are compiled and accumulated and that current scattered data are systematised.* Many existing memory organisations are mentioned in the national research infrastructure roadmap. This roadmap opens up development opportunities that the Research Council for Culture and Society believes should be seized. Future plans must also be drawn up for an e-infrastructure.

New broad-based data archive centres must be developed similar to the Finnish Social Science Data Archive.

Some of Finland's current infrastructure projects are related to the ESFRI Roadmap. In the field of language technology and language resources Finland is in the position to assume a leadership role in the Common Language Resources and Technology Infrastructure (CLARIN) project.

It is crucial to ensure the continued growth of library collections and the continuity of their services.

Strengthening cooperation

National and international cooperation is of increasing importance at all levels. The Research Council for Culture and Society stresses the importance of promoting mobility at all levels both nationally, internationally and between different sectors of society. Further long-term development efforts are needed to ensure the diffusion of research knowledge and the recruitment of researchers into a variety of different positions in society.

Steps are needed to strengthen cooperation among different national bodies to make research career paths more predictable and to minimise career uncertainties. The Research Council considers it useful to intensify cooperation between the Academy and the Finnish Council of University Rectors. A common point of interest for all parties concerned is how to attract young people into a career in science and research. There is broad agreement on the four-tiered structure of the research career, with demands progressively increasing step by step: researcher training leading to the PhD, the postdoctoral stage, Academy fellow/university researcher, and finally professor. This model is intended to describe the professional career in research only. In cultural and social research in particular, postgraduate studies are pursued extensively outside the graduate school system as well. The Research Council considers it important that other avenues of researcher training are also developed and supported.

Closer cooperation and networking generate added value both for individual researchers and for research teams. It is also important that cooperation with research institutes is further intensified.

The profiling of research funding

The Research Council for Culture and Society is keen to stress that despite the growth of competition, it is crucial that enough room is given for new initiatives, for it is this that ultimately drives the renewal of science and the development of disciplines. Workshops hosted by the Research Council for Culture and Society offered interesting insights into the latest themes in different fields of research. In many fields the focus of research attention has now turned to emotions and everyday practices, which deepen and diversify our understanding of the human condition. On the other hand, old materials are also studied from new angles and using new methods and in collaboration with researchers representing different disciplines.

Global perspectives and ethical research considerations have also assumed increasing weight in science and research. *These perspectives must be incorporated as an integral part of national science policy.*

The *Finnsight 2015* report identified a number of significant future challenges, such as multicultural exchange, business development and changes in communication. *All of this requires multidisciplinary research.* Many fields have made significant moves in that direction, but it is still not systematically organised.

The profiling of research funding can help to improve the quality of research. Centres of Excellence have indeed had a clear positive impact on their research environment *The Research Council for Culture and Society plays a crucial role in the profiling of research funding, since the Academy is still the most important source of external funding for research in the humanities and social sciences.*

The role of the Academy of Finland and universities

With the continuing changes that are sweeping the national research system, the Research Council for Culture and Society expects to see different partnerships gain increasing significance. Safeguarding the traditional role of the educational university involves much more than just fostering innovation chains. *The Research Council wants to emphasise and protect the independence of the Academy of Finland and research communities.* Only that can produce the knowledge and understanding that otherwise would not exist.

Appendix 1. Participants in SIGHT 2009 workshops organised by the Research Council for Culture and Society

Workshop I: philosophy, education, linguistics, psychology, theology

Leila Haaparanta, University of Tampere
Jussi Haukioja, University of Turku
Mikko Ketola, University of Helsinki
Kristiina Kumpulainen, University of Helsinki
Janne Lepola, University of Turku
Terttu Nevalainen, University of Helsinki
Jari-Erik Nurmi, University of Jyväskylä
Risto Näätänen, University of Helsinki
Martina Reuter, University of Helsinki
Erja Salmenkivi, University of Helsinki
Martti Vainio, University of Helsinki

Workshop II: law, social sciences, economics, political science and administrative science

Mika Aaltola, University of Tampere
Pertti Alasuutari, University of Tampere
Ritva Engeström, University of Helsinki
Yrjö Haila, University of Tampere
Maj-Britt Hedvall, Hanken School of Economics
Kimmo Jokinen, University of Jyväskylä
Juhani Koponen, University of Helsinki
Kevät Nousiainen, University of Helsinki
Kimmo Nuotio, University of Helsinki
Hannu Nurmi, University of Turku
Heikki Paloheimo, University of Tampere
Kari Palonen, University of Jyväskylä
Mika Pantzar, National Consumer Research Centre
Kirsi Saarikangas, University of Helsinki
Mirja Satka, University of Jyväskylä
Maija Setälä, University of Turku
Otto Toivanen, University of Helsinki
Reetta Toivanen, University of Helsinki
Heli Valtonen, University of Jyväskylä

Workshop III: history, cultural studies, art studies, communication studies

Sari Autio-Sarasmo, University of Helsinki
Pauline von Bonsdorff, University of Jyväskylä
Petri Halinen, University of Helsinki
Pekka Isotalus, University of Tampere
Maijastina Kahlos, University of Helsinki
Turkka Keinonen, University of Art and Design Helsinki
Ullamaija Kivikuru, University of Helsinki
Pirjo Lyytikäinen, University of Helsinki
Pirjo Markkola, Åbo Akademi University
Kaarle Nordenstreng, University of Tampere
Matti Polla, University of Helsinki
Ilkka Pyysiäinen, University of Helsinki
Maili Pörhölä, University of Jyväskylä
Jussi-Pekka Taavitsainen, University of Turku
Sirpa Tenhunen, University of Helsinki

Appendix 2. Members of the Research Council for Culture and Society contributing to the SIGHT 2009 project in 2008–2009

Research Council for Culture and Society

Eila Helander (chair), University of Helsinki
Pertti Haapala, University of Tampere
Päivi Hovi-Wasastjerna, University of Art and Design Helsinki
Anne Kovalainen, Turku School of Economics
Pauli Niemelä, University of Kuopio
Jaakko Pehkonen, University of Jyväskylä
Lea Rojola, University of Turku
Pekka Ruohotie, University of Tampere
Katariina Salmela-Aro, University of Jyväskylä
Marja Tuominen, University of Lapland
Jan-Ola Östman, University of Helsinki

Culture and Society Research Unit

Senior Science Adviser Hannele Kurki
Science Adviser Tiina Forsman
Director Pirjo Hiidenmaa
Project Officer Sanna Hytönen
Senior Science Adviser Raija Matikainen
Project Officer Vera Raivola
University Trainee Paul Tiensuu
Science Adviser Risto Vilkko

Solicited discipline reviews

Professor Leila Haaparanta, University of Tampere
Academy Professor Kevät Nousiainen, University of Helsinki
Professor Hannu Nurmi, University of Turku
Professor Jussi-Pekka Taavitsainen, University of Turku

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3 Research in the Natural Sciences and Engineering

Contents

1 Operating environment

Structural changes

The Finnish university system is currently in the midst of a major overhaul. The new Universities Act allows individual universities to expand their funding base and also gives them greater scope to develop their strategic management. The reforms that are ongoing at the same time to restructure government research institutes are aimed at enhancing the impact of sectoral research, promoting closer cooperation with universities and at improving overall efficiency. The mergers and alliances between universities and research institutes are intended to support the creation of stronger national centres of expertise and networks (Valtioneuvoston kanslia, 2005).

In the natural sciences and engineering field, high-quality and competitive research environments typically engage both in cutting-edge science and in more application-oriented, problem-driven research (Hjelt et al. 2009; Suomen Akatemia, 2006a). It is imperative to ensure that the overhaul of the research field is carried out in such a way that existing research environments in universities and research institutes are maintained and strengthened.

With the entry into force of the new Universities Act, universities have greater freedom than before to secure funding from external sources. However, if adequate resources are not made available to address research questions arising from within the scientific community, opportunities for long-term research at the highest level will be severely hampered. This presents a major challenge for engineering fields in particular. If the bulk of research resources are tied to short-term projects, basic research and the related skills and knowledge will inevitably suffer. Already there are indications that this is happening in mechanical engineering and energy technology, for instance (Academy of Finland, 2008; Academy of Finland, 2006b). In the future it is important that university research is geared more clearly to international excellence. University budget funding must cover both education and part of their research costs. External funding must support the universities' primary objective rather than try to dictate and determine the content of science and research.

As part of the broader structural overhaul, universities are expected to profile themselves more clearly in their main areas of strength. Government policy for universities of technology is that the biggest units shall concentrate on research and on further developing their priority areas (Opetusministeriö, 2008a). The choice of these areas of strength shall reflect existing areas of scientific competitiveness. In some engineering fields that are central to the national economy, this will be problematic in that the scientific research they do is not internationally competitive (Academy of Finland, 2008; Academy of Finland, 2006b; Suomen Akatemia, 2004a). The challenges faced by universities in profiling themselves and identifying priority areas is further complicated by the difficulty of forecasting future needs and trends. Even though universities will have somewhat different research profiles, it is important that there remains an element of competition so that the high standards of domestic research are maintained.

Many other countries have already moved to overhaul their research institute and university systems before Finland. The international trend is for universities, research institutes and business companies to cluster into the same areas and to form centres of expertise with strong international appeal. In the natural sciences and engineering fields, these kinds of clusters often develop in areas that have the infrastructure to support frontier research. Examples include clusters that have grown up in Grenoble, France around the European Synchrotron Radiation Facility and the ILL neutron laboratory, and the high-tech research and business centre in Silicon Valley, California. In Finland, a similar cluster of expertise has formed around the Otaniemi campus. The most effective way to develop new applications out of research results is to have a research environment where experts from several different fields are working in close physical proximity to one another rather than just exchanging ideas through virtual networks.

The role of basic research in the innovation system

Recent policy decisions concerning the Finnish research funding system have leaned quite heavily towards to applications-driven research. Based on a decision taken by the Science and Technology Policy Council of Finland (renamed as the Research and Innovation Council of Finland as of 1 Jan 2009) in June 2006, preparations were launched for the creation of Strategic Centres for Science, Technology and Innovation. The purpose of the Strategic Centre concept is to significantly increase the allocation of research resources to subject areas that are important to business and industry and to society as a whole (Tiede- ja teknologianeuvosto, 2006a). The same emphasis on user-driven research aimed at immediate application is repeated in the national innovation strategy prepared under the Ministry of Employment and the Economy (Työ- ja elinkeinoministeriö, 2008) and in the Government's innovation policy report to Parliament (Valtioneuvosto, 2008). In the workshops organised by the Research Council for Natural Sciences and Engineering in spring 2008, this strategic emphasis on applied research was identified as one of the major threats to science (see Appendix 1). The ongoing process to develop the research funding system must also include measures to increase the resources available for long-term basic research.

Finnish engineering research is very much focused on business-driven research (Academy of Finland, 2008; Academy of Finland, 2007b; Academy of Finland, 2006b). During periods of economic upswing, universities receive large numbers of commissions from industry, which is then reflected in the low number of applications submitted for general research grants in the engineering field (Figure 1). In the past few years, applied research has accounted for around 60–80 per cent of the total volume of engineering research at Finnish universities (Figure 2). Close contact and exchange between university researchers and industry is generally considered an asset.

In 'hard technology' fields, the emphasis on applied research has undermined the role and position of basic research. Research driven by business needs is by definition less interested in scientific development and new scientific breakthroughs. One indication of this is the low

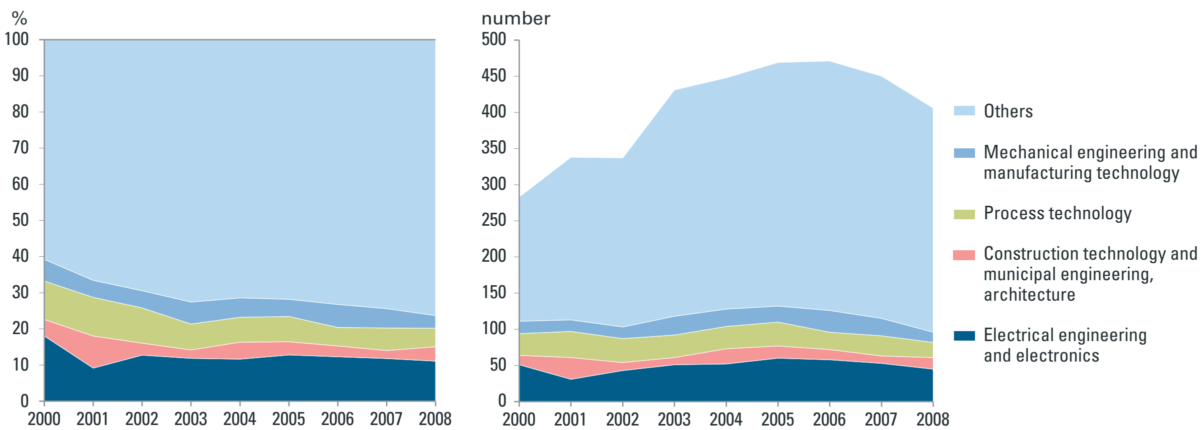

Figure 1. Number of applications submitted in the engineering field and their proportion of all natural sciences and engineering applications for general research grants from the Academy of Finland in 2000–2008.
Source: Academy of Finland.

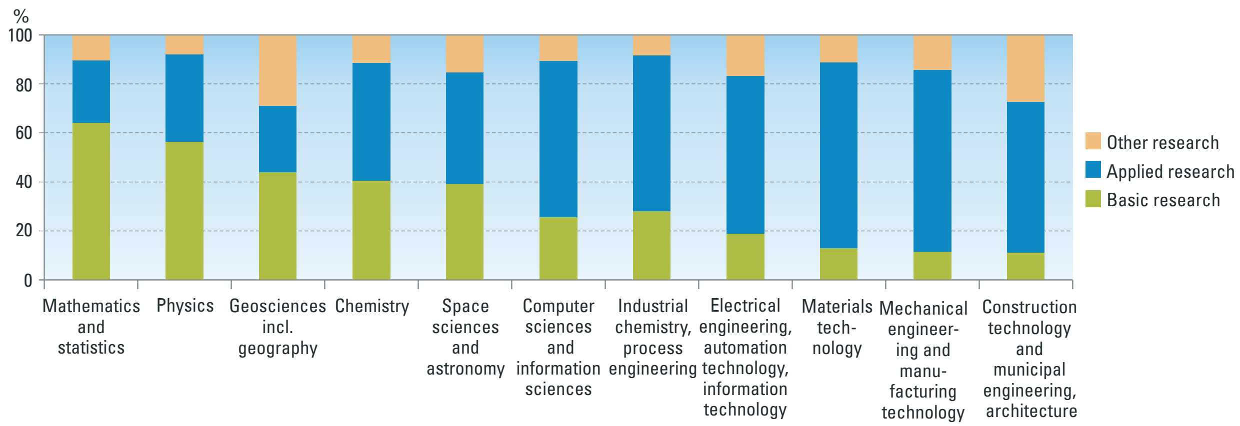

Figure 2. Breakdown of external funding between basic research*, applied research and other research at universities in natural sciences and engineering fields in 2007. *Source: Statistics Finland.*

* Basic research is defined as comprising Academy of Finland funding and Ministry of Education funding for graduate schools; applied funding as comprising funding from Tekes, business companies and EU sources; and other funding as comprising other sources of funding.

number of publications appearing in scientific journals. The international panel of experts that evaluated mechanical engineering research in Finland predicted in its final report that the shortage of challenging scientific research will in the future be reflected in the country's industrial competitiveness (Academy of Finland, 2008). It is crucial that the focus of research is shifted as quickly as possible from business-driven problem solving to fundamental scientific research.

According to a recent report on sustainable innovation (Hautamäki, 2008), the only way to generate significant new knowledge is through investment in high-level basic research primarily at universities and public research institutes. Innovations, for their part, are created in business companies in processes of product and service development in the competitive global marketplace. The primary purpose of scientific research is not to produce new innovations, but to generate new information and knowledge. High-level research grounded in the principles of science can pave the way to significant breakthroughs, both scientific and economic. Since it is impossible to predict in what fields the next major breakthroughs will happen, or which disciplines will contribute to those breakthroughs, it is essential that skills and competencies are maintained at as high a level as possible in a broad spectrum of fields.

Research infrastructures

Research infrastructures are of paramount importance in the disciplines that come under the Research Council for Natural Sciences and Engineering. There has been active debate about research infrastructure decision-making and funding since 2004, when the Science and Technology Policy Council published its general assessment of current principles and procedures (Tiede- ja teknologianeuvosto, 2004). Two years later, the Council outlined a national infrastructure strategy for science and research (Tiede- ja teknologianeuvosto, 2006b). It recommended that the necessary funding mechanisms for these infrastructures be created; that existing national infrastructures be charted; and that a roadmap be prepared for their development. Furthermore, the Academy and Tekes were to open a joint infrastructure call on a regular basis, and the Academy's overheads share was to be increased so as to cover the maintenance of infrastructures.

The Research Council for Natural Sciences and Engineering spends close to 2 per cent of its total research funding on research infrastructures. Any future investment by the Research Council on new infrastructures is contingent on the Academy drawing up a separate infrastructure policy. The Research Council has outlined its own visions for such a policy. It also conducts regular assessments of the effectiveness of the infrastructures it finances (Luonnontieteiden ja tekniikan tutkimuksen toimikunta, 2006). As far as international infrastructures are concerned, it is the Research Council's position that participation in those infrastructures shall always be based on the criterion of the scientific quality of Finnish research in the field concerned. Contributions to high-level research equipment can even exceed Finland's nominal share if that is deemed to benefit research excellence in Finland. In order to maximise scientific and technological benefits, it is important that Finland is actively involved in developing hardware and equipment as well as in decision-making. It is also important that infrastructure decisions do not exclude Finland from future areas of research that may be of strategic importance.

The Research Council is prepared to make funding available for national infrastructure projects, whereas funding for local infrastructures shall primarily be sourced through universities' and research institutes' own performance target negotiations. National infrastructures typically consist of major measurement equipment, archives or distributed computer networks. Equipment and hardware need to be updated and replaced at regular intervals, and therefore it is necessary to have regular infrastructure calls as well. The Academy last opened such a call in 2004. According to the findings of a report on the impact of this call, it has contributed significantly to maintaining the international competitiveness of research in Finland (Suomen Akatemia, 2007a). With a view to future infrastructure calls the Research Council wants to specially emphasise the benefits of centralisation and appropriate shared use of equipment. In some fields it might be worthwhile to plan for a national register of research equipment.

The workshops organised in connection with the 2009 review of the state of science and research in Finland clearly underscored the importance and urgency of increasing the level of infrastructure funding. An ageing and inadequate equipment base presents a definite threat to successful science and research, and a further deterioration in this situation could become very hard to reverse.

The building and maintenance of research infrastructures require very substantial investment. At the national level annual user costs or membership fees are in the region of 60 million euros. Building costs for the infrastructures included in the national roadmap are estimated at around 230 million euros. It is important that a decision-making mechanism is put in place that can prioritise and finance infrastructure projects through competitive calls. Given its broad expertise in the science and research field, it is clear that the Academy of Finland must be involved in this decision-making mechanism.

In its final report the steering group in charge of the national infrastructure project recommends that an infrastructure council be set up (Opetusministeriö, 2009). The council would be charged with the development of an infrastructure strategy, coordination of international participations, conducting infrastructure reviews, issuing statements, updating the infrastructure roadmap, and preparing and to some extent making funding decisions. The Research Council for Natural Sciences and Engineering takes the view that the Academy of Finland is the most appropriate home for such a decision-making body, provided that there is a broad enough funding base. The Academy has the necessary expertise and competence to serve as an objective decision-making forum.

Nordic infrastructure cooperation: Nordic Data Grid Facility

The Nordic Data Grid project was launched in 2003 on the initiative of NOS-N, a collaborating body for four Nordic research councils. Finland's contribution to the project was covered by the Academy of Finland until 2007; since then the project has been funded by the Ministry of Education. The Finnish partners in the Nordic Data Grid project are the Helsinki Institute of Physics (HIP) and CSC – IT Center for Science.

The project laid the foundation for a Nordic Grid centre which serves as the Nordic node in the European computing network. That network is intended primarily to process the data coming from the Large Hadron Collider at CERN, but its computing resources can also be accessed via grid centres for use in other fields of research.

The Nordic Data Grid Facility (NDGF) and NDGF specific software have been developed for purposes of allocating these computing resources. NDGF is one out of a total of 11 Tier-1 centres, the primary computing resources used in processing LHC data. Tier-1 centres manage the data mass of 15 million gigabytes that come out of CERN each year, and process even larger amounts of information extracted from raw data. NDGF performs around 6 per cent of this globally distributed task, the biggest responsibility ever entrusted to the Nordic scientific community. In contrast to other Tier-1 computing resources, NDGF is itself a distributed resource that combines resources from nine computing centres in the four Nordic countries. NDGF's innovative Grid solutions mean that it can provide higher efficiency and service levels than other Tier-1 resources.

2 Researcher training and research career

The four-tiered research career model

In order to function properly, the research and innovation system needs excellent human resources with the ability to generate and use new knowledge. To respond to the needs of the research and innovation system and society more generally, the Ministry of Education has launched an action programme for the development of researcher training and the research career (Opetusministeriö, 2007). In the four-tiered research career model that is designed to support this action programme, the academic career proceeds from the initial step of doctoral student through the postdoctoral stage and Academy and university research fellowship to the professorship (Opetusministeriö, 2008).

An efficient research system needs to have a balanced distribution of researchers across these four career stages. Compared to many other countries Finland currently has a disproportionately large number of doctoral students relative to postdoctoral and senior researchers. The focus of funding should be shifted to supporting the postdoctoral research career because postdoctoral and senior researchers are crucial to the formation of high-level research teams.

Table 1 shows the number of graduate schools, graduate school positions and the number of Academy Postdoctoral Researchers, Academy Research Fellows, Academy Professors and Centres of Excellence in the natural sciences and engineering field. Compared to the natural sciences, the number of doctoral students in engineering fields is several times higher than the number of Academy Postdoctoral Researchers and Academy Research Fellows. Recent discipline assessments in engineering fields have also drawn attention to the low number of experienced researchers, pointing out that this constitutes a serious threat to the future of basic research in engineering fields and to the competitiveness of Finnish business and industry (Academy of Finland, 2008; Academy of Finland, 2006b).

Table 1. Number of Ministry of Education graduate schools and graduate school positions and number of Academy Postdoctoral Researchers, Academy Research Fellows, Academy Professors and Centres of Excellence in the natural sciences and engineering fields. The figures are indicative only as many graduate schools and Centres of Excellence are multidisciplinary and categorised on the basis of the predominant discipline. Situation as at 1 Jan 2009. *Source: Academy of Finland.*

Field of science	Graduate schools	Graduate school positions	Post-doctoral researchers	Academy Research Fellows	Academy Professors	Centres of Excellence
Space sciences and astronomy	1	8	7	6	0	0
Mathematics and statistics	6	42	14	13	3	2
Physics	2	31	24	12	0	2
Materials science	4	88	13	8	3	1
Chemistry	5	50	17	13	2	1
Process technology	1	30	8	4	1	1
Geosciences	2	18	12	4	1	1
Industrial management and industrial design	1	10	3	0	0	0
Construction technology and municipal engineering, architecture	2	21	2	2	0	0
Electrical engineering and electronics	4	96	13	9	2	2
Computer sciences	9	152	21	13	1	3
Mechanical engineering and manufacturing technology	5	47	6	0	1	1
Energy technology and environmental engineering	1	10	4	0	0	0
Pulp and paper technology	1	15	2	2	0	1
Total	44	618	146	86	14	15

The Research Council for Natural Sciences and Engineering has sought consistently to allocate research posts to those engineering and ICT fields where there is an apparent need to strengthen basic research. Nonetheless, there are some engineering fields that are central to the national economy where there are no Academy Research Fellows at all. Part of the explanation for the breakdown of research personnel in engineering fields lies in the fact that PhD graduates in engineering are in strong demand in the private business sector, and therefore there are accordingly less applicants to Academy research posts. From 1998 to 2008, the number of applications in the engineering field as a proportion of all Academy Research Fellowship applications submitted to the Research Council for Natural Sciences and Engineering has been in the range of 10–25 per cent.

Doctoral education

The Ministry of Education is committed to the goal of further strengthening the system of graduate schools and making this the principal route to a professional research career (Opetusministeriö, 2007). As the number of new PhD graduates continues to rise, it is clear that the majority of these people will have to find employment outside academia. For this reason it is important that doctoral education programmes focus on those fields where there is a genuine demand for PhDs outside of universities. Furthermore, it is important that these programmes provide the skills that graduates will need in business and industry workplaces. A diverse range of workplace skills will improve PhD graduates' employment opportunities in different sectors of society. Further effort is still needed to lower the mean age of PhD graduates, even though some progress has already been made in this regard.

The demand for graduates with a PhD in natural sciences and engineering is well illustrated by the large number of doctoral students at Ministry of Education funded graduate schools who are sponsored by business companies and from other than Ministry of Education sources. According to reports submitted in connection with the 2008 graduate school call, three in four full-time doctoral students at graduate schools in the natural sciences and engineering fields were funded from other than Ministry of Education sources. The proportion of foreign doctoral students in the natural sciences and engineering fields was 17 per cent, just short of the 20 per cent target set by the Ministry of Education for 2012 (Opetusministeriö, 2007).

According to reports submitted for the 2008 graduate school call, PhDs graduating from natural sciences and engineering graduate schools have had good success finding employment (Figure 3). Over 35 per cent of engineering PhDs found employment in business and industry immediately upon

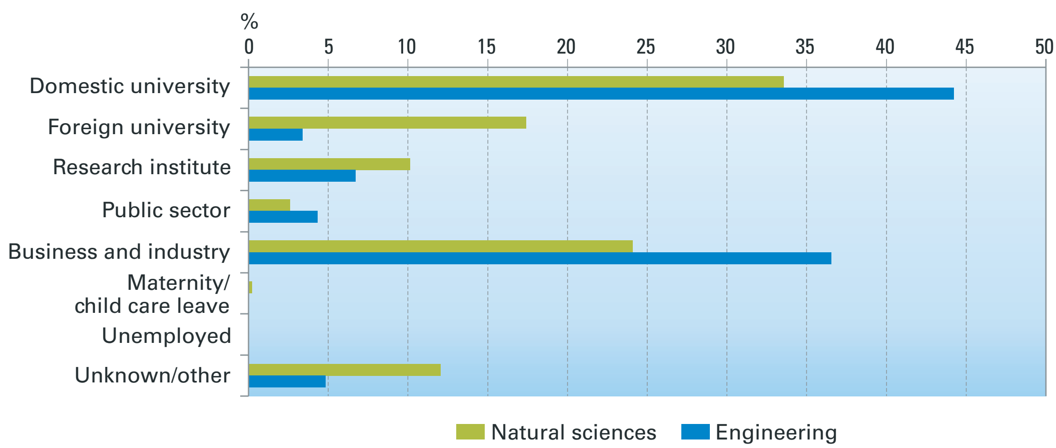

Figure 3. Placement of PhD graduates in natural sciences and engineering in 2006–2007.
Source: Graduate school reports for the 2008 graduate school call.

graduation. The highest private sector employment rates were recorded for graduate schools in the fields of process technology and materials engineering, construction technology and municipal engineering, and electrical engineering and electronics.

For the future and continuity of basic research in engineering disciplines in particular, it is crucial that a proportion of PhD graduates remain in research positions at universities. After less than three years since earning their doctorate, just over one-third of PhDs continued in research at a Finnish university. Almost one in five natural science PhDs had moved to a university abroad, in physics the proportion was as high as over one-quarter. The new ideas and methods that researchers pick up abroad contribute to enhance the skills and knowledge base at home when they repatriate.

Challenges facing the professional research career

The Research Council for Natural Sciences and Engineering contributes to ensure that there is an appropriate balance between the number of graduate school positions, Postdoctoral Researcher's projects, grants for senior scientists and posts for Academy Research Fellow and Academy Professor (Figure 1). This is the best way to promote the professional research career and to strengthen the Finnish research system. It is the Council's position that the focus in research projects should be shifted to supporting the postdoctoral stage of the research career. This shift in emphasis would have significant implications because in 2008, 49 per cent of Academy funding was allocated to research projects (Academy of Finland, 2009). Support for the doctoral education stage should be channelled primarily through graduate schools.

In order to gain a clearer understanding of the challenges encountered in the Academy Research Fellowship stage of the research career, the Research Council for Natural Sciences and Engineering conducted a questionnaire survey among Academy Research Fellows who started their term during 1999–2003. Academy Research Fellowships are the main instrument through which the Academy seeks to promote professional research careers. Competition for these fellowships is intense, and in natural sciences and engineering fields typically no more than one in ten applicants can be offered a position. The questionnaire was sent to 80 persons, 60 of whom replied.

Among the most important perceived benefits of the Academy Research Fellowship was the opportunity to concentrate on independent research and to establish one's own research team. The appointment was described as highly beneficial for career advancement, and it was said to have contributed significantly to gaining the qualifications needed in more demanding research positions. Academy Research Fellowships play a key role in the training of future professors. Over half of the respondents had been deemed as possessing the necessary qualifications for a professorship, and almost one in three had accepted a tenured professorship. Many said that full-time commitment to research had increased their publishing activity, and the supervision of postgraduate students offered valuable experience of team management. Another reason why Academy Research Fellowships were valued so highly was that they gave the opportunity to spend longer periods in research abroad.

Among the weaknesses identified in the Finnish research system were the lack of full-time, permanent research positions at universities and research institutes. One of the solutions suggested was the creation of a tenure track system, as outlined in the Ministry of Education four-tiered research career model (Opetusministeriö, 2008).

3 Impact

The impact of science and research can be approached and assessed from various angles. From a science and competence point of view, key indicators of impact include not only research outputs but also the networking and mobility of researchers. The impacts of research are also reflected in society more generally. The practical application of research results and the competencies generated in research contribute to economic growth and strengthen international competitiveness, which in turn contribute to promoting the population's well-being. The Academy of Finland and Tekes have recently completed a major project on ways of describing and analysing the impacts of science, technology and innovations (Lemola et al. 2008).

Scientific impact

The most obvious quantitative indicators of scientific impact are the number of research publications and degrees completed. According to research reports for 2007 and 2008, projects receiving general research grants through the Research Council for Natural Sciences and Engineering produced on average 2.3 doctoral degrees and 3.3 higher university degrees per one million euros of funding. There were no marked differences in PhD completion rates between different fields of research. Publishing practices did, on the other hand, differ in different disciplines. The number of articles published in science journals relative to the amount of funding awarded was highest in physics, space sciences and astronomy as well as in mathematics and statistics (Figure 4). In engineering fields the main focus of publishing was on conference publications, which in the long term may have the effect of undermining the scientific impact of engineering research. Publication and citation trends in different disciplines are examined in closer detail in Appendix 3.

Research advances and the discovery of new multidisciplinary interfaces are crucial in facilitating the renewal of science and the development of new fields of inquiry. In the natural science and engineering fields, disciplines that have shown

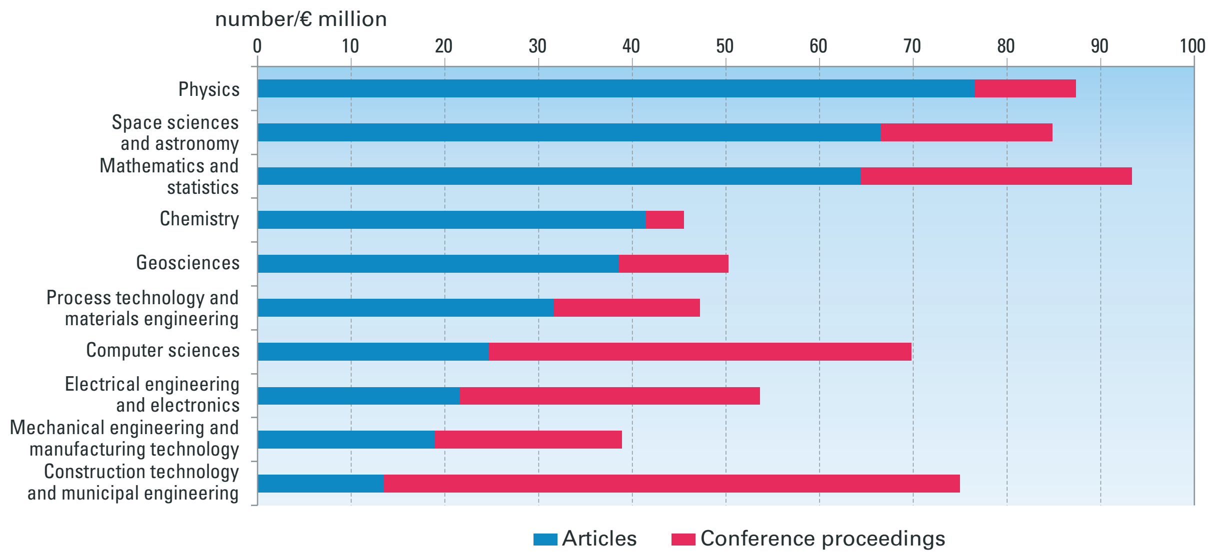

Figure 4. Number of publications produced in natural science and engineering projects funded by the Academy of Finland per one million euros of Academy funding. *Source: Academy of Finland, research reports for 2007 and 2008.*

strong growth in the 2000s include computational science as well as biological physics, bioinformatics and materials science. The rapid proliferation of spatial data has in turn paved the way to a new area of research concerned with the management and use of that data, i.e. geoinformatics, which in terms of its research interests lies somewhere in the middle ground between computer sciences and geosciences. Methods based in natural sciences and engineering as well as the results from these lines of inquiry are used widely in other fields of research, too. Most of the work to develop these methods continues to take place primarily within the natural sciences.

The tasks of the Research Council include the identification of emerging new fields and supporting research in those fields. Table 2 shows the funding made available by the Research Council to strategic growth areas and the research programmes started on the Council's initiative in 2006–2010. The social importance and potential of these subject areas is underscored by the fact that they have also received funding from other sources.

Networking and mobility

National networking has continued to increase among researchers working in the natural sciences and engineering field. This is reflected, among other things, in the significant increase in consortium applications filed for the Academy's general research grants (Figure 5). In 2002–2008, the share of consortium applications in the natural science and engineering fields increased threefold. In 2008, almost one in three applications in these fields was filed as part of a consortium project.

A review of consortium applications for general research grants shows that research collaborations between universities and research institutes have increased in recent years. In 2008, 45 per cent of all consortium applications involved cooperation

Table 2. Allocation of strategic research funding by the Research Council for Natural Sciences and Engineering and research programmes launched on the Research Council's initiative in 2006–2010.

Allocation of funding	
2006	Remote sensing and geoinformatics research
2007	Smart products and processes in forest industry
2008	Processor architectures and software development methods in embedded systems
2009	Research utilising space science and astronomy infrastructures
2009	Mechanical engineering research
2009	Water engineering research
Research programmes	
2006	Sustainable production and products, KETJU (2006–2010)
2006	Nanoscience, FinNano (2006–2010)
2008	Sustainable energy, SusEn (2008–2011)
2009	Ubiquitous computing and diversity of communication, MOTIVE (2009–2012)
2010	Photonics and modern imaging techniques
2010	Computational Science Research Programme

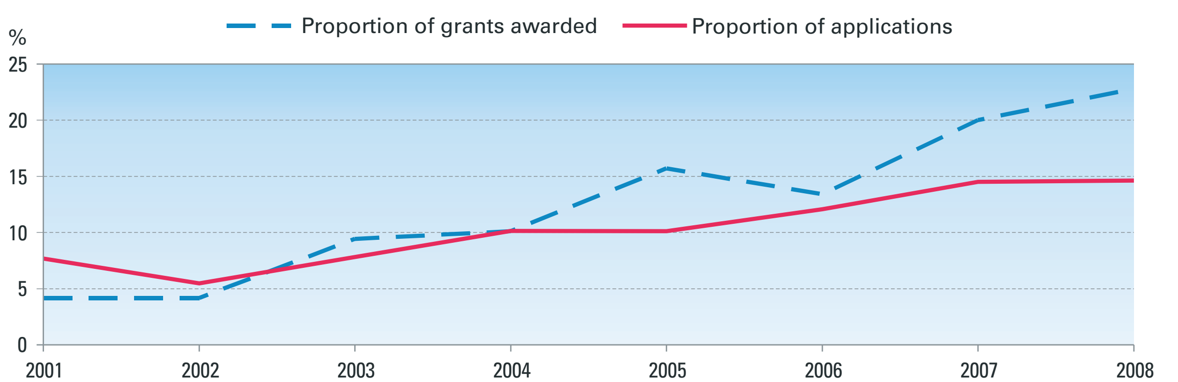

Figure 5. Research consortia as a proportion of total applications and grants awarded in natural science and engineering fields in 2001–2008. *Source: Academy of Finland, applications for general research grants 2001–2008.*

between universities and research institutes, compared to just 24 per cent in 2005. By contrast collaborations between research teams based in different regions show a slight downward trend. In 2006 these kinds of collaborations occurred in 55 per cent of all consortium applications, in 2008 the figure was down to 47 per cent.

Since the early 2000s, the Research Council for Natural Sciences and Engineering has consistently encouraged researchers to network with colleagues from a wide range of backgrounds. As the funds made available to the Research Council for the allocation of general research grants have doubled from 2005 (14.2 million euros) to 2007 (29.1 million euros), it has now been in the position to give the fullest possible support to research consortia. This is reflected in the growing share of consortia among funding recipients (Figure 5). In 2008, over 40 per cent of all projects funded were conducted as part of a consortium. In the 2008 call, the international experts reviewing the applications concluded that consortium applications were scientifically more ambitious than individual applications.

General purpose research grants are the single most important funding instrument at the Research Council's disposal for the promotion of international research cooperation. According to the 2007 and 2008 research reports for projects receiving general research grants in the natural sciences and engineering fields, three in four of those projects involved international cooperation. One-sixth of the projects recruited foreign researchers, and on average they participated in research in Finland for just over one year. Over half of the foreign researchers travelling to Finland originated from other European countries (Figure 6). The largest number of visit-months was recorded for researchers arriving from China. According to the research reports 40 per cent of all projects receiving general research grants involved foreign visits, and their average duration was five months. The largest number of visits was made to North America and European countries, particularly to France, Germany and Switzerland.

Among the applicants for Academy Postdoctoral Researcher's projects in natural sciences and engineering fields in 2006–2008, almost one-quarter were foreign nationals (Figure 7). In all there were 586 applicants. The proportion of foreign applicants was particularly high in

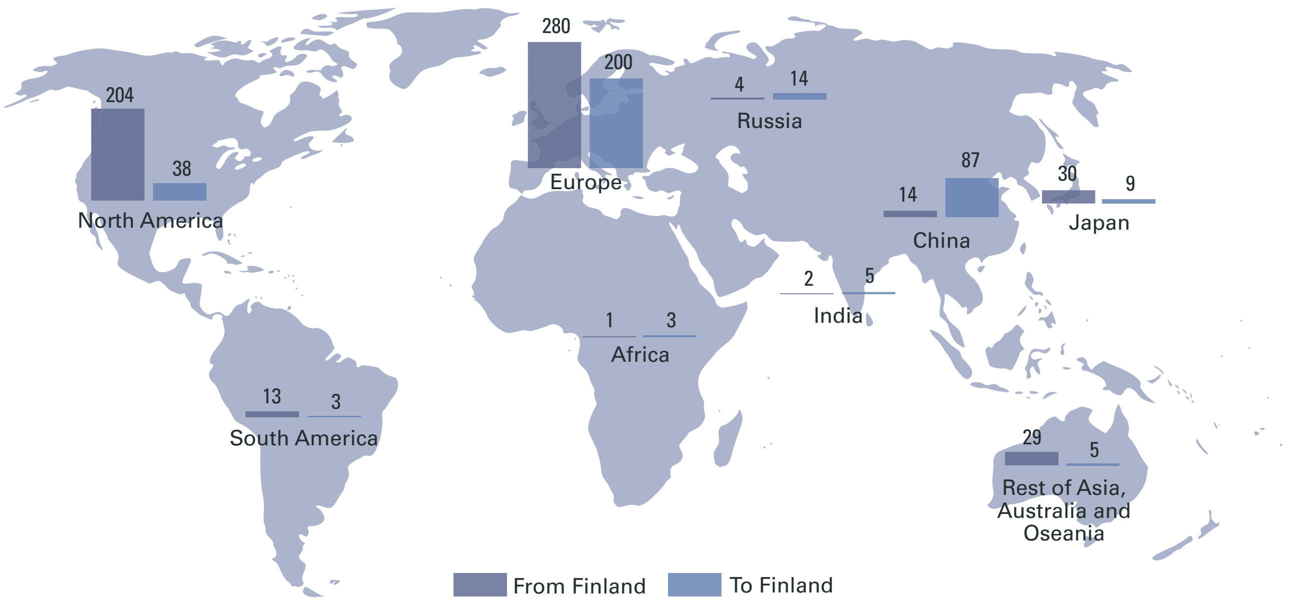

Figure 6. Researcher mobility funded through general research grants in natural sciences and engineering fields. Figures indicate the number of visit-months in each geographic region. *Source: Academy of Finland, research reports for 2007 and 2008 general research grant projects.*

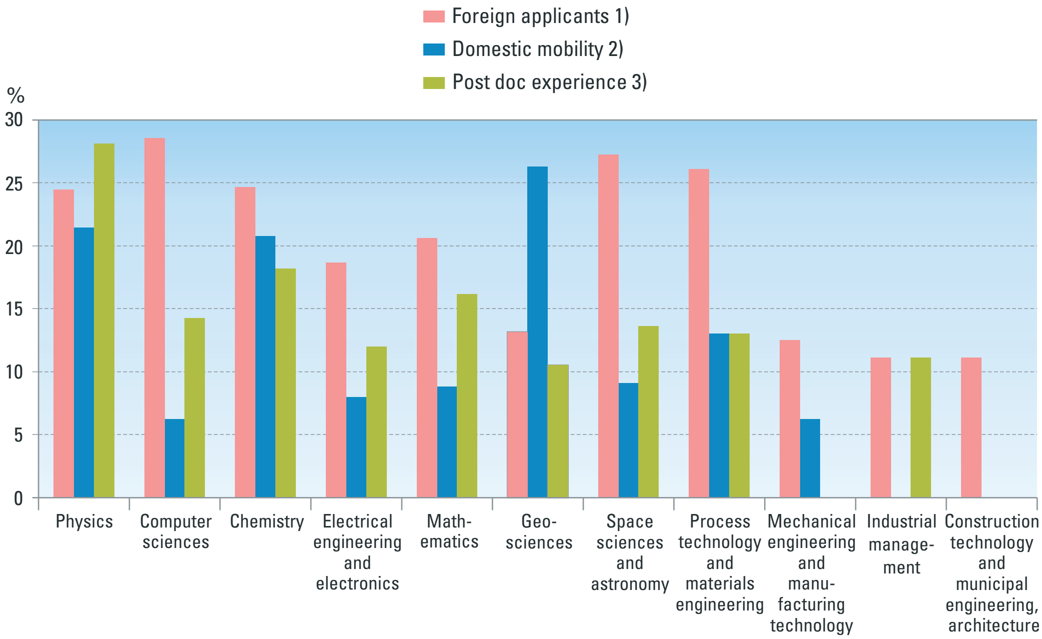

Figure 7. Mobility of applicants for an Academy Postdoctoral Researcher's project in natural sciences and engineering fields in 2006–2008. *Source: Academy of Finland, applications for Postdoctoral Researcher's projects 2006–2008.*

1) Proportion of foreign applicants by discipline.
2) Proportion of applicants with experience from more than one domestic research organisation by discipline.
3) Proportion of Finnish applicants with more than six months of postdoctoral experience in a foreign research organisation by discipline.

computer sciences, space sciences and astronomy and process technology and materials engineering. One in six of all Finnish applicants to Postdoctoral Researcher's projects had postdoctoral research experience from a foreign country. The proportion of researchers with foreign experience was highest in physics, chemistry and mathematics.

Based on the applications filed with the Research Council for Postdoctoral Researcher's projects, there is only limited mobility between domestic research organisations in natural sciences and engineering fields (Figure 7). No more than one in six applicants had worked in more than one domestic research organisation. Domestic mobility was higher than average in geosciences, physics and chemistry, whereas applicants in construction technology and municipal engineering, mechanical engineering and manufacturing technology, and computer sciences had most often worked in the same organisation all their career.

Impact in society

One of the major impacts of research in natural sciences and engineering fields is its contribution to the growth of skills and new knowledge within the scientific community and society at large. Research in these fields plays a critical role in addressing global environmental issues, in combating climate change, in facilitating the sustainable use of natural resources and in developing future energy solutions. The exposure given to science and research in the media increases the general public's awareness of how research can help to resolve the global problems that lie ahead. Research results also enable more informed political decision-making. The Research Council for Natural Sciences and Engineering has sought to contribute to the science policy debate and to influence research, technology and innovation policies and strategies.

Natural sciences and engineering research enjoys a positive public image, which is an important incentive for young people to choose to study in this field. The standard of school education also plays a major part in this respect. The National Board of Education's LUMA programme in 1996–2002 and the LUMA Centre that was set up in its wake have contributed significantly to improving science and mathematics education and in this way aimed to attract the interest of students.

High-level basic research in natural sciences and engineering fields and the effective application of research results provide a solid foundation for sustainable social and economic development. The new products, processes, methods and techniques developed through research contribute to strengthening the competitiveness of business and industry. There is traditionally close cooperation between academia and industry in the natural sciences and engineering fields. Close relations of cooperation facilitate the efficient transfer of new research knowledge and by the same token promote the practical application of research results. Some 10 per cent of the projects funded by the Research Council report that they cooperate with business companies. Most people graduating with a PhD or higher degree from projects funded by the Research Council for Natural Sciences and Engineering were employed in companies that were involved in the research. Cooperation with business and industry was most common in engineering disciplines and in chemistry research.

The number of patent applications and invention disclosures provides one measure of the commercial potential of research results. According to research reports for 2007–2008, 5 per cent of the general research grant projects funded by the Research Council filed patent applications or invention disclosures, or 0.42 patent applications and 0.36 invention disclosures per one million euros of Academy funding. The largest number of patent applications and invention disclosures was recorded in electrical engineering and electronics, chemistry and physics projects. Commercial applications of research results are also developed through spin-off companies. Especially in the materials science and engineering fields new companies started up by researchers play a very significant R&D role.

4 Research fields

The following provides an overview of the current state of science and research in the fields that come under the Research Council for Natural Sciences and Engineering and discusses their strengths and weaknesses. The analyses are based on workshops organised by the Research Council separately for each discipline, which were attended by invited leading researchers from the fields concerned as well as representatives of business and industry, different ministries and other funding organisations (see Appendix 1). In the fields of energy technology and environmental engineering, mechanical engineering and manufacturing technology, and computer sciences, the analysis is based on separate discipline assessments conducted by the Research Council. The pulp and paper technology section is based on an e-mail questionnaire and a seminar hosted by the Academy of Finland in spring 2004.

Space sciences and astronomy

The Moon and Mars are currently a major focus of interest in international space research. In the field of astronomy, one area of continuing research interest is the use of large telescope observation programmes in explorations of the structure of the universe. Astrobiology is emerging as an important new line of inquiry.

Compared to the size of this field there is quite a large number of research teams at Finnish universities and research institutes. Nevertheless, each team has a well defined area of specialisation, and there is also good cooperation between these teams and the industry that has grown up in the space sector. The main problems faced by these teams stem from the scarcity of senior research personnel. Measurement devices designed and developed by Finnish teams are producing a steady flow of high-quality observation data, but lack of resources means that some of these data are destined to remain unused. In the space sciences and astronomy field participation in international equipment development projects is often crucial to the conduct of cutting-edge research. This in turn requires large enough research teams, because hardware and equipment development should not be separated from the analysis of measurement data.

The national space strategy (Työ- ja elinkeinoministeriö, 2009) stresses the importance of taking every possible advantage of memberships of international research organisations. The European Space Agency (ESA) and the European Southern Observatory (ESO) provide a sound and solid platform for international excellence in the space sciences and astronomy. Finland's membership of the ESA has contributed to generate high-level expertise both in space research and in equipment development. ESO's observation programmes have greatly increased the international visibility of Finnish astronomy. In the future, it is important that Finland contributes actively to ESO's technology development programmes. The incoherent scatter radar system EISCAT and the Canary Islands NOT telescope as well as the local infrastructures that take advantage of Finland's geographical position are particularly valuable resources for researcher training and the implementation of smaller scale projects.

The space sciences and astronomy fields continue to have a sufficient number of students and young researchers. For the time being at least, PhDs have found employment in positions appropriate to their training. However, in the future it is important that doctoral programmes are diversified and that space research experts are employed in increasing numbers in other fields, too. Steps are needed to strengthen national cooperation with other disciplines and to promote the networking of researchers with leading international teams.

Strengths

- There is a healthy age mix in this field and its expansion has brought in large numbers of young researchers.
- There is good cooperation between universities, research institutes and industry.

- Researchers in this field have access to excellent national and international research infrastructures.
- The fascination of the general public with all matters relating to space means this field has enormous publicity potential.
- The national graduate school has promoted national networking.

Weaknesses

- It is difficult to secure long-term funding for projects that often last 10 years or more.
- The research community is small and there is a scarcity of university posts after the postdoctoral stage.
- A small country has only limited influence in large international organisations.

Opportunities

- Membership of international organisations gives a degree of say over important decisions.
- Space-related competencies will have increasing use in the future in various sectors of society.
- Finland occupies a unique geographical location from a space physics point of view.

Threats

- Basic research is suffering under the weight that innovation society is placing on applications-oriented research.
- Expensive research must be justified by reference to extra-scientific arguments.
- The small size of the research community means it is heavily dependent on a few highly skillful and competent individuals.

Recommendations

- Finland has taken good advantage of the opportunities offered by ESA to develop research equipment and related technologies. ESO opportunities, on the other hand, remain under-exploited. In the future it is necessary to ensure that adequate resources are available so that the scientific observations produced by major infrastructures as well as the scientific observation time allocated on observation instruments can be properly and fully utilised. Furthermore, Finnish researchers must be encouraged more actively to apply for vacancies at international organisations.
- Space researchers and astronomers are well networked internationally. The aim is to increase national cooperation within this field and to forge closer network contacts with other disciplines, particularly with methods experts.
- Since it is not expected that there will be any marked increase in the number of researchers in this field, doctoral programmes should be designed and developed with the aim of providing graduates with the skills and knowledge they will need in employment outside of academia.

Physics

Physics has a growing role in multidisciplinary research. Computational physics methods are central to research in materials science, and their application is increasing in biosciences in particular. Key areas of emerging research interest include modern optics and photonics, quantum coherent phenomena and quantum information as well as research that uses synchrotron radiation sources and free-electron lasers.

Current physics research has close ties with major international science projects. Finland has traditionally been rather reluctant to join infrastructure projects that are not directly connected to Finnish research. A more strategic approach needs to be taken to infrastructure decisions so that Finland is not sidelined from key areas of future research.

There are several highly respected physics research teams in Finland, and physics researchers in general are well networked. Because of the scarcity of resources available for experimental work, physics research in Finland is heavily focused on theoretical and computational research. However, the current high standards of physics research can only be maintained if resources are allocated to experimental research, too. One of the challenges faced in experimental research is that there are no established funding mechanisms in Finland for the creation and maintenance of national-level research infrastructures.

The number and quality of physics students in Finland continues to remain high when compared to many other European countries. Graduating PhD physicists have found employment without much difficulty, and a large proportion of experimental physicists in particular are employed in industry. Physicists with academic research ambitions often move abroad after taking their PhD, which is reflected in their exceptionally high level of international mobility early on in their career when compared to other natural science and engineering fields (Figure 7). After the postdoctoral stage, however, career advancement becomes more problematic as the number of vacant posts is limited and the insecurity of the academic research career in Finland means that some of those who have moved out of the country decide not to return. The tenure track system and other options must be considered in order to increase the predictability of the academic career path.

Basic physics research, particularly in subjects related to particle physics and cosmology, have very high visibility in domestic media. The favourable public image of this field helps to stimulate interest in the natural sciences and to attract a steady influx of university students in the natural sciences.

Strengths

- Physics research is of international excellence.
- Finnish physics researchers command great respect abroad.
- The research community is well networked internationally.
- Finland has large numbers of talented students in this field compared to other European countries.
- Doctoral programmes in physics are highly diverse and varied.

Weaknesses

- There are no established funding mechanisms for infrastructure development and maintenance.
- The scarcity of university budget funding means that research is too heavily dependent on external funding sources.
- The scarcity of permanent posts and the absence of a tenure track system mean that the research career is insecure.

Opportunities

- The application of physics methods in multidisciplinary research (and biosciences and materials science research in particular) is continuing to increase.
- European research infrastructures and funding sources are used more effectively.
- International recruitment is being increased.
- Centres of expertise with international appeal are being created in Finland.

Threats

- Short-sighted strategic direction of research is undermining basic research.
- There is not enough support for experimental research, infrastructure funding is drying up and equipment is ageing.
- A Finnish decision to drop out of major international projects.

Recommendations

- Mechanisms for the provision of national infrastructure funding must be set up immediately.
- Decisions to join major international projects in the physics field must be made immediately.
- University budget funding in the natural sciences must be revised. The current system is too closely tied to the number of degrees completed, and the costs of laboratory-intensive research are not sufficiently taken into account.
- A tenure track system must be created in Finland.
- More resources must be made available for research career stages after PhD graduation.

Geosciences

For the purposes of this report, geosciences is defined as comprising geology, geophysics and geomatics as well as their various branches, including atmospheric sciences and glaciology. Geosciences research teams in Finland are based at both universities and sectoral research institutes. In many fields sectoral research institutes account for a large proportion of all active research units. Finland has an internationally high-level infrastructure and a growing industry in this field, which in the future will be needing increasing numbers of people with a degree in geosciences.

The global operating environment is changing. Environmental threats are fuelling increased interest in remote sensing methods that are based on space technology. As Finland, unlike many other countries, is self-sufficient in ores and minerals, it is important that adequate resources are made available for a strong basic research effort in raw materials.

Research interests in the geosciences field are becoming more and more interdisciplinary. The introduction of modelling methods from physics, chemistry and mathematics in different geosciences fields opens up new research opportunities, but also presents a challenge for education. In order to break through to the international forefront, it is vital to have the capacity for interdisciplinary research and to transfer methodological knowledge between different fields of research. Environmental research is continuing to gain increasing importance. In particular, measures to combat climate change will require an interdisciplinary research effort that cuts across the entire physical system. The sustainable management of natural resources, waste disposal and spatial information are issues of great social significance in which geosciences research can make a major contribution.

Geosciences research units have close working relations with business and industry, which benefits both research and development and the social and commercial application of research results. However, the development of applications must be supported by high-level basic research. As it is, most research units are small and scattered, and therefore increased effort must be invested in networking, project cooperation and the development of independent research profiles.

Long time series are one of the most important infrastructures in the geosciences field, and it is vital that their continuity is ensured as observation networks are upgraded. Easy and inexpensive access to a wide range of observation materials is crucial for sustaining multidisciplinary research and for the diversity of research perspectives.

In the school curriculum, geosciences teaching is incorporated in physics, chemistry, biology and geography, and therefore schoolchildren do not have a clear picture of this discipline as a whole and the opportunities it offers. This means that extra effort is needed to attract talented students and future researchers into this field.

Strengths

- Research teams in the field are of a high international calibre and internationally well networked.
- There are strong research institutes of academic excellence in this field.
- There will be increasing job opportunities in the geosciences industry for Master's graduates and PhDs.
- Long-term, comprehensive and high-quality measurement datasets are internationally interesting.

Weaknesses

- Geosciences research and education are fragmented between several small units and departments.
- There is inadequate national networking among research organisations.
- Small units are dependent on short-term project funding.

Opportunities

- Geosciences research can support informed decision-making on energy policy, environmental problems, climate change, the depletion and use of natural resources and sustainable development.
- Applications based on geosciences research have the potential to create new world-class industry.
- The interfaces between different disciplines offer new areas of potential research interest.
- The Finnish research environment is innovative and ICT skills are of a very high level.

Threats

- The discipline is unable to meet the challenges presented by society.
- Decision-makers and funding bodies are preoccupied with applied research and focus on short-term results.
- Areas of research focus are increasingly determined by research and innovation policy.

- Geosciences education at schools remains fragmented and incomplete.

Recommendations

- Further steps are needed to strengthen interdisciplinary collaboration in geosciences research with a view to increasing its social and economic impact. It is recommended that an Earth System Science network be created that covers all the various fields of geosciences. In addition, closer links of contact must be established with the various basic and technical sciences.
- The growth of regional research clusters shall be promoted both by intensifying research and education collaboration between small university units and by networking research institutes engaged in basic and applied research with university units.
- Information about geosciences research must be increased in order to advance awareness of the social significance of geosciences and to promote the brand of geosciences in line with the current global situation.
- Steps are needed to ensure that internationally competitive research infrastructures are in place with a view to facilitating international research cooperation.

Chemistry

Chemistry competencies have a crucial part to play in addressing and resolving the global challenges that are now facing industry and society (energy consumption, environmental threats, food, water, forest and health, etc.). Areas of current research interest and important trends in development include chemical biology, wood-based products in wood processing, liquid biofuels, green chemistry, green technologies and catalysis research. Bio, nano and materials research and areas of intensive development focus also require the input of chemistry expertise. It is therefore important that the development of chemistry is driven by the interests of chemistry researchers so that this is not relegated to the status of an auxiliary discipline. Nevertheless, chemistry does engage in interdisciplinary research, too, most particularly with physics and biosciences.

The research community in the chemistry field is comparatively small but nonetheless internationally competitive. There are large numbers of relatively small research units in the field, but they are all well networked. International cooperation and networking is also strong, and according to the 2007 and 2008 research reports chemistry was one of the most active disciplines in terms of international researcher mobility. A discipline assessment in chemistry would help to identify different universities' main areas of strength: that would provide important information for purposes of university profiling.

Hardware and equipment often play a significant part in chemistry research. For the time being, most of the equipment available is up-to-date and the research facilities and other infrastructure are in reasonably good condition. However, equipment maintenance is resource-intensive and maintenance costs are often high. Another source of difficulty is the availability of equipment updates and spare parts. It is often easier to secure funding for purchases of new equipment than for operating and maintenance costs, especially in the case of joint acquisitions by a number of departments. Joint acquisitions and shared equipment use would help to improve overall cost efficiency.

The first requirement for the creation of a sound knowledge and skills base is to have good and talented students. The current mix of research staff is not properly balanced in that there are not enough postdoctoral researchers compared to PhD students (Table 1). Funding opportunities at the postdoctoral level remain inadequate, and there is a real threat of a brain drain at the highest level.

Strengths

- There are high-level research teams in the chemistry field, including some that are at the very cutting edge internationally.
- Research has close and well-established links with domestic industry and applications.
- Finnish research teams are internationally well networked.
- Research equipment, facilities and other infrastructure are up-to-date.

Weaknesses

- International research funding is too heavily focused on applied research.
- Chemistry units are small and scattered because of the demands of education.
- There is not enough chemistry education at schools and its quality is inconsistent.

Opportunities

- The chemistry field plays a crucial part in addressing major global challenges.
- Cooperation with physics, materials science and biosciences can pave the way to multidisciplinary research initiatives.
- School science education can be improved and made more inspiring.

Threats

- Basic research driven by chemistry interests dries up and chemistry is reduced to the status of an auxiliary discipline.
- The field can no longer attract the best student and research talent, and the best researchers move to other jobs.
- Research equipment, facilities and infrastructure deteriorate.
- The significance of chemistry research in resolving global challenges is not understood.

Recommendations

- Investment in basic research must be stepped up. University budget funding must also be increased so that universities can identify and further invest in the development of their strategic priority areas as required.
- Public awareness must be increased of the role that the chemistry field can play in resolving major global problems.
- Natural sciences must be incorporated in all curricula as broadly as possible with a view to supporting multidisciplinary thinking.
- School science education shall be improved so as to make it more exciting and inspiring.
- A discipline assessment shall be conducted in the chemistry field and a survey carried out to establish the demand for PhDs.

Mathematics and statistics

Finnish research in pure mathematics is traditionally very analytically oriented. Another major trend of pure mathematics in Finland is discrete mathematics, which has grown out of algebra and number theory and moved increasingly towards combinatorics related to theoretical computer science. In recent years research in applied mathematics has also become more diversified, both in the form of theoretical applied mathematics and direct applications.

Many key areas of mathematics are either very small or non-existent in Finland. Examples include geometry and algebra. This is unfortunate but inevitable, given the small size of the country. It is very difficult, if not impossible to try and alter the situation artificially. Nonetheless, it is important to make sure that all major branches of mathematics are properly covered in the basic curriculum. If the necessary expertise in the relevant areas is not available in Finland, the most talented students must be encouraged to move abroad to continue their studies.

Statistics is continuing to gain in importance, and it has far-ranging areas of application in society. At most universities mathematics and statistics are integrated into the same department. For the time being, this has not prompted closer cooperation in the research or education field, but it may open up interesting prospects for the future as students cross the border between these two disciplines.

The standard of mathematics research in Finland is very high indeed, especially in analytic and discrete mathematics. Applied mathematics has also made impressive progress and is now on a par with pure mathematics. Finnish publications in the mathematics field receive at least as frequent citations as world mathematics publications on average (see Appendix 3). The high standard of mathematics is also reflected in the large number of top international positions held by Finnish mathematicians and invited lectures delivered at major congresses. All successful research teams in Finland are internationally well networked.

The systematism that people acquire in mathematics education has many uses in society, and employment prospects are particularly good for graduates with an applied mathematics PhD. Nonetheless, movement outside of academia could be encouraged to a greater extent than is currently the case.

Mathematics is a highly abstract discipline and therefore popularisation is extremely difficult, especially in the case of pure mathematics. Any attempt to delve beyond the surface requires a fundamental knowledge of the basic terminology and concepts. This goes some way towards explaining why mathematicians are often rather modest in assessing the significance of their discipline. Another reason is that mathematics applications can take decades to filter through.

Strengths

- Finnish mathematics research is capable of reforming and diversifying itself.
- Research is of international excellence, particularly in analytical and discrete mathematics and in applied mathematics.
- Mathematics continues to attract talented students.

Weaknesses

- Mathematicians are often rather modest and do not sufficiently market the importance of their discipline.
- It is difficult to explain the significance of abstract results to the general public.

Opportunities

- Computational methods have increasing importance in different disciplines.
- The rise of applied mathematics is paving the way to increased exchange and interaction with industry and society.
- The interplay between mathematics and statistics can open up new lines of research inquiry.
- Mathematics will achieve increasing appreciation with growing awareness of its significance in society.

Threats

- Excessive focus on applications-oriented research detracts from the funding available for basic research.
- The lack of long-term funding precludes the development of new lines of research inquiry.
- Comparisons of different disciplines and science policy decision-making rely too heavily on bibliometric indices.
- Universities focus on developing their strategic growth areas, sidelining such methodological disciplines as mathematics and statistics.

Recommendations

- University budget funding must be secured and must allow for the renewal of mathematics research and education.
- Graduate schools must be strengthened and the needs for renewal must be taken into account in funding decisions on graduate schools.
- Thematic exchange programmes in the field of mathematics must be continued.

Materials science and engineering

Materials science and engineering is a multidisciplinary field that brings together knowledge from a wide range of fields, including physics and chemistry as well as electrical engineering and process technology. It also incorporates elements from such emerging fields as nanomaterials science and photonics. Materials science and engineering does not yet have a sufficiently well-defined profile in Finland. Researchers in this field publish and make visits within the mother discipline, but their contribution to major international materials science conferences is still relatively modest.

Materials science and engineering is a fast developing discipline, and new areas of research are emerging all the time. In the future, key areas of research will include energy technology materials as well as composites and hybrid materials. Other emerging fields include printed electronics, biomaterials, nuclear reactor materials, energy saving equipment, extracting industry and related materials development as well as optics and photonics and optical materials.

In the field of materials research, the practical applicability of research results correlates closely with scientific quality. Research units that publish in leading journals also generate the most innovations and, in the long term, the most business.

There is strong networking among researchers at national level. These contacts have formed spontaneously, and there is a high level of mutual trust among researchers. The dense national network is certainly a competitive asset, but so far that asset has not been utilised to its full potential.

The equipment needed in experimental materials research is in a poor state of repair, both at universities and at VTT Finland. Urgent steps are needed to improve the facilities and framework conditions for experimental research. The infrastructure for computational science is in good shape. In Europe there are a number of internationally important materials science infrastructures. It is imperative that Finland contributes actively to those infrastructures.

The number of PhDs graduating in materials science and engineering is in reasonably good balance with the current demand for PhDs. Employment prospects in the field are very good and from this point of view the number of graduate school positions could be even higher than it is. A high standard of education translates into skilled and competent researchers who publish a lot and who create spin-off companies. In the field of materials research new important collaborations have been established between business companies and research units: examples include the Finnish Nanocellulose Center, a joint venture between the forest industry giant UPM, Helsinki University of Technology and VTT Finland, and the Open Innovation centres created by Nokia and the Helsinki and Tampere universities of technology. In these ventures the inputs of universities are funded from business sources, allowing for the kind of long-term research effort that otherwise would not be possible.

Strengths

- Finland has international-level expertise in both experimental and theoretical research as well as in modelling.
- In Finland the intake of natural science students is still very strong compared to many other countries.
- Research teams are well networked with one another and with business and industry.

Weaknesses

- The research infrastructure has seriously deteriorated in many fields of materials research, and the share of computational science has increased at the expense of experimental research.
- Research is scattered across different universities and research teams are very small.

Opportunities

- National coordination of nanoscience research enables a unified research and infrastructure policy (NanoCentre Finland).
- Interdisciplinary cooperation will open up new opportunities and make it easier to respond to changing needs and interests in the research field.
- Materials science is included in the research agendas of several Strategic Centres for Science, Technology and Innovation.

Threats

- Strategic choices (e.g. Strategic Centres for Science, Technology and Innovation) are too constrictive, restraining basic research and effectively preventing significant new breakthroughs.
- Inputs are inadequate or too short-term.
- Research requires increasingly expensive infrastructures.

Recommendations

- Research funding bodies must recognize that materials research is a long-term commitment.
- International cooperation must be researcher-driven rather than tied to research policy goals and objectives.

- Materials science must be recognized as a distinct discipline in the Academy's classification of research fields.
- Standing mechanisms must be created for the funding of research infrastructures.

Energy technology and environmental engineering

Research in the energy technology field is conducted at more than ten universities and a number of research institutes. One of its most outstanding features is a high level of systemic and technological competence. Research teams performing basic research of international excellence are found in the fields of combustion technology, electric power technology and nuclear engineering. In applied research there is ongoing and fruitful collaboration between research teams and industry.

In 2006, the Finnish energy and environment sector had a combined turnover of 32 billion euros, accounting for roughly one-quarter of the country's total industrial turnover. The value of exports totalled 12 billion euros. The sector provides employment to 65,000 people. In 2008, a company called CLEEN was established to manage operations of the Strategic Centre in the energy and environment field. The Strategic Centre's main research interests are carbon-neutral energy production, distributed energy systems, sustainable fuels, the energy market and smart grids, efficient energy use, resource-efficient production technologies and services, recycling of materials and waste management, and the measurement, monitoring and assessment of environmental efficiency.

The international evaluation of the energy technology field commissioned by the Research Council for Natural Sciences and Engineering in 2006 concludes that there is a scarcity of experienced senior researchers at Finnish universities, which is reflected in the quality of both scientific research and the supervision of doctoral students (Academy of Finland, 2006b). The report also makes the critical point that the completion of doctoral studies takes a long time and that average age at doctorate is high. Most researchers in the energy technology field, the report says, are primarily funded through short-term projects. This funding concept is not viable in view of the interests of promoting academic research careers. Both the shortage of senior researchers and the slow progress of doctoral studies are chiefly attributable to the prevailing funding model.

Graduate schools have proved a highly effective way of speeding up the PhD process in the energy technology field. The Research Council is convinced that the number of graduate school positions at this time is inadequate in view of current needs. There is just one Ministry of Education graduate school in the energy technology field with a total of 10 graduate school positions. In all there are 50 PhD students working full-time on their doctorate. Energy technology subjects are also included in the curricula of the Graduate School in Chemical Engineering and the Graduate School in Electrical Energy Engineering.

Strengths

- Finland has research teams of international excellence in the fields of combustion technology, electric power technology and nuclear engineering.
- There is a high level of systemic and technological competence.
- Finland and the Nordic countries generally have a diverse and varied production base, i.e. a wide range of fuel capabilities and technologies.
- There is excellent cooperation between research units and industry.

Weaknesses

- There is not enough basic research compared to applied research.
- There is a scarcity of senior researchers.
- The PhD process is too slow.
- The coordination of research between universities and VTT Finland needs improving.
- There is not enough international mobility among researchers.

Opportunities

- Energy technology knowledge and competence play a pivotal role in combating climate change.

- Major European science projects in the energy technology field can open important new avenues for research.
- Research cooperation is set to increase between universities, research institutes and researchers in different disciplines.
- Graduate school opportunities shall be expanded to match current needs in the field.
- Long-term research has a clear and prominent role in the research portfolio of the energy and environment sector Strategic Centre.

Threats

- Funding for public energy research is predominantly channelled via the energy and environment sector Strategic Centre, and scientific basic research has only a marginal role.
- Nuclear research and education in particular are at a low level.
- The intake of talented young students in energy technology is not high enough.

Recommendations

- Steps are needed to increase basic research as well as international mobility and cooperation.
- Investment in basic research in nuclear engineering must be proportionate to the importance of this field in Finland's energy production.
- Research should be concentrated in larger units than is currently the case, which will facilitate multidisciplinary research and the maintenance of a high-quality infrastructure.
- The number of graduate school positions in energy technology must be increased.

Mechanical engineering and manufacturing technology

Research in mechanical engineering and the manufacture of basic metals is conducted at four Finnish universities and at VTT Finland. Three of these universities have recently undergone a major organisational overhaul, including mergers of departments and faculties. There are five Ministry of Education graduate schools in the field: the National Graduate School in Engineering Mechanics, the Graduate School in Computational Fluid Dynamics, the Graduate School on New Materials and Processes, the Graduate School in Concurrent Mechanical Engineering and the Graduate School in Process Engineering for Paper Manufacturing Technology and Paper Machine Automation.

In 2008, the Research Council for Natural Sciences and Engineering commissioned an evaluation of mechanical engineering research in Finland, including comparisons with the international state of the art (Academy of Finland, 2008). The expert reviewers concluded that there is world-class research in this field that is founded on a strong national skills and knowledge base. On the other hand, the evaluation also identified units with a shortage of motivation and new research ideas, which was attributed to the age structure of research personnel and to the university's short-term wage policy. In some units the teaching of undergraduate students consumes valuable research resources. Long-term basic research is bound to suffer in places that have large numbers of short-term product development projects funded by industry. Publishing in scientific journals is at a lower level than in other countries. Another source of concern is the lack of appreciation shown for research and the PhD degree.

In 2008, the management of operations at the Strategic Centre in the metal products and mechanical engineering field was taken over by a company called FiMECC, whose role it is to support dynamic and interactive research. Its main research areas include business services, user experiences, global networks, smart solutions and breakthrough materials. Another challenge for FiMECC is to support long-term basic research and to inspire the most promising young students to develop fresh ideas.

Strengths

- There is a high level of technological competence in machine automation and control technology, mechatronics and materials engineering.
- There is excellent cooperation between research units and industry.
- Several Finnish mechanical engineering companies are market leaders in their fields.

Weaknesses

- Research has been slow to reinvent itself and there are very few new and innovative lines of basic research.
- There is a scarcity of PhD researchers in the field.
- Scientific publishing is at a low level.
- The PhD process is slow and the mean age at doctorate is high.
- There is not much multidisciplinary research.

Opportunities

- PhD education in the field is set to increase and graduate schools to expand.
- Cooperation with electronics, information technology, materials engineering, energy technology and the natural sciences will increase, paving the way to multidisciplinary mechanical engineering research.
- Long-term research will have a stronger footing in the metals and engineering Strategic Centre.
- International mobility among researchers will increase.
- International research funding opportunities will be put to better use.

Threats

- Numbers of auxiliary staff at universities are reduced as a result of the Government productivity programme.
- There is not a strong enough influx of new research blood.
- The competitiveness of mechanical engineering in Finland declines.
- Research in mechanical engineering moves abroad with the growth of foreign ownership of Finnish companies.

Recommendations

- The focus of research must be shifted from applied to basic research.
- Investment must be increased in graduate schools and in doctoral programmes more generally.
- Publishing must be increased in scientific journals in particular.
- Steps are needed to increase cooperation between research teams.
- Interdisciplinary cooperation must be increased especially among researchers in the fields of natural sciences, information technology, electronics and in the energy sector.

Process technology

Process technology research is conducted by research teams in the fields of chemical technology, pulp and paper technology, metallurgy, materials engineering, fuel and energy technology as well as food technology and biotechnology at five universities. It has particularly close links with the pulp and paper industry, the oil refining and petrochemical industry, basic chemical industry, the metallurgical industry, the food and pharmaceuticals industry, and fine and special chemical industry. One of the most significant strengths of process technology research lies in the close collaboration between industry and academic research.

The process industry has provided employment to large numbers of graduating PhDs, so much so that universities have suffered a shortage of postdoctoral researchers. There is one national graduate school in the field, the Graduate School in Chemical Engineering, which from 1995 to 2007 has produced more than 100 PhDs.

The bulk of process technology research is experimental work. There is not much sharing of research equipment in this field, and for the time being there are no established funding mechanisms for the development and maintenance of research infrastructures. The creation of a national register of research equipment would allow for more effective use of that equipment and also make it easier to build up a higher-quality range of hardware and equipment. These arrangements would serve to generate value added and also promote the creation of joint research projects.

The adaptation of Finnish study and degree programmes to the Bologna process is a huge challenge. The Master's degree in process technology should be developed into a broad-based, pan-European degree that provides students with a sound basic understanding of process technology phenomena and unit operations as well as a basic knowledge in the natural sciences.

Research in process technology has significant impact. The process industry requires process competence, and Finland also has many strong machine and equipment companies. Research in this field has helped to enhance the efficiency of production and to reduce its environmental impact. In the wood processing industry, Finland continues to remain a world leader. The country's high level of process expertise has even persuaded some foreign companies to relocate their research function operations in Finland, even though many Finnish companies are currently moving in the opposite direction.

Strengths

- Finland has a strong international status in certain fields (e.g. chemical technology in the forest sector, bioenergy, combustion technology).
- The standard of PhD education is very high, and the graduate school system has improved it even further.
- There is good cooperation between industry and academia.

Weaknesses

- There is not enough free innovative research in the field, and the disproportionate funding levels for applied research at the expense of basic research means that researchers are drawn to short-term, scientifically low-risk projects.
- Research teams in the field are small and research projects are small and often isolated.
- There is only limited research cooperation within universities.

Opportunities

- Sustainable development requires sound knowledge and competence in process technology.
- Chemical technology and process technology skills and competence are applied outside traditional industries (manufacturing of chemicals, metallurgy, forest industry), for instance in pharmacy and food technology.
- Good existing international networks can be put to more effective use.
- There is deeper interaction between basic science (chemistry, physics) and process technology.

Threats

- The image of process technology is failing to inspire young people.
- The focus on applied research will cause basic skills and knowledge to be eroded.
- The ageing of the research equipment will compromise the prospects of experimental research.
- Industrial R&D operations are moved abroad.

Recommendations

- A national register of research equipment shall be created to increase the shared use of equipment.
- The disproportion of funding between basic research and applied research must be addressed. The position of basic research must be safeguarded.
- The Master's degree in process technology shall be developed into a broad-based, pan-European degree that provides students with a sound basic understanding of process technology phenomena and unit operations as well as a basic knowledge in the natural sciences.
- University cooperation in the provision of education must be increased. Basic courses must be provided locally, advanced courses on a broader national basis.

Pulp and paper technology

Finnish forest industry has traditionally invested only a very small proportion of its turnover in R&D. For the industry to succeed with its ongoing structural reform programme, it will need to develop new products and new processes, which clearly underscores the role of research as a strategic success factor. In 2006 the forest industry published its joint new research strategy (Metsäteollisuus ry – Finnish Forest Industries Federation 2006), 2007 saw the launch of the forest industry Strategic Centre (Forest Cluster Ltd), and in early 2008 the Finnish Nanocellulose Center was launched to developed new uses for pulp.

For the time being, pulp and sawngoods are still the key lines of production, but in the future the focus will shift increasingly towards the chemical industry and energy production. Interesting areas of future research include biorefineries and their diverse uses of wood; smart wood and fibre products; wood in energy production; chemical products; and nanocellulose. Scientific breakthroughs in these areas can only be achieved through interdisciplinary research networks coupled with long-term research funding.

In a bid to foster interdisciplinary research networks, the Research Council for Natural Sciences and Engineering allocated in 2007 two million euros to innovative basic research aimed at supporting the competitiveness of the forest cluster. The specific subject area for research funding was the development of smart products and processes in the forest industry. Funding was only granted to multidisciplinary consortia involving a research partner from the forest industry and one or more other partners representing some other field, such as information technology, physics, chemistry, automation technology, electronics or mechanical engineering. Launched at the beginning of 2008, the projects involved a total of 12 research teams and six research organisations.

At the beginning of 2009, there was just one graduate school in the forest industry sector. Because of the interdisciplinary nature of this research field there is an apparent need to expand the current graduate school network. It is critical for the success of the Finnish forest industry to attract a sufficient intake of young talented students.

Strengths

- There is close cooperation between research organisations and business and industry.
- There is a strong tradition of competence in applied research.
- Training programmes in the forest sector are broad and diverse.

Weaknesses

- There is a strong emphasis on applied research.
- The tradition of scientific research is weak and with the exception of a few research units, scientific publishing is all but non-existent.
- There are no supportive structures for the academic research career, and therefore it can be difficult to persuade the best research talent to stay on at universities.

Opportunities

- Interdisciplinary research will help to establish a research tradition in the field.
- The forest cluster Strategic Centre will help to consolidate the position of basic research.
- With the recession that started in 2008, increasing numbers of promising young students will opt to stay on for postgraduate studies.
- Renewable wood raw material is an inspiring source for the development of new innovative products, which requires a sound foundation in basic research.

Threats

- The bleak outlook for the forest industry may drive away the best student talent.
- The forest sector fails to increase its R&D investment as expected.
- Industrial R&D is relocated to other countries.

Recommendations

- Interdisciplinary PhD education programmes must be improved and developed.
- National research cooperation must be strengthened.
- International interdisciplinary cooperation must be stepped up.
- Long-term funding for basic research must be increased.

Construction technology and municipal engineering, architecture

The built environment is of great significance to the national economy. Almost three-quarters of our national wealth is tied to buildings, transport infrastructures and networks. This is therefore a field that is crucial to both the competitiveness of society and to sustainable development. Furthermore, the current emphasis on mitigating and adapting to climate change has given heightened urgency to the research challenges in this field.

Civil and environmental engineering departments and architecture departments at universities of technology all suffer from a shortage of research staff and research resources. There are only few research units that conduct basic research and that produce internationally refereed articles. The current structure of university research teams is not conducive to the balanced development of research skills and competencies. The units are scattered and small in size, and often have no postdoctoral researchers on their staff. This is also reflected in the low number of applications filed for Postdoctoral Researcher's projects and Academy Research Fellowships. In 2004–2008, the Research Council received 12 applications for Postdoctoral Researcher's projects in architecture fields and 10 applications for Academy Research Fellowships. In order to advance the state of scientific research in this field, it is necessary to put structures in place to support the postdoctoral researcher career, such as postdoctoral research positions that are funded from core budget sources.

There is a high demand for PhDs in this field both at universities and in business and industry, particularly in companies in the building construction and real estate markets that are becoming more and more international. The number of PhD graduates in this field has shown a moderate increase in recent years (Suomen Rakennusinsinöörien Liitto – Finnish Association of Civil Engineers, 2008). There are two Ministry of Education graduate schools in this field, which have contributed to speed up and professionalise the PhD process. The Research Council for Natural Sciences and Engineering has aimed to support this development as well.

Public research funding through ministries and government agencies that are responsible for the maintenance of the country's building stock and infrastructure has been reduced. It is crucial that the resources made available for supporting long-term research are adequate so that the necessary competencies in key areas of society can be maintained. All Academy and Tekes funding is competitive, and their science policy objectives do not necessarily support the needs of the administration of the built environment.

Research funding in this field is typically short-term and predominantly earmarked for applied research and the development of practical solutions. Cooperation between research units and industry has worked well in the case of applied research, but businesses have failed to see the benefits of basic research to industry development. Since there is a broad commitment in business and industry to set up a Strategic Centre in the built environment field, it appears that attitudes to basic research may now be changing.

Strengths

- Young, talented students are continuing to come into the field.
- There is good cooperation between different players and across cluster boundaries.
- VTT Finland has good international networks and the necessary competence for the coordination of major EU projects.
- Competence in applied research has paved the way to innovative practical solutions.

Weaknesses

- The scarcity of core budget funding means that adequate resources are not available in all places for education, let alone for research.
- The volume of basic research remains low, and there is no long-term funding.
- There is no tradition of scientific research, and international publishing is very limited.
- There are few postdoctoral researchers in the field.

Opportunities

- The field has central importance to the competitiveness of society and sustainable development, and the research challenges facing the field are of considerable current interest.
- Graduate schools are helping to make the PhD process more professional.
- Researcher mobility is contributing to increase national and international networking and joint publications.
- The launch of a Strategic Centre in the built environment field in 2009 demonstrates the commitment of business and industry to invest in research.

Threats

- Lack of resources, the discontinuation of professorships and the ageing of the infrastructure are undermining the burgeoning research culture and the quality of basic studies.
- Reducing the volume of public research funding through ministries and government agencies has an adverse effect on research competencies in areas that are of central importance to society.

Recommendations

- Budget funding for this field must be increased so that the most basic functions can be handled without the need to resort to external funding.
- Staff and administrative structures need to be streamlined so that staff numbers in administration can be reduced and staff resources allocated to research increased, for example by opening postdoctoral positions that are funded from core budget sources.
- In the assignment of teaching duties to professors, special consideration should be given to the new needs arising from ongoing changes in society.
- The culture of scientific research in this field needs to be strengthened by attaching greater importance to the criterion of scientific quality in the recruitment of professors and research staff.

Electrical engineering and electronics

Electrical engineering has gained increasing importance and prominence in recent years, and it has become a core area of competence in many fields. It has developed very strongly and rapidly, and the field now comprises an impressive range of technologies. Electronics and automation are becoming integrated in products, and their impacts are seen in all areas of society. The research challenges facing electrical engineering are interdisciplinary in nature, and cooperation among different fields is becoming more and more important. This is problematic for the development of electrical engineering in that research is increasingly driven by interests stemming from other fields, while electrical engineering itself is seen as having merely a supporting role.

The field of electrical energy engineering is in the midst of profound change. Centralised energy production is giving way to a new system of distributed energy production in which consumption is controlled in real time. The efficiency of energy conversion and use processes is central to reducing emission levels. There is a global need and political demand for smart energy systems and for improved levels of energy efficiency. The tools that are needed for this change are provided by ICTs, local intelligence and power electronics. However, a number of issues must first be addressed and resolved before distributed energy production can become a cost-effective solution.

Some fields of electrical engineering are highly equipment-intensive. Simulation alone is not sufficient, but in some cases infrastructures are needed to conduct experimental studies. It is important that universities continue to develop more flexible and concrete forms of collaborations in infrastructure development and to deepen their cooperation with VTT Finland. European infrastructures should be put to better use and researchers should be encouraged to make longer exchange visits.

Finland has only a few research teams of international excellence, and only few of the best teams have grown to become large. Since Finland is not in the position to support broad-ranging research efforts that cover everything, it is necessary to apply a strict and selective focus and to engage in international cooperation. The quality of research can be enhanced by strengthening basic research, by concentrating resources in larger research units, by increasing the number of international research projects and by promoting researcher mobility.

The number of PhDs graduating from the electrical engineering field is continuing to rise, and the number of doctoral theses in the field as a proportion of the national total has also increased. By international comparison the standard of doctoral theses in Finland is high, although in recent years the quality has become less consistent. Part of the reason for this lies in the fact that doctoral theses are often produced in project settings, and those projects are often very differently placed in terms of their framework conditions. Mobility among PhDs and PhD students in the field is alarmingly low. Employment rates for PhD graduates in electrical engineering are very high.

Strengths

- There are strong research teams and strong areas of competence in the field.
- There is good interaction between basic and applied research.
- Research teams can flexibly combine different sources of funding.
- The strength of the industry means that PhD graduates in electrical engineering have excellent employment prospects.
- Both undergraduate and PhD education is of a high quality.

Weaknesses

- There is a scarcity of budget funding and long-term research funding.
- The field has had poorer than average success in the Academy's postdoctoral researcher calls.
- Involvement in international joint projects and EU funding are both at a low level.
- The competence base is narrow and concentrated around a few strong centres and teams.
- Researcher mobility is limited.

Opportunities

- Steps are taken to systematically increase and develop international cooperation.
- The research competence in the field is put to more effective use in such areas as energy technology, mechanical engineering and process technology and in the welfare cluster.
- Strategic Centres encourage and facilitate collaboration between industry and research organisations.
- The field play a central role to play in facilitating sustainable development.

Threats

- Short-term funding is threatening to undermine the quality of research.
- Electrical engineering has dwindling appeal as an area of study and research career option.
- An asymmetrical brain drain may deprive Finland of its best research talent.
- Industrial product development is relocated out of Finland.

Recommendations

- Funding for high-quality basic research must be secured.
- The student to supervisor ratio in doctoral education must be redressed by increasing the proportion of postdoctoral researchers.
- Participations in EU and Eureka projects must be increased.
- European infrastructures must be used more effectively.
- Steps are needed to shift the focus of emphasis in Finland from expertise in components to system management.

Computer sciences

The international discipline assessment commissioned by the Research Council for Natural Sciences and Engineering in 2007 (Academy of Finland, 2007b) concluded that the main areas of strength in this field were data mining, machine learning and ubiquitous computing. New emerging multidisciplinary fields such as bioinformatics, computational biology and bioinformation technology have also developed significantly. In the fields of software engineering and telecommunications engineering, Finnish research is of international excellence, but closer cooperation with world-leading research teams would contribute to further enhancing the impact of Finnish research.

In many fields of computer science the visibility of research is not as high as it ought to be in view of its high quality standards. This may be explained by inadequate international mobility; by research teams having no clear publishing strategy; and by the failure of researchers to target the most important publishing channels. On the other hand, many of the major conferences in the field do not enjoy the esteem they deserve and are not taken into account with sufficient weight. In some fields the lack of visibility may be due to the fact that most of the research in those fields is done in applied research projects together with business partners, which means that the publication of research results is not a priority concern or indeed even possible. Sometimes the publishing forums for multidisciplinary projects fail to recognize the underlying computer science solution. For instance, research in machine learning might be able to gain a stronger international position if it worked more closely with theoretical computer science.

Computer science often has an auxiliary or supporting role in research. This applies most particularly to multidisciplinary research in which the main focus is on some other discipline, but which in terms of its methods relies heavily on information technology. This brings a constant flow of new research problems into the field of computer science and adds to its significance. However, core competencies may well disappear because of the needs and interests of other disciplines, which in the long term presents a serious threat to the development of this field. For this reason it is crucial that the high quality of basic research is maintained. However, the quality of basic studies in computer science is high and provides future researchers with excellent background knowledge.

For the past 10 years substantial investment has been made in improving doctoral education within this field. This is reflected in a sharp increase in the number of PhD graduates and in their lowered average age, and accordingly in the lower age of researchers. Unfortunately, though, under the heavy administrative burden and teaching duties of their new position, many young professors have struggled to find the time they need to set up their own research team. Nevertheless, the rise in the number of professors in this field is now beginning to level out.

In Finland the IT industry is closely tied up with telecommunications and associated industry. In Strategic Centres, computer sciences occupy a key strategic role. Active interaction with business and industry is a major asset for research in this field. At the same time, it is crucial that the quality of basic research is at the highest possible level in all the necessary areas. For instance, there is only limited research in programming language, even though one would presume this to be an important area for the IT industry. On the other hand, there is strong research in the broad and developing field of human-computer interaction.

Strengths

- The research field is broad and diverse yet sufficiently focused on certain key areas.
- There is good cooperation in the field with other disciplines.
- Research has close contact with business and industry and with the rest of society.
- There is a sound infrastructure in place.

Weaknesses

- Attendance at international conferences is not active enough.
- National and international mobility is inadequate.
- Core computer science accounts for a relatively small proportion of the whole research field.
- There is room for improvement in terms of the systematic organisation of postgraduate studies and in the supervision of doctoral theses.

Opportunities

- EU funding opportunities are used more effectively.
- The share of women researchers in the field is growing.
- High-level basic research in computer sciences is put to better use at Strategic Centres in the ICT and other sectors.

Threats

- The national research profile will become too one-sided if interdisciplinary cooperation and applied research are emphasised at the expense of basic research.
- Research is increasingly driven by the short-term needs and interests of business and industry, while the role of theoretical basic research is increasingly constrained.
- A low level of national and international mobility may cause the field to become increasingly introverted.
- The main publishing forums in the field are not respected enough or taken into account in discipline assessments.

Recommendations

- Mobility must be encouraged and increased at all levels, and both nationally and internationally. In addition, it is necessary to attract and recruit more foreign researchers into Finland.
- The field must develop its own publishing strategy and pay more attention to publishing forums.
- The field must start its own foresight exercise to ensure its various areas (theoretical vs. applied; core computer science vs. new multidisciplinary fields) are in healthy balance.

Industrial management and industrial design

Research in the fields of industrial management and industrial design is characterised by its proximity to applications. There is only a relatively short tradition of basic research, particularly in the field of design research. Another characteristic in both fields is the small size of research teams. The creation of Aalto University will have significant implications for both industrial management and industrial design.

Industrial management brings together engineering, behavioural and economic sciences. Business services have emerged as an important new area of industrial management alongside the traditional area of knowledge management. Other areas of topical research interest include life cycle cost analysis, the linking up of products with services, innovation processes, the administration of production data, service design and business environment research from an R&D environment and business concept development point of view. Key areas of strength in Finnish industrial management research are business services, logistics, cost management and technology management. Publishing volumes are on the increase (see Appendix 3).

The industrial design field couples a multidisciplinary approach with a dialogue between art and science. Design is not just about creating a product, but also about how it is used and the user interface. Since this is a relatively young discipline, it still suffers from a lack of conceptual and methodological coherence. Owing to the scarcity of long-term funding it is also characterised by intense research cycles, which tends to produce current state-of-the-art descriptions rather than analytical research results. According to the participants at the workshops hosted by the Research Council, the research field of industrial design has now reached a stage where industrial management was 15 years ago.

In both fields the number of students seeking admission to undergraduate courses far exceeds the number of student places, which means that the admissions process of highly selective. The long-serving graduate school in industrial management involves all universities with active units in this field, i.e. Helsinki University of Technology, Lappeenranta University of Technology, Tampere University of Technology, the University of Oulu, and Åbo Akademi University. Industrial employment rates are high among PhDs graduating in the field of industrial management, and many also start up in business. There are three graduate schools with industrial design connections, with a total of 20 places funded by the Ministry of Education. In the industrial design field there is a scarcity of PhDs in university teaching positions.

Strengths

- The fields are highly popular among talented students.
- Finland has internationally high-level research teams in the industrial management field, and publishing is on the increase.
- Industrial design has close links of contact with technology industry innovations and markets.

Weaknesses

- Research teams in the field are small and leading-edge research is quite thin.
- It is difficult to secure long-term research funding.
- Research in industrial design lacks in conceptual and methodological coherence.
- International cooperation leans too heavily towards Western countries, while contacts with Asia have been very much neglected.

Opportunities

- Closer integration with behavioural sciences, communication, marketing and technology will support the achievement of international excellence in service research.
- Cooperation between industry and academia is set to increase.
- There is significant untapped potential for design use and for strengthening Finnish competitiveness, especially in SMEs.
- Finland can position itself as a pioneer in ecological design and ecological thinking.

Threats

- The number of graduate school positions in industrial management is not increasing.
- The best student talent is coaxed out of an academic career to work in business and industry.
- Design competence is not appreciated at the strategic business level as a competitive asset.

Recommendations

- A graduate school should be created that brings together both industrial design and industrial management.
- The graduate school in industrial management should be expanded to comprise the area of business services.
- New professorships should be established in the area of business services.
- The size of research teams needs to be increased.
- State funding organisations must ensure that design research has access to adequate resources.
- When making decisions on the allocation of production development and innovation funding, Tekes must ensure that design-driven research methods are incorporated in research projects.

5 Recommended measures

The following provides a summary outline of the development measures recommended by the Research Council for Natural Sciences and Engineering in the four key areas of basic research, research infrastructures, the academic research career, and school education and information.

1. Long-term basic research

- The Finnish research and innovation system shall be developed in such a way that the availability of public funding for long-term basic research is increased.
- University budget funding shall be developed in such a way that budget funding covers teaching costs in full and research costs in part.
- The Academy of Finland must continue to strengthen its profile as a source of a long-term funding for basic research.
- At least 20 per cent of the funding through Strategic Centres for Science, Technology and Innovation calls shall be allocated to long-term research projects.

2. Research infrastructures

- Participation in major international research infrastructures shall be based on the criterion that Finnish research in the field is of international excellence.
- A system must be created and established for the funding needs of national research infrastructures that covers the costs arising both from the building and installation of equipment and from maintenance.
- Budget funding for research organisations shall cover the acquisition, maintenance and development of local infrastructures.

3. Research career

- Funding for postdoctoral stages of the research career shall be increased so that the most talented individuals recognize a career in academic research as a competitive option.
- Universities must commit themselves to the most promising researchers through a tenure track system that is based on open competition.
- Research funding agencies shall adopt international cooperation and mobility as a criterion that cuts through all their funding decisions.

4. School education and information

- School education shall be developed in such a way that there is greater awareness of the role and significance of natural sciences and engineering in resolving major social and global challenges and so that talented young students find them interesting and inspiring.
- The Academy shall keep the general public better informed about the results of basic research.

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The Research Council for Natural Sciences and Engineering also thanks the following workshop participants and others for providing background material for this review:

Raimo Alén, University of Jyväskylä
Elja Arjas, University of Helsinki
Mark Hughes, Helsinki University of Technology
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Appendix 3. Publication and citation trends in natural sciences and engineering fields

The Figures in this Appendix describe recent publication and citation trends for research in natural sciences and engineering and show how they compare internationally. The publication and citation numbers have been calculated using the fractionalisation methods developed by the Swedish Research Council, in which both publications and the citations they have received are weighted according to the proportion of authors from the country in question (Swedish Research Council, 2006; see also Appendix 2 to this report, which provides a detailed description of the bibliometric data and methods used). The publication and citation data used by the Swedish Research Council are based on the Thomson Reuters Science Citation Index Expanded database[1] (Appendix Table 1). The country classification is based on the addresses given by the authors. If a given publication is ascribed to two or more disciplines, the citations it receives are divided between these disciplines accordingly. The number of citations received by each publication is counted three years after the date of publication. Since the analyses here use the Swedish Research Council's fractionalisation method, the indicators shown in this Appendix are not fully comparable with the bibliometric analyses of earlier Academy reports on the state of science and research in Finland.

The first series of Figures describes the development of relative citation impacts from 1988 to 2007. The relative citation impact is the number of citations received by Finnish publications relative to the average number of citations for the discipline in question divided by the number of Finnish publications in that field. If the relative citation impact for Finland in any given field is one, this means that Finnish publications are cited equally often as publications in that field on average. Three-year moving averages are used in the indicators. Comparisons are provided with Sweden, Switzerland and the United States.

The second series of Figures describes the development of Finnish publication numbers and the proportion of the highly cited articles. The bars indicate the number of Finnish publications in each field of research. The line indicates the proportion of Finnish publications among the top 5 per cent of the internationally most cited articles. Both publication numbers and top 5 per cent statistics are computed using three-year moving averages.

The chart in Appendix 3c provides an overview of publication and citation numbers in natural sciences and engineering fields. The size of each coloured circle is proportionate to the number of Finnish publications. The location of the circle on the X-axis indicates the average number of citations received by Finnish publications in that field. Its location on the Y-axis, then, indicates the number of citations received by Finnish publications compared to world publications. If Finnish publications are cited as frequently as world publications in this field on average, the circle is located at Y-coordinate 1. The chart is based on publication and citation numbers from 1984–2007.

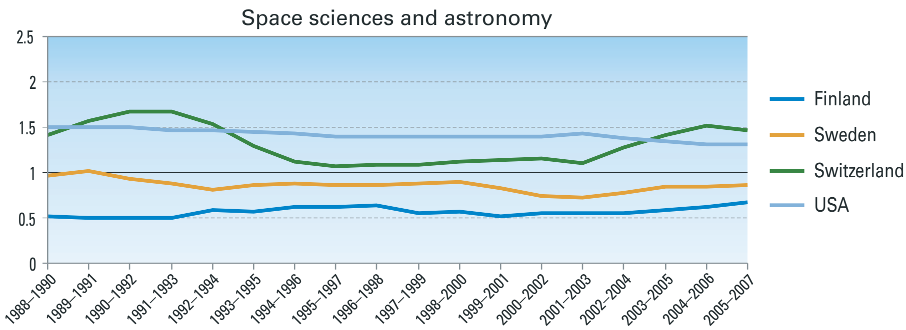
1 Certain data included herein are derived from the Science Citation Index Expanded® prepared by Thomson Reuters®, Philadelphia, Pennsylvania, USA

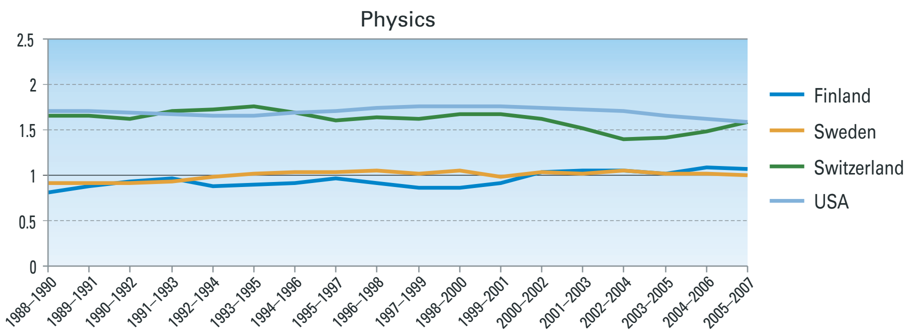
Table 1. Field of research classification used in the bibliometric analyses for natural sciences and engineering research.

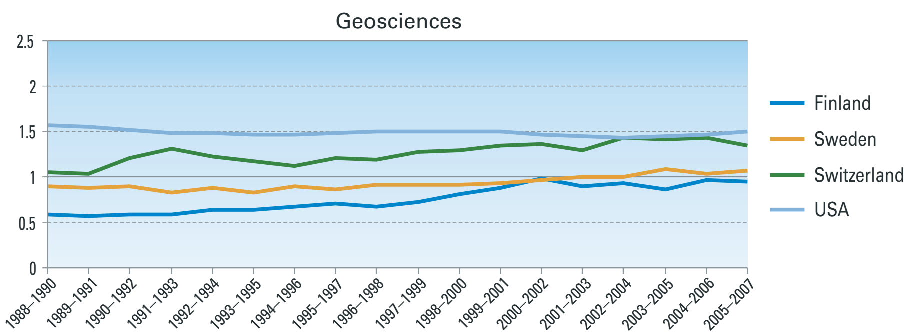
Field of research	Science Citation Index Expanded Database: Subject Categories	
Space sciences and astronomy	Astronomy & Astrophysics	
Physics	Acoustics Physics, Applied Physics, Fluids & Plasmas Physics, Atomic, Molecular & Chemical Physics, Multidisciplinary Physics, Condensed Matter	Physics, Nuclear Physics, Particles & Fields Physics, Mathematical Nuclear Science & Technology Thermodynamics
Geosciences	Geochemistry & Geophysics Geography, Physical Geology Geosciences, Multidisciplinary Meteorology & Atmospheric Sciences	Mineralogy Oceanography Paleontology Remote Sensing
Chemistry	Chemistry, Applied Chemistry, Multidisciplinary Chemistry, Analytical Chemistry, Inorganic & Nuclear Chemistry, Organic	Chemistry, Physical Crystallography Electrochemistry Polymer Science Spectroscopy
Mathematics and statistics	Mathematical & Computational Biology Mathematics, Applied Mathematics, Interdisciplinary Applications	Mathematics Statistics & Probability
Materials science	Materials Science, Ceramics Materials Science, Multidisciplinary Materials Science, Biomaterials Materials Science, Characterization, Testing Materials Science, Coatings & Films	Materials Science, Composites Materials Science, Textiles Nanoscience & Nanotechnology Optics
Energy technology and environmental engineering	Energy & Fuels	Engineering, Environmental
Mechanical engineering and manufacturing technology	Engineering, Aerospace Engineering, Manufacturing Engineering, Mechanical	Ergonomics Mechanics
Process technology	Engineering, Chemical Metallurgy & Metallurgical Engineering	Mining & Mineral Processing
Pulp and paper technology	Materials Science, Paper & Wood	
Construction technology and municipal engineering, architecture	Architecture Construction & Building Technology Engineering, Civil	Transportation Transportation Science & Technology
Electrical engineering and electronics	Automation & Control Systems Engineering, Electrical & Electronic Instruments & Instrumentation	Robotics Telecommunications
Computer science (ICT)	Computer Science, Artificial Intelligence Computer Science, Cybernetics Computer Science, Hardware & Architecture Computer Science, Information Systems	Computer Science, Interdisciplinary Applications Computer Science, Software Engineering Computer Science, Theory & Methods
Industrial management	Engineering, Industrial	Operations Research & Management Science

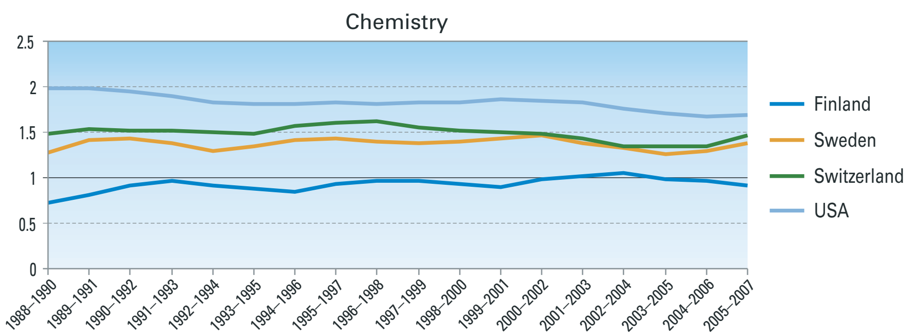
Appendix 3A. Relative citation impacts in natural sciences and engineering fields

Source: Thomson Reuters Science Citation Index Expanded, Swedish Research Council 2009.

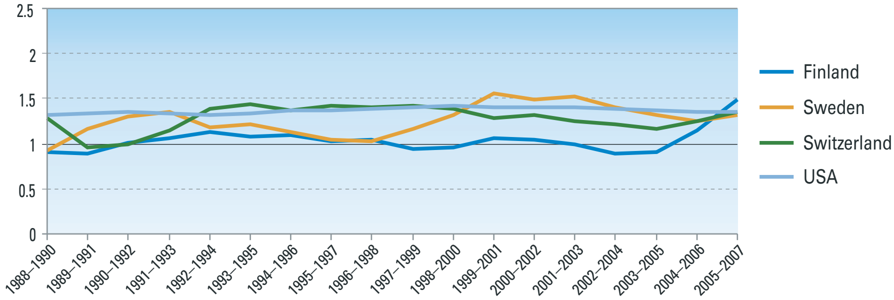




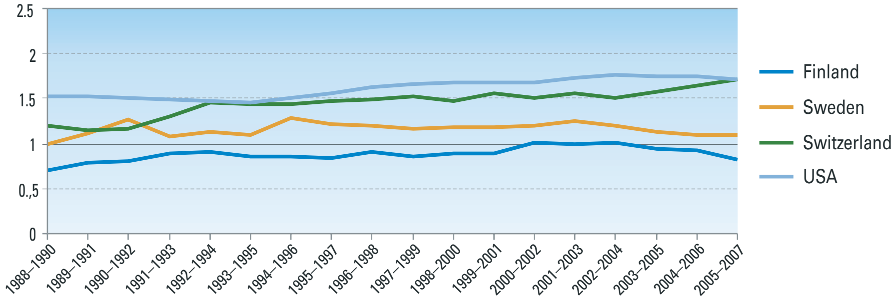




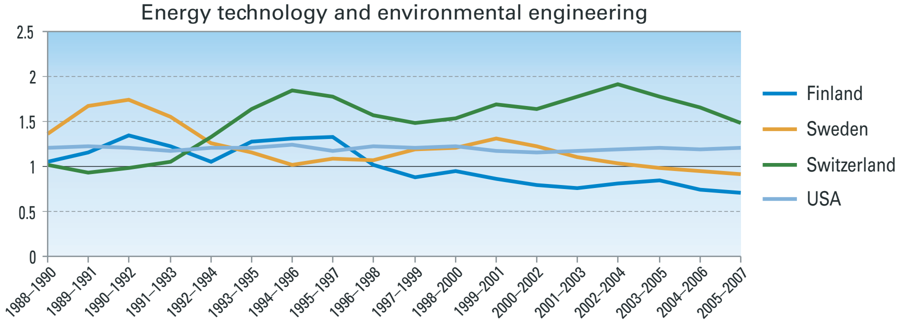
Mathematics and statistics



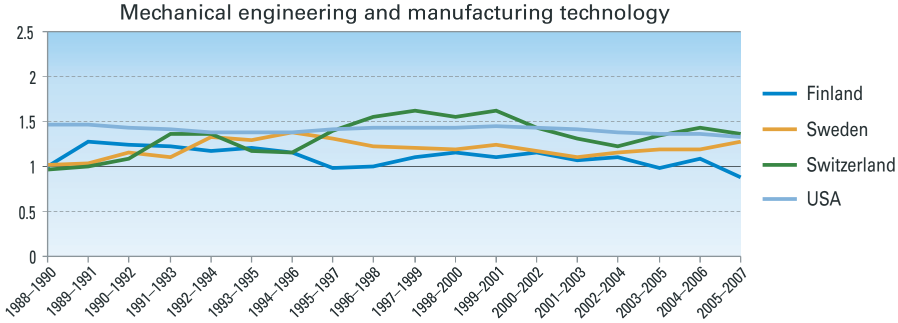
Materials science



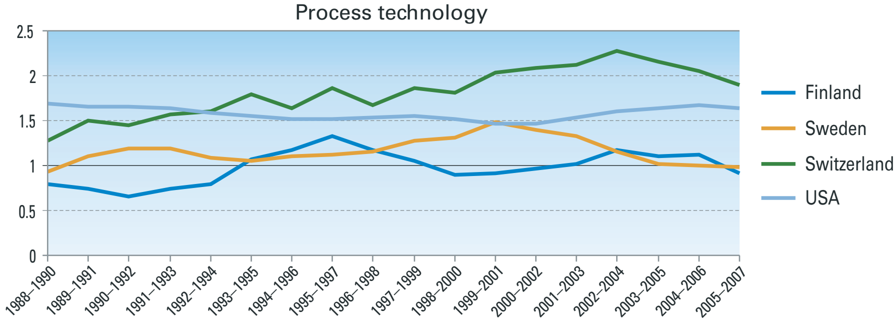
Energy technology and environmental engineering



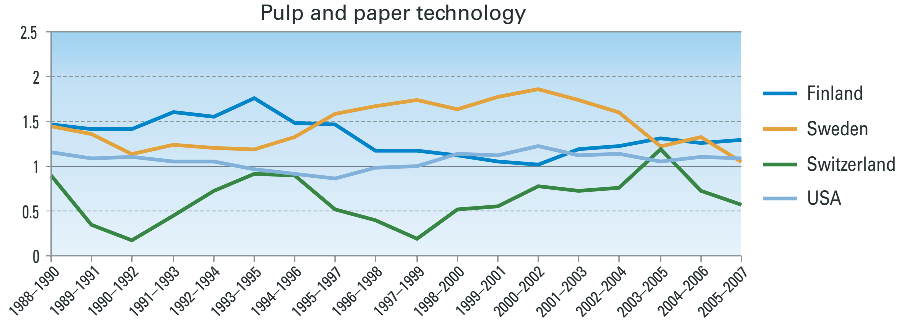
Mechanical engineering and manufacturing technology



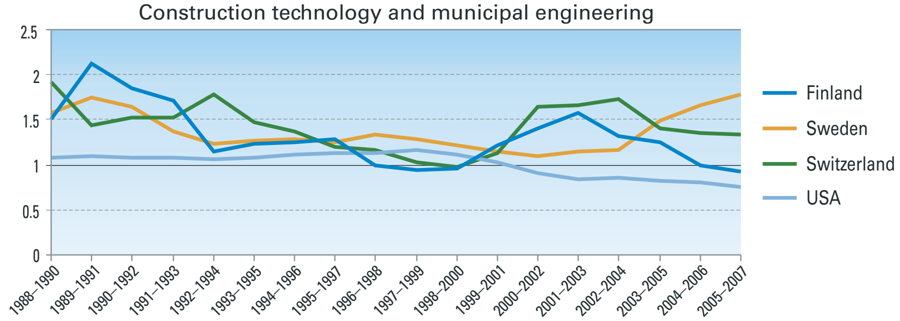
Process technology



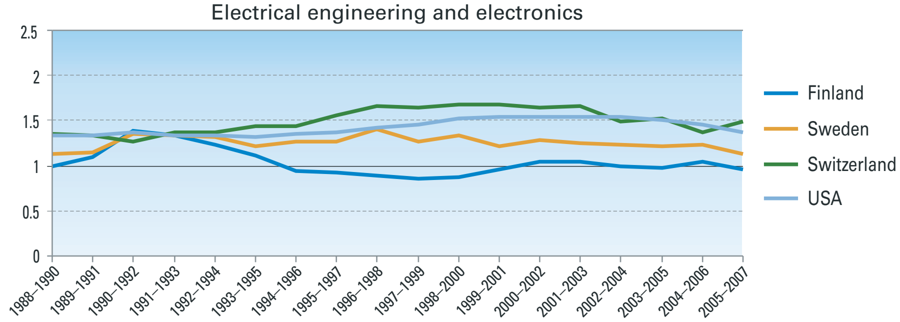
Pulp and paper technology



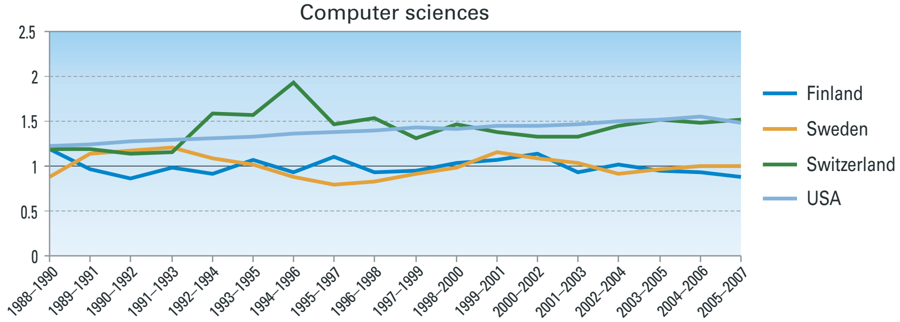
Construction technology and municipal engineering



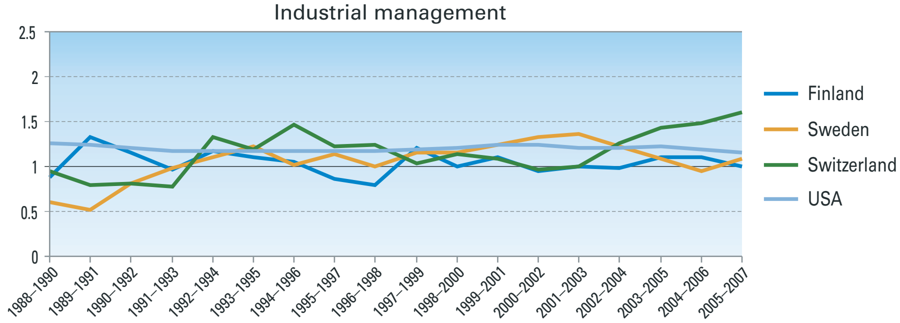
Electrical engineering and electronics



Computer sciences

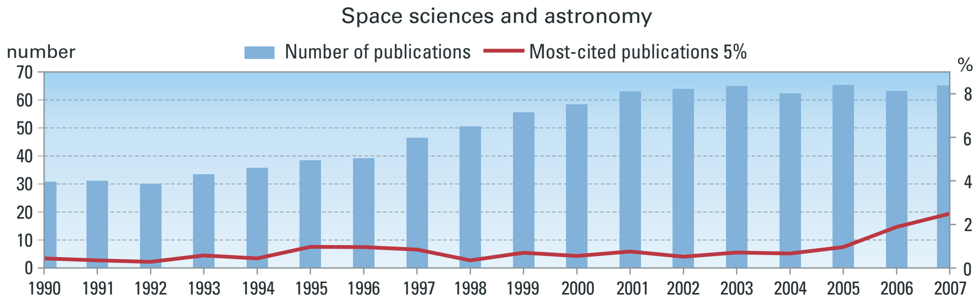


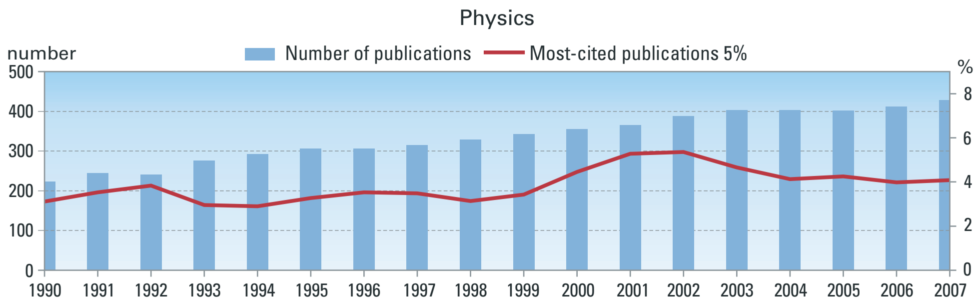
Industrial management

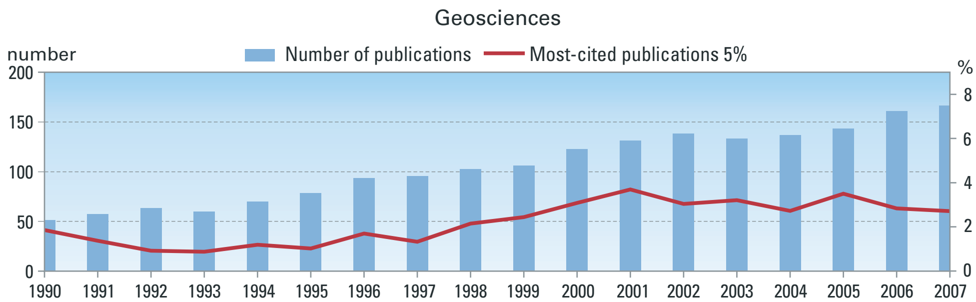


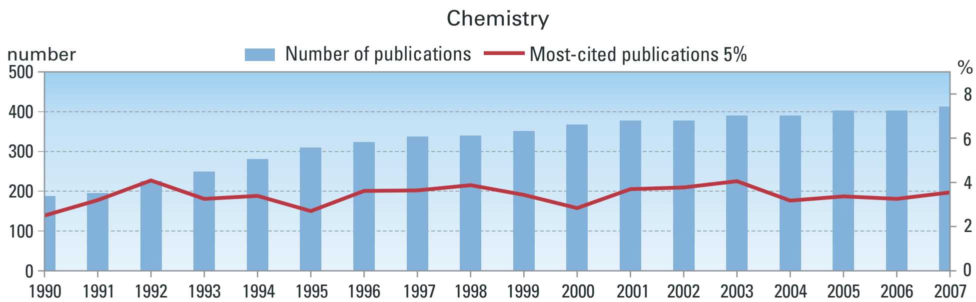
Appendix 3B. Publication numbers and proportion of highly cited publications in natural sciences and engineering fields

Source: Thomson Reuters Science Citation Index Expanded, Swedish Research Council 2009.

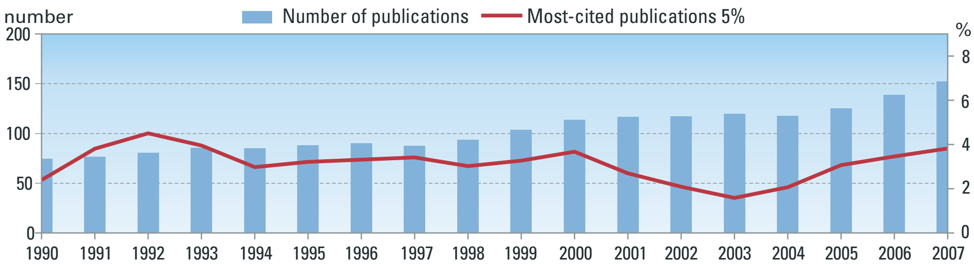




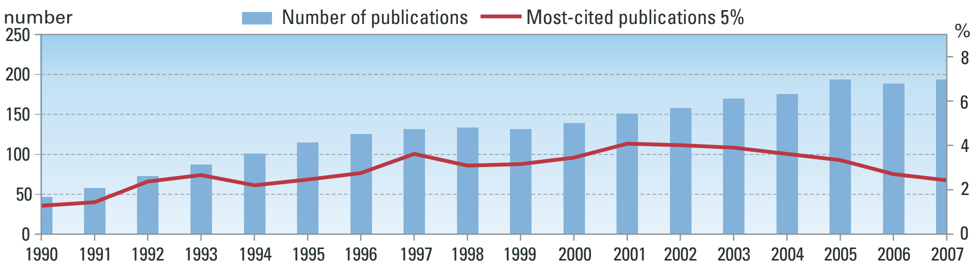




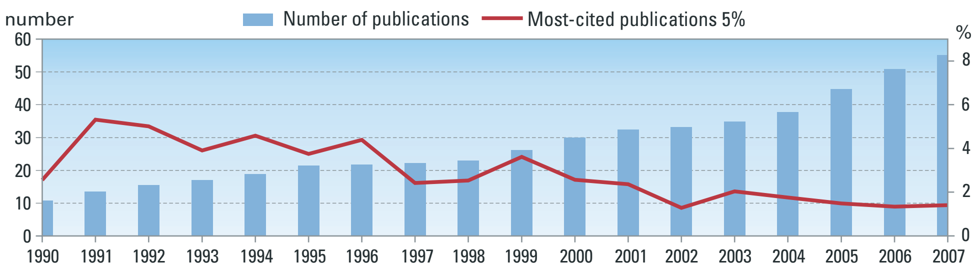
Mathematics and statistics



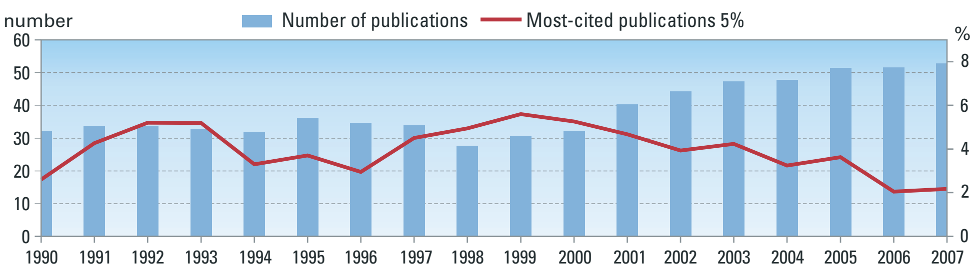
Materials science



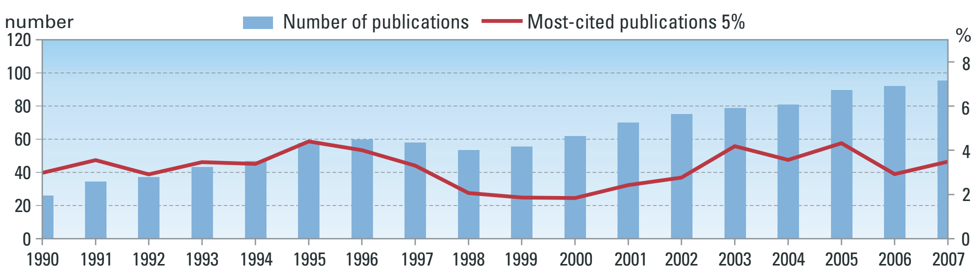
Energy technology and environmental engineering



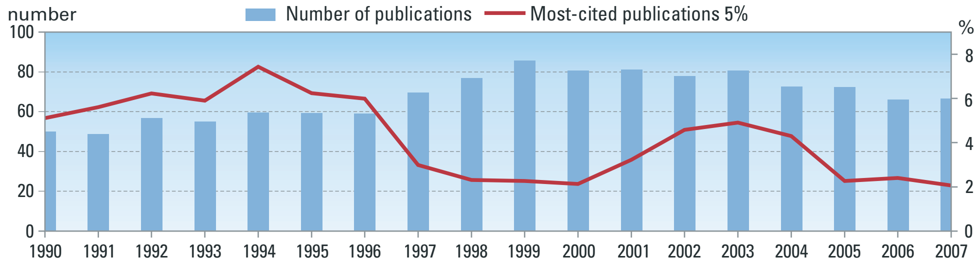
Mechanical engineering and manufacturing technology



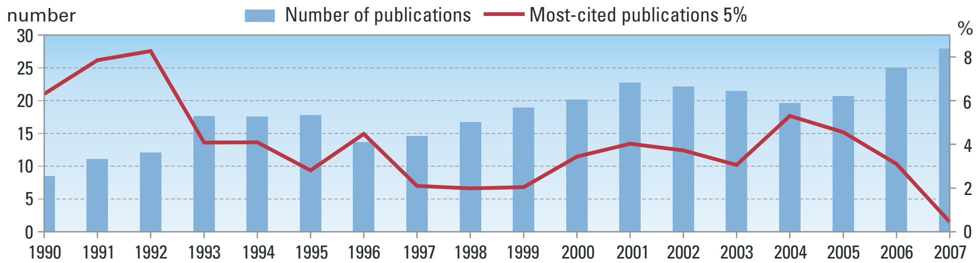
Process technology



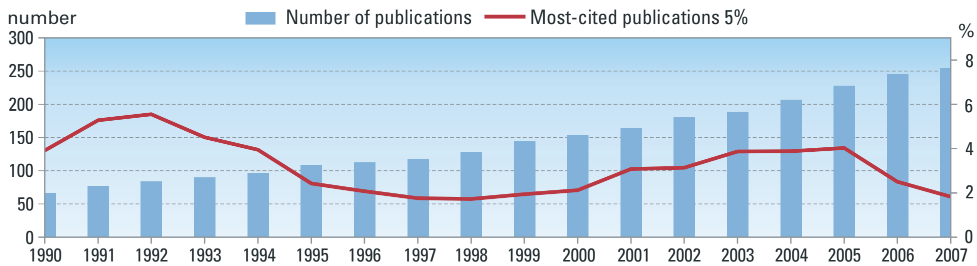
Pulp and paper technology



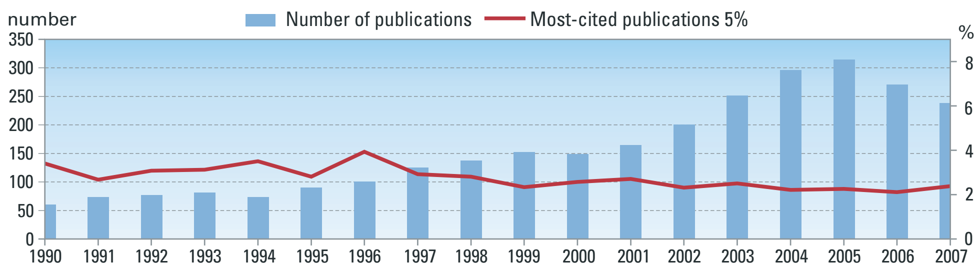
Construction technology and municipal engineering



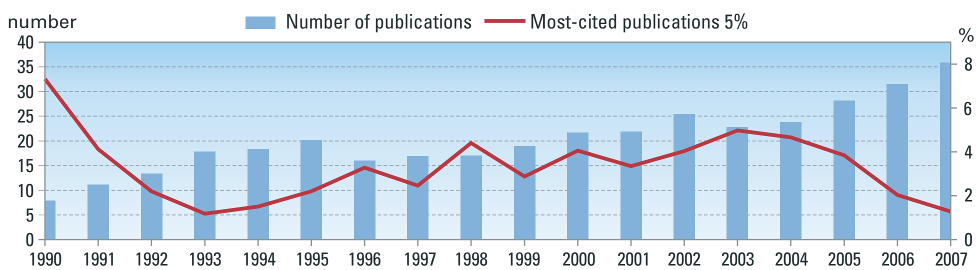
Electrical engineering and electronics



Computer sciences

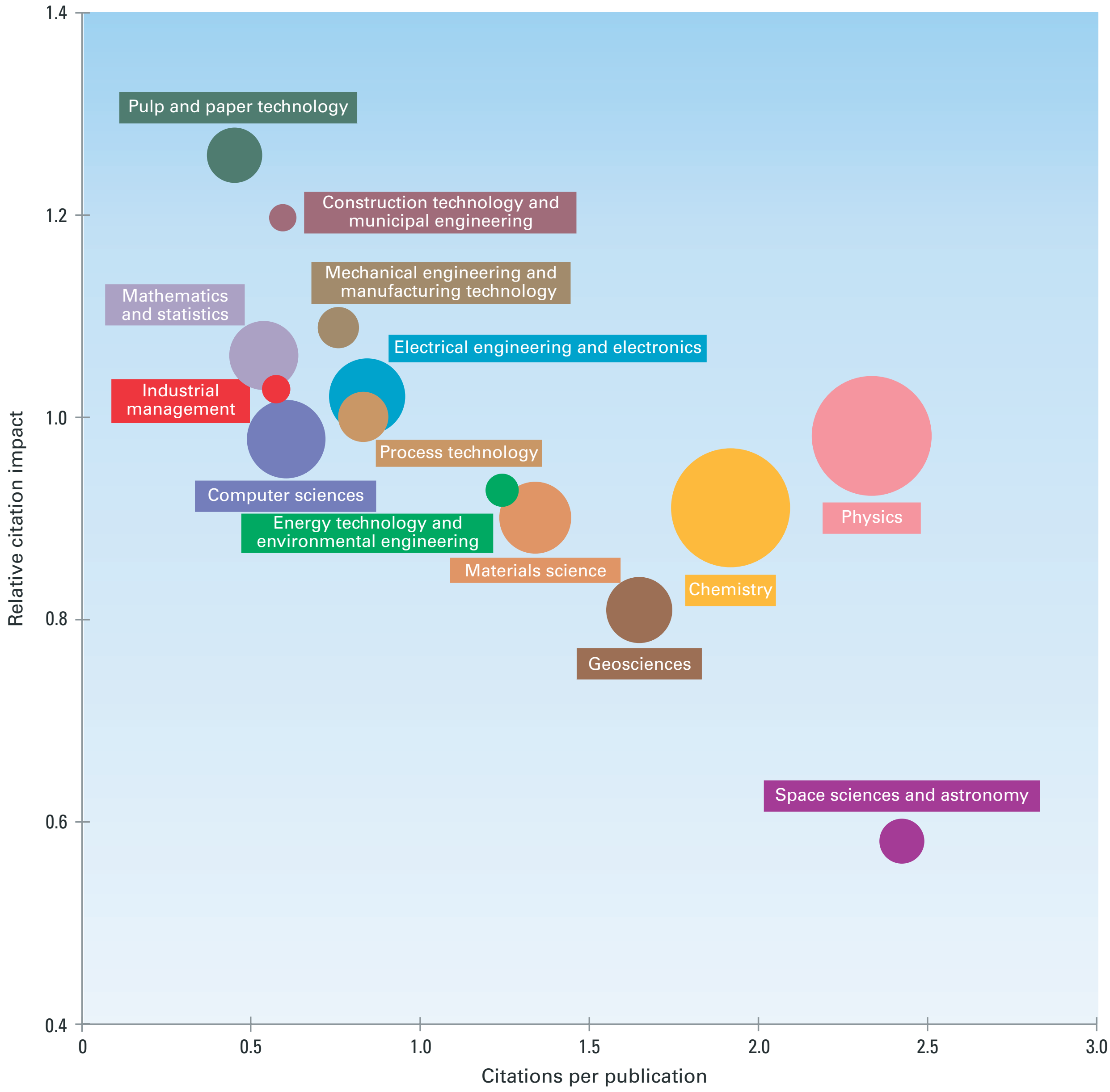


Industrial management



Appendix 3C. Publication and citation numbers in natural sciences and engineering fields

Source: Thomson Reuters Science Citation Index Expanded, Swedish Research Council 2009.



4 Health Research

Contents

1 Health Research: Current State, Quality and Development Needs

Research funding

The Research Council for Health has charge of research in the fields of biomedicine, veterinary medicine, dentistry, clinical medicine and pharmacy; and health sciences research in the fields of nursing science, public health, sport science, nutrition science and environmental and occupational health. This research is carried out at universities, university hospitals and a number of sectoral research institutes.

In 2006, the combined R&D expenditure for medical and health sciences and pharmaceuticals development in Finland came to 551.6 million euros (three-year average 2005–2007, Statistics Finland 2008). The higher education sector accounted for 47 per cent of this, the pharmaceuticals industry for 38 per cent and the public sector for 14 per cent.[1] However, pharmaceuticals development contributes no more than five per cent to total private sector R&D expenditure in Finland.

Each year, Finnish universities[2] invest 2,700 person-years in research in the field of medical and health sciences (three-year average 2004–2006, Auranen et al. 2008). This is 16 per cent of all research person-years contributed by Finnish

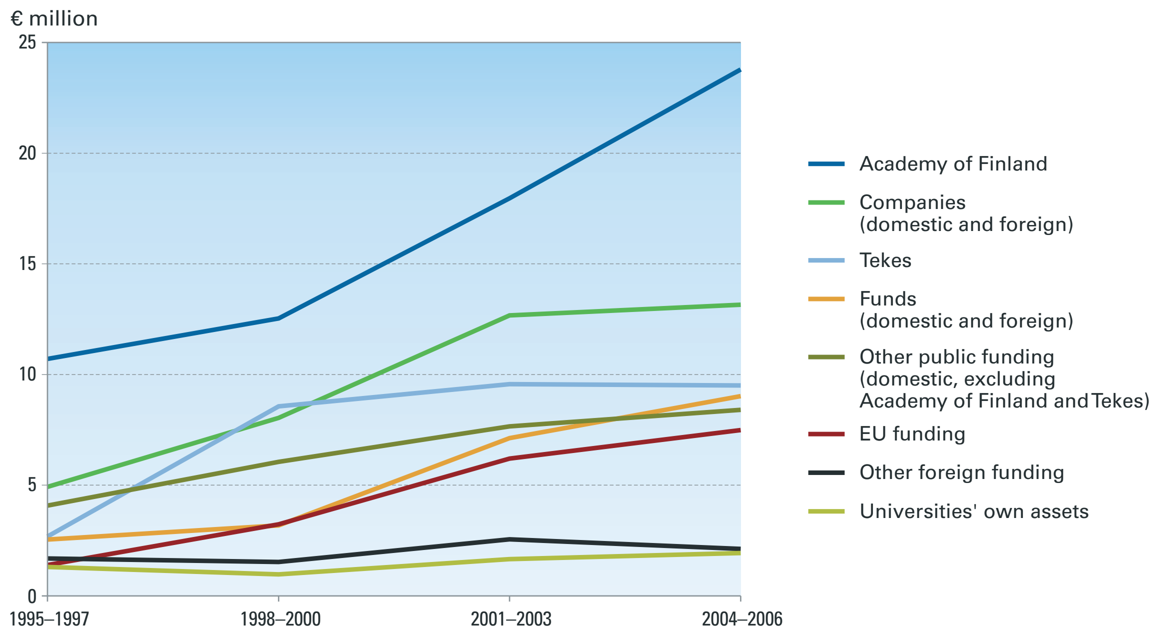


Figure 1. External funding for medical and health research at universities by source of funding from 1995–1997 to 2004–2006 (million euros*, three-year averages).
Sources: Statistics Finland; Unit for Science, Technology and Innovation (TaSTI), University of Tampere.

* Figures for university research expenditure are deflated by Statistics Finland public expenditures price index items describing changes in universities' costs (Auranen et al. 2008). The index base year is 2000. Personal grants from private foundations are not included in the statistics because they do not show up in universities' accounts.

1 The higher education sector comprises universities, university hospitals and polytechnics. Sectoral research institutes are part of the public sector.

2 Figures for person-years in medical and health research and for research expenditure at universities do not include university hospitals.

universities. Over the past decade, the number of research person-years in medical and health sciences has increased on average by 58 per cent. The sharpest increases over the period from 1995–1997 to 2004–2006 are recorded for nutrition science (309%), veterinary medicine (122%), biomedicine (102%) and pharmacy (98%).

In the mid-2000s, Finnish universities spent 146.9 million euros on medical and health sciences research (three-year average 2004–2006, Auranen et al. 2008). Since the mid-1990s, the absolute and relative amount of external funding has been increasing. In the mid-2000s, external funding for medical and health research amounted to 75.4 million euros, up 157 per cent from the figure roughly a decade earlier (Figure 1).

In the mid-1990s, external funding accounted for about one-third of overall research expenditure in medical and health sciences (see Figure in Appendix 1). This share has increased significantly: in the mid-2000s half of the money spent by universities on health research came from non-core budget sources. The Academy of Finland remains the most important source of external funding, although its share has fallen from the mid-1990s to the mid-2000s (Figure 2; see also the Table in Appendix 1 for a breakdown by fields). The relative contributions of the EU, Tekes and funds, on the other hand, have increased.

The level of external funding varies in different fields of medical and health research (see Figure in Appendix 1). In nutrition science, 70 per cent of research is funded from external sources, in dentistry, nursing science and sport sciences the share is around one-quarter. However, with the single exception of nursing science, the proportion of external funding has increased in all fields of medical and health research from 1995–1997 to 2004–2006.

Bibliometric analysis

Bibliometric indicators are one way of measuring the output and scientific impact of research. The quantity and quality of research are also assessed in international peer evaluations of university research and in discipline assessments by the Academy of Finland. In these and other evaluations bibliometrics provides a useful supportive tool. However, bibliometrics involves some methodological restrictions and therefore special attention must be paid to the interpretation of the results (see Appendix 2 of

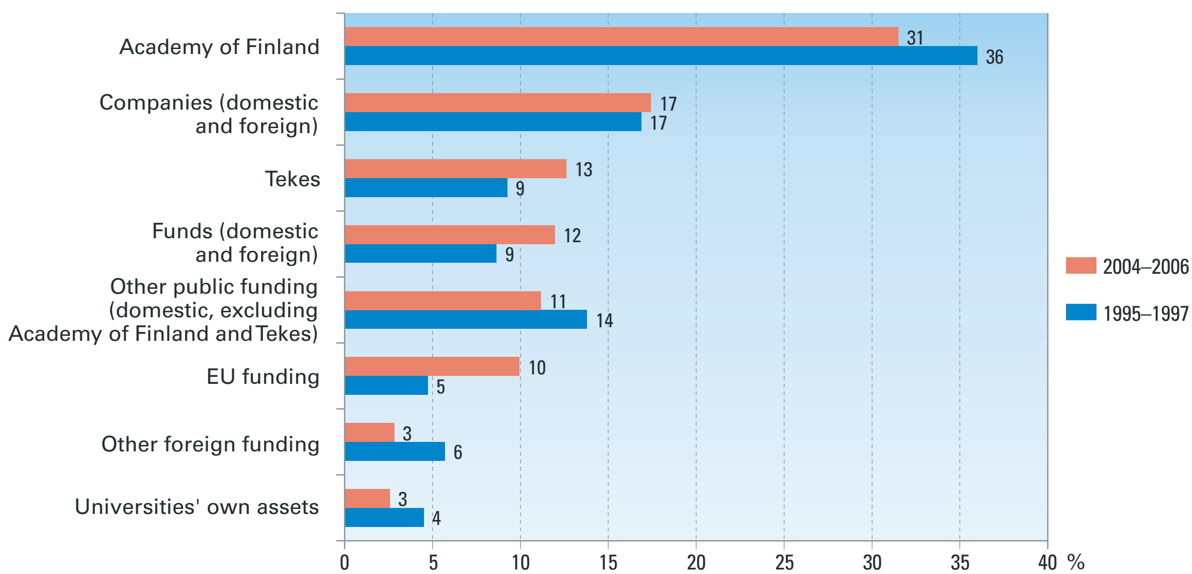


Figure 2. External funding for medical and health research at universities by source of funding (%) in 2004–2006 and 1995–1997. *Sources: Statistics Finland; Unit for Science, Technology and Innovation (TaSTI), University of Tampere.*

this report, which provides a detailed description of the bibliometric material and methods).

In 2008, more than 2,900 scientific articles were published in different fields of Finnish health research (Figure 3). In terms of **publication numbers** research classified under the heading of clinical medicine accounted for the largest share or 58 per cent. The figure for biosciences and biomedicine[3] was 30 per cent and for health sciences 12 per cent. An examination of the **share of publications** shows that during the 2000s, world publications in these fields have increased on average more sharply than

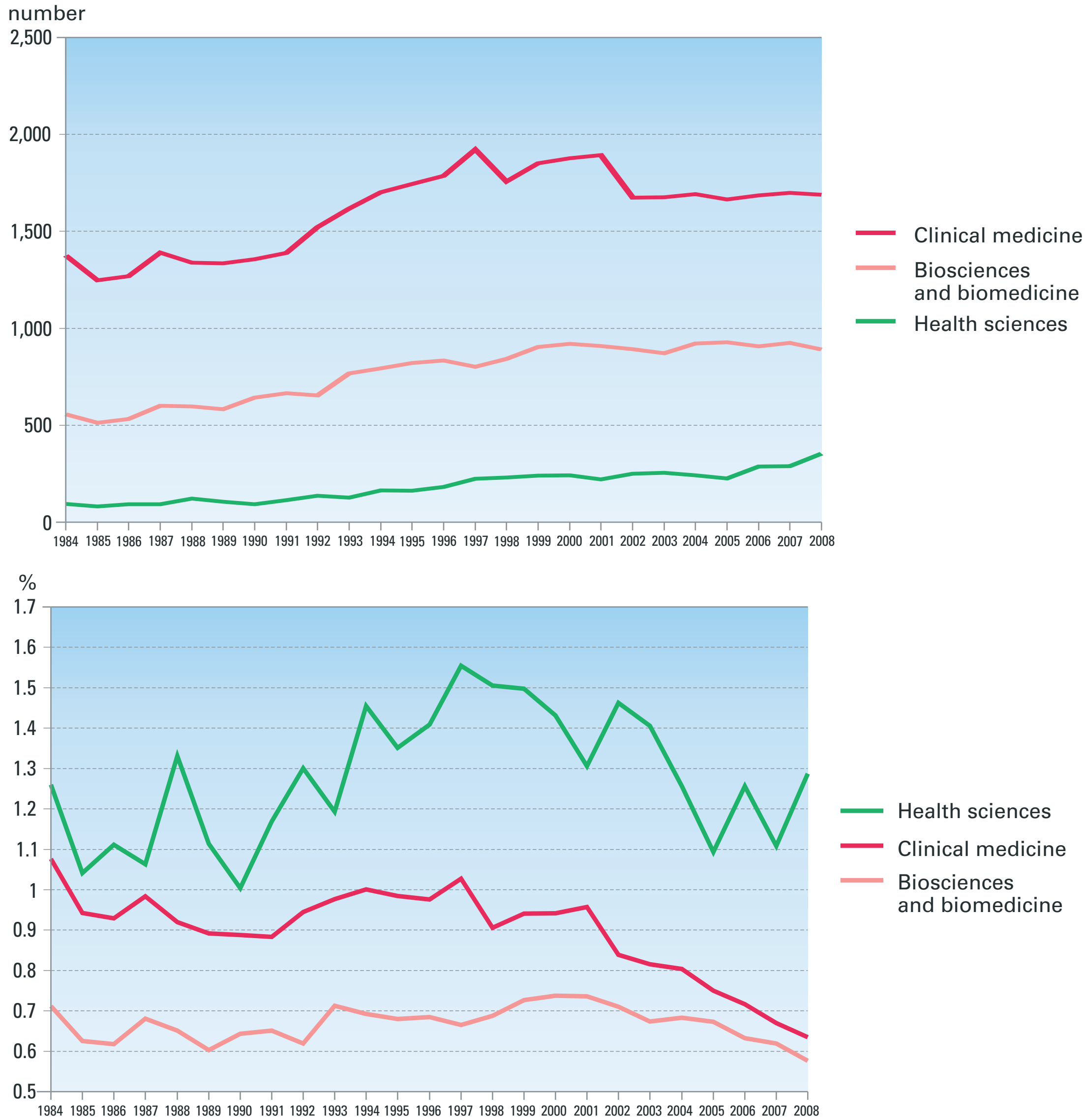


Figure 3. Research in biosciences and biomedicine, clinical medicine and health sciences: number of Finnish publications and percentage of world publications (%) in 1984–2008.
Source: Thomson Reuters Science Citation Index Expanded, Swedish Research Council 2009.*

3 The biosciences and biomedicine category comprises not only biomedical but also other basic research in biosciences.

in Finland (Figure 3). Finland's share of world publications has decreased, even though the number of publications in health sciences has increased, and in the biosciences and biomedicine remained unchanged from the level recorded in the early 2000s. In clinical medicine the number of publications declined most particularly in the early 2000s.

The relative citation impact provides a rough measure of the scientific impact and quality of research. Around the turn of the millennium, Finnish studies in clinical medicine received 20 per cent more citations (relative citation impact 1.20) than the world average (Figure 4). During 2005–2007, the number of citations received was 11 per cent higher than the world average. At the millennium, articles in health sciences received 25 per cent more citations than the world average. In the period from 2005 to 2007, Finnish publications received 10 per cent more citations than publications in this field on average. Finnish research in biosciences and biomedicine receives fewer citations than world research in these fields on average. In 2005–2007, the number of citations received was 9 per cent lower than in the world on average, which corresponds to the figures recorded in the late 1990s.

A useful analytical tool that complements the relative citation impact and the picture it paints of the quality of research is the proportion of publications produced within a certain field of research or country which rank among the **highly cited publications** in the world (Karlsson & Jonsson 2009). Citations are very unevenly distributed between different publications: only very few publications receive an exceptionally large number of citations, while the majority receive only few or no citations at all. The share of highly cited publications thus has a major effect on the country's average number of citations.

Half a per cent of the publications in Finnish biosciences and biomedicine ranked among the most-cited 1 per cent of publications in the world during 2005–2007 (Figure 5). When this analysis was extended to the most-cited 10 per cent of publications, Finland's share in the biosciences and

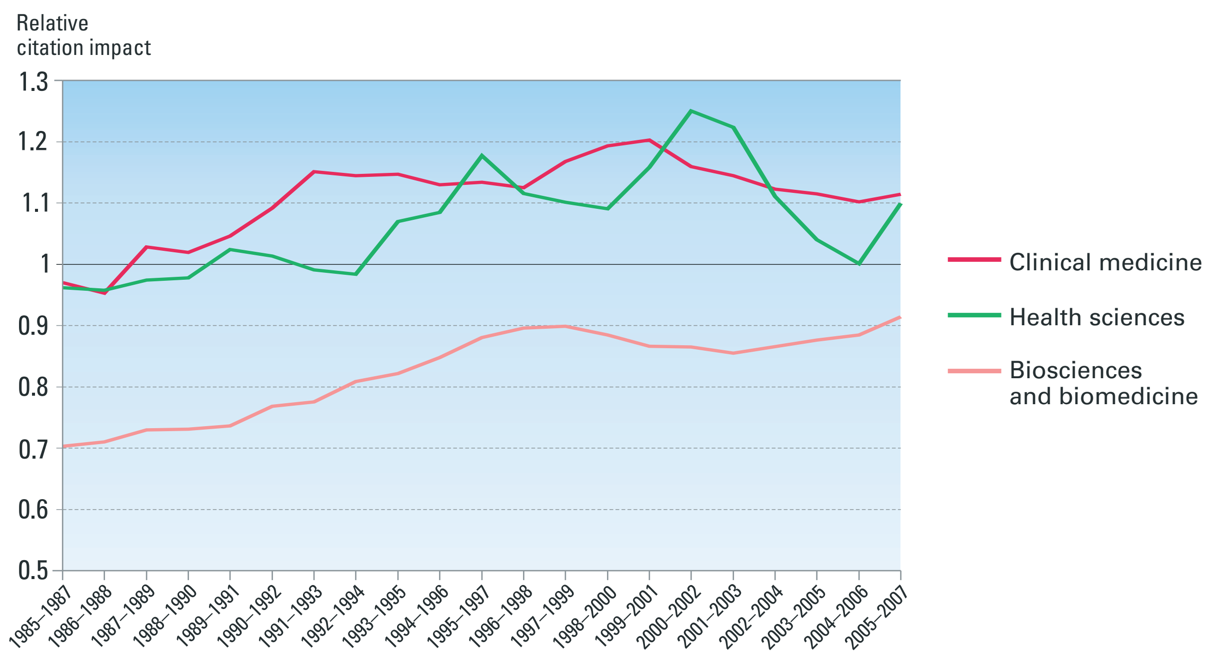


Figure 4. Finland's relative citation impact in the biosciences and biomedicine, clinical medicine and health sciences in 1985–2007 (moving three-year averages, world average citation impact is 1).
Source: Thomson Reuters Science Citation Index Expanded, Swedish Research Council 2009.

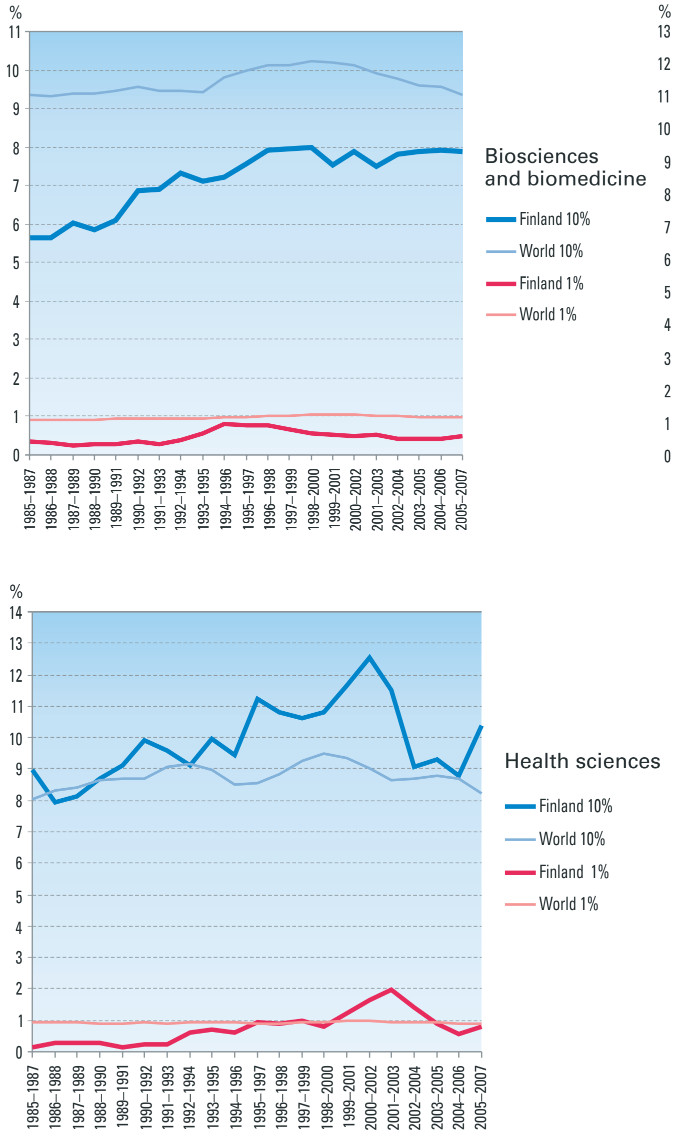


Figure 5. The percentages of Finland's highly cited publications in biosciences and biomedicine, clinical medicine and health sciences in 1985–2007 (moving three-year averages)*. *Source: Thomson Reuters Science Citation Index Expanded, Swedish Research Council 2009.*

* Finland's share of publications in this field of research indicates the proportion of Finnish publications that rank among the highly cited publications in the world. The Figures show the most-cited 10 per cent and 1 per cent of publications for the research fields in question.

biomedicine climbed to almost eight per cent in this same period.

In the field of clinical medicine, 1 per cent of Finnish publications ranked among the world's most-cited 1 per cent of publications in 2005–2007. Extending this analysis to the most-cited 10 per cent of publications, the figure for Finnish publications at 10.2 per cent exceeded the world share for the same period. This situation has remained the same since the late 1980s. The proportion was at its highest around the turn of the millennium, when almost 12 per cent of Finnish publications in the field of clinical medicine ranked among the most-cited 10 per cent of world publications.

In health sciences, 0.8 per cent of Finnish publications ranked among the most-cited 1 per cent of publications in the world in 2005–2007. In the same period, 10.4 per cent of Finnish publications in this field ranked among the most-cited 10 per cent of publications in health sciences. In these fields, too, the proportion of Finnish most-cited publications among the world's most-cited 10 per cent of publications has exceeded the world average almost consistently since the mid-1980s.

Biomedicine

Current state of the discipline 2008

Biomedical research is a large, broad-ranging and strong field in Finland. It comprises various points of intersection between clinical and basic research and serves as the frontline for translational medicine. Translational research processes and converts the knowledge produced by basic research into practical applications that benefit the patient.

Dedicated funding from the Ministry of Education and the establishment of biocentres at the universities in Helsinki, Kuopio, Oulu, Tampere and Turku have given a significant boost to the biomedicine field. Biocentres are high-profile, multidisciplinary research environments and major driving forces of development. They have strong infrastructures, including both high-level research facilities and centralised services, and their research staff add critical mass to the research environment. Biocentres also have a major role in researcher training and innovation, and they also play host to well-organised graduate schools in biomedicine.

Biomedical research is well funded in Finland, and Finnish scientists in this field have been highly competitive in international calls. The funding system is fragmented, however, which is a common structural problem in the Finnish research field. Development is often rather erratic because there are no guarantees of long-term funding and because interests tend to shift. All this combines to make the Finnish research environment quite unpredictable. Despite this, research in the field is of outstanding excellence and committed to long-term goals. Nevertheless, the threat remains that the best research talent may want to move out of the country in search of more secure research environments. The Academy of Finland should work to develop and establish long-term funding opportunities among other things by guaranteeing continued funding for the most successful projects after the termination of research programmes.

Even though basic research in Finland has many areas of strength, existing sources for research funding do not necessarily favour multidisciplinary research. The lack of resources means that it is extremely difficult for high-risk projects to secure funding in their early stages. A good example is provided by the translational stage of biomedical research which is aimed at drug formulation. Tekes (Finnish Funding Agency for Technology and Innovation) does not provide funding for early-stage applied research, nor are EVO grants available for this purpose (EVO grants are a form of state compensation payable to health care units for research and education purposes). The Academy of Finland should have better tools for promoting high-risk and innovative fields of research.

University budget funding is one of the most basic conditions for excellence in research. If teaching resources for undergraduate studies are inadequate and if student group sizes are too large, this will inevitably be reflected in leading-edge research, too. Any further reduction in university budget funding will undermine the base that has supported the growth and development of Finnish research over the past couple of decades.

Biomedicine makes a vital contribution to translational research. Its most important interface is with clinical medicine. The challenges associated with improving the cooperation between biomedical and clinical researchers mostly stem from the fact that in the current health care system, clinical work detracts from the time that could be spent on research.

Quality of research

The excellence of Finnish biomedicine is well illustrated by the large number of internationally cutting-edge research teams and Centres of Excellence in this field. However, the quality of research is very high across the board. Research teams in the field are by and large very well networked internationally.

Major areas of research strength in Finland include genome research, cancer and blood vessel biology, neurosciences, connective tissue research and cell biology, all of which have well established research traditions. These areas provide important support to translational research related to the most common diseases in Finland (i.e. cardiovascular diseases and diabetes). With the important advances that have been made over the past five years in sequencing the genome of humans and other organisms, the methods of genome research are now also applicable to studying various diseases. These new approaches that require expensive infrastructure are developing at breathtaking pace; a good example is provided by systems biology. The research challenge now is to determine the roles of genetic predisposition, the environment and lifestyle factors in the causation of different diseases. Another important future direction for research is diagnostics that enables personalised care.

Development needs

- Measures must be taken to secure the continuity and predictability and long-term research funding with a view to maintaining the international excellence of biomedicine.
- University budget funding must be established on a firm foundation to secure international excellence in research.
- Basic funding and investment must be secured for multidisciplinary biocentres and the necessary research infrastructures.
- Steps are needed to ensure the preservation of nationally valuable research materials and their best possible use.

Veterinary medicine

Current state of the discipline 2008

Research in veterinary medicine is a multidisciplinary exercise which comprises elements related to both animal and human health. The challenges faced by veterinary researchers are further amplified by the wide range of animal species covered, from production animals to pets. Veterinary medicine comprises the study of animal health and diseases as well as research and testing to determine food hygiene and microbiological safety. The approaches applied in studies of animal health and diseases are either specific to animal species or diseases, specific to disease mechanisms, epidemiological or behavioural. Veterinary science research is needed both in basic research and in applications-oriented research driven by specific needs in society.

Veterinary science research is conducted at two units, i.e. the Faculty of Veterinary Medicine at the University of Helsinki and the Finnish Food Safety Authority (Evira). Both these units are focused on two specific areas of research, i.e. food safety and human health and animal health and well-being. The units have fully up-to-date laboratory facilities as they are housed in buildings that are less than 10 years old. Veterinary science research at the Viikki Campus is a collaborative effort with several different university units, particularly with the Institute of Biotechnology.

Basic studies in veterinary medicine is a broad-based degree programme that provides a sound foundation for an academic career in research. Graduating PhDs have excellent employment prospects: there is strong demand for people graduating with a PhD in veterinary medicine not only in research but in other non-academic positions, too.

Research in this field and research funding have improved noticeably during the 2000s. At the same time, research has become more target-minded, and research team thinking has helped to make PhD education more systematic and also better supervised. The size of research teams varies to some extent, but they are predominantly small. A common structural problem for these teams is the absence of supervisors with research experience, leaving professors to carry the burden of supervision. Even though the share of complementary, competitive funding has increased, the development of research in this field has been hampered by a scarcity of resources. There are some differences in how individual research teams have adopted the team culture as well as in the level of their research funding. The Faculty of Veterinary Medicine at the University of Helsinki is home to a national Centre of Excellence in Research funded by the Academy of Finland and it has one FiDiPro professor. A few PhD students in veterinary science are funded through the Applied Bioscience Graduate School or through dedicated university funds. Doctoral education programmes in clinical fields will have a more solid foundation as of 2010 when the Graduate School of Animal Wellbeing is launched in response to the Academy's recommendations. Furthermore, steps are needed to encourage international engagement among researchers in this field. At the postdoctoral stage in particular, researchers now are increasingly inclined to stay at home.

Quality of research

A recent evaluation of veterinary science research in Finland rated this as a high-quality and competitive field (Haila, Holm & Niemelä 2006). However, resources in this field are scarce, which is going to make it difficult to maintain the diversity of research in this field. Increased cooperation with experts in such fields as molecular biology, genetics and genomics has contributed to enhance the quality of research. In particular, research related to food safety and various areas of clinical veterinary research, such as studies of animal diseases, genetics, infectious diseases and reproduction disorders, are highly advanced and competitive.

Development needs

- For the time being, veterinary science research in Finland consists mainly of doctoral thesis research, which means that high-risk subjects are unlikely to appear on the research agenda. There is marked variation in the level of research teams in different areas of veterinary science. The quality and internationalisation of research are priority areas of development.
- Budget funding for the Faculty of Veterinary Medicine at the University of Helsinki has been inadequate for a long time now, which is reflected in the resources available for research. There is a need to target research to key strategic areas and to secure increased long-term funding.
- Research equipment is in need of updating and replacement because the Faculty has not had the resources to do this for some years. Guarantees of regular and predictable funding are needed for the research infrastructure.
- Steps are needed to make a professional career in research a more attractive career option. In particular, measures are needed to get young veterinarians interested in research and to choose veterinary research as a life career. The academic research career must be made more predictable, giving special attention to researchers at the postdoctoral level.
- In the field of clinical research special consideration must be given to how clinician-researchers can be encouraged to pursue doctoral thesis research in clinical fields, to remain in research and to develop clinical research.
- Measures are needed to promote the internationalisation of postdoctoral researchers and to encourage them to spend periods at research institutes abroad.

Dentistry

Current state of the discipline 2008

Dentistry research is conducted at the universities of Helsinki, Oulu and Turku; at the dental and oral surgery units at the corresponding university central hospitals; at the Institute of Biotechnology in Viikki; at the Regea Institute for Regenerative Medicine based at the University of Tampere; and finally at the Kuopio University Hospital.

Research funding comes primarily from regular allocations to university departments and EVO grants; some research teams have Academy-funded research posts and grants from the Academy and Tekes. The Academy's Research Council for Health has acknowledged this situation and in 2008–2009 allocated 2.3 million euros for purposes of encouraging and promoting high-level dentistry research in Finland.

At university and departmental level there is only limited international networking and cooperation; any contacts that do exist are almost entirely those of individual researchers or research teams. Among dentistry PhD students, however, the proportion of Finnish dentists has been falling, with increasing numbers admitted from Eastern Europe, Asian and Arab countries, South America and Africa. On completion of their doctoral thesis, however, the majority of these young foreign researchers have moved back home, or taken up postdoctoral positions in other countries. Increasing numbers of Finnish biochemists, biologists and statisticians have been recruited into dentistry research teams. The number of Finnish dentists moving out of the country to take up postdoctoral positions elsewhere has been falling in recent years. The most common destinations for those who are still leaving are North America and EU countries.

Most research teams are small in size, and with the reorganisation of basic clinical studies all dentistry departments have seen a cut in the number of lower academic posts. In 2000–2003, responsibility for the provision of basic clinical training was transferred to primary health centres. A few PhD students have been researching their theses at local graduate schools in Helsinki and Turku, and at the national clinical graduate school in Helsinki and Oulu. Most PhD students in dentistry engage in research on a part-time basis, and their funding is through grants. Some foreign researchers are funded through the Centre for International Mobility (CIMO), others are hired with local EVO and departmental grants. Earlier attempts to create a national graduate school in dentistry have failed, but the situation is changing in 2010 with the launch of the Finnish Graduate School of Oral Sciences.

Quality of research

Dentistry research in Finland is of a high quality, to some extent of international excellence (Academy of Finland 2007). In particular, development biology research focused on the head and facial area at the Institute of Biotechnology has established a strong international reputation. Another noteworthy strength is that research covers all aspects of dentistry, which means that the field is well placed to produce future experts for all those areas. It is considered a weakness of the dentistry field that all the high-level work is produced by a select few researchers: the evaluation report mentioned just five research teams by name (two from Helsinki and Turku and one from Oulu). The strength of all these five high-level research teams lies in their multidisciplinary or interdisciplinary orientation: research in four of these teams is based on cooperation with biochemistry, molecular biology and biomedicine research teams, in one case (materials research) on cooperation with industrial and commercial partners and thereby on funding secured through Tekes.

Development needs

- Closer attention needs to be paid to the continuity and predictability of long-term research funding, especially with the discontinuation of Tekes funding for materials research.
- Steps are needed to enhance the quality of dentistry research by improving national and international PhD programmes and by targeting funding to young researchers. As recommended, the Academy will provide funding from the beginning of 2010 for the Graduate School of Oral Sciences and its nine student places. In this connection every effort must be made to maximise opportunities for national and international networking: closer cooperation would certainly be conducive to enhancing the quality of research.
- There is no apparent solution in sight to the difficulty of recruiting young dentistry researchers, which is currently the biggest development and continuity problem in this field. Working closely with universities, the Ministry of Education and the Ministry of Social Affairs and Health, the Academy must take urgent steps to find national solutions to the problems that continue to beset this field. These problems include the low pay of PhD students compared to clinical dentists, the scarcity of resources available for research posts and research work, the low importance accorded to the doctoral thesis in screening candidates for professional posts, and the lack of continuity in the academic research career.
- Opportunities to recruit talented foreign dentists in Finland should be improved by allocating earmarked development cooperation funds for this purpose, as in the Norwegian model. This has clearly helped to increase the volume and enhance the quality of dentistry research in Norway.

Clinical research

Current state of the discipline 2008

Clinical medical research is concerned with the causes, diagnosis, prevention and treatment of diseases in humans. Another aspect of modern clinical research is translational research, which builds bridges between clinical questions and up-to-date laboratory methods, for example.

For future needs it is increasingly important that in addition to basic researchers, we have a contingent of clinical scientists who can say which aspects of disease pathophysiology should be targeted in treatment, which tissues should be targeted, what kind of treatment response is clinically significant, what kind of treatment is ethically justified, what kinds of side effects there may be in a certain treatment, how those side effects are treated, etc. Evidence-based medicine requires that the effectiveness of new treatments is demonstrated in clinical experiments. The Finnish population and health care system provide an excellent framework within which to conduct large-scale clinical trials of medical treatments, but this requires that there is a sufficient number of doctors with a clinical researcher training.

The post-genomic era will increase the demand for high-level clinical research. In order to unravel the causes of multifactorial public health problems and to identify methods of treatment and prevention, basic researchers must work closely with both clinical scientists and epidemiologists. The clinical scientist's most important contribution in this collaboration is the exact determination of phenotypes. In the last instance, the significance and quality of this kind of research depends on the accuracy of phenotype characterisation. The individual tailoring of treatment presents new challenges for clinical research. Regenerative medicine will bring along new alternative treatments, but it is imperative that they are extensively trialled and evaluated before they are put to widespread clinical use.

However, there are a number of obstacles to expanding and developing high-quality clinical research. From 2000 to 2008, central government investment in clinical research has fallen sharply (Figure 6): state EVO grants for research conducted at university hospitals have declined in real terms by 34.4 per cent (Science and Technology Policy Council of Finland 2008). In 2008, EVO research grants accounted for no more than 2.7 per cent (48.7 million euros) of total central government research funding. This decline has not been offset by additional funding from other sources. At the same time, the role of university hospitals as a major centre of high-quality clinical research has declined markedly. This is no longer a priority concern for municipally-owned university hospitals, and has not been one for a long time.

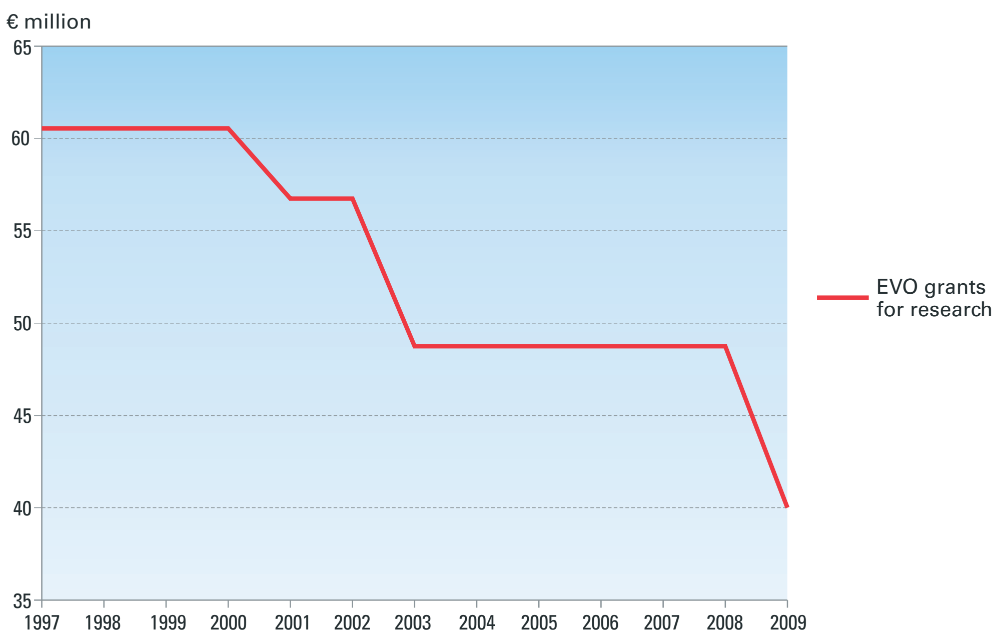


Figure 6. EVO grants for research* in 1997–2008 (guaranteed allocation for 2009).
Source: Ministry of Social Affairs and Health 2009.

* Special state subsidies for research conducted at university hospitals.

Clinical research teams in Finland are predominantly quite small, consisting typically of a team leader and a few doctoral thesis writers. The bulk of clinical research is conducted as part of doctoral thesis projects; work by postdoctoral and more senior researchers accounts for only a relatively minor part of research. Even in university hospitals it is impossible for senior physicians to find the time in their daily schedule to engage in research; if they do have any research interests, they need to find the necessary time outside normal working hours. The growth of bureaucracy around research has become a major deterrent for the launch of new research projects. The clinical researcher's career is fraught with uncertainty, and for the time being there are no positions in the hospital system that would flexibly combine clinical and scientific work. The economic incentives for doing research are virtually non-existent in Finland. For the medical doctor, engaging in clinical research almost invariably means taking a pay cut.

Quality of research

Clinical research is traditionally one of the key areas of strength in Finnish science. Unless decisive action is taken, the outlook for the future appears much bleaker. International competition in the clinical research field is continuing to intensify, and the first signs are already emerging that clinical research in Finland is beginning to fall behind. The relative citation impact of Finnish publications in the field of clinical medicine increased sharply from the early 1980s to the turn of the millennium, but during the 2000s these trends have been reversed: in 2005 the relative citation impact was at the same level as in the early 1990s (Karlsson & Jonsson 2009).

Bibliometric indicators confirm that clinical research in Finland continues to remain of international excellence. Finnish publications receive more citations than world publications on average (Karlsson & Jonsson 2009). In some fields Finnish clinical research is at the very cutting edge internationally; examples include research on cardiovascular diseases and diabetes, neurological research and imaging studies. Clinical research in Finland has some clear competitive advantages. A high level of education, an efficient public health care system, extensive register databases and favourable attitudes towards medical research provide a strong platform for improving the quality of clinical research.

Development needs

- Clinical research teams must be encouraged to set increasingly ambitious targets for themselves. Academy funding for clinical research must be targeted in such a way that it supports this objective.
- Central government investment in clinical research must be increased: other leading clinical research nations have already done that, or have plans in place to do so in the next few years.
- The Academy must commit itself to supporting the development of the National Graduate School of Clinical Investigation.
- The Academy must establish on a permanent basis its funding mechanisms for clinical researchers.
- A clear career track must be established for clinical researchers.
- The size of clinical research teams must be increased and support for intermediate level researchers in particular must be stepped up. It is also necessary to create support mechanisms that allow trained clinicians to participate in research, for instance while they are in specialisation training. Postdoctoral researchers must be recruited into clinical research teams.
- Clear incentives must be created for clinical research at university hospitals.
- Part of the increased input shall be allocated to creating new posts at university hospitals that allow for the flexible integration of research with clinical work. The share of research could range from 30 to 50 per cent.
- Measures are needed to strengthen the leading role of university hospitals as a clinical research site. This may require that the state claims ownership of university hospitals so that their research environments can be made more attractive.
- A centre for clinical research should be established in every university hospital, providing clinical researchers with the full range

of services they require. For researcher-driven clinical trials, a national or Nordic coordination centre needs to be created that provides, at cost price, the services, databases and statistical analyses required by clinical trials. This will allow researchers to concentrate on their own job, i.e. research.

Pharmacy

Current state of the discipline 2008

The discipline of pharmacy is committed to promoting scientific research into pharmaceutical substances and drugs, pharmaceutical care, the manufacture of pharmaceuticals and the development of pharmaceutical drugs and products. The research field covered by the discipline overlaps in large part with medicinal research. The latter includes computer aided modelling, the screening of bioactive compounds, the biotechnical and synthetic production of medical substances, and analytical know-how. The mission of pharmacy is to develop physically and biologically usable forms for pharmaceutical substances as well as the technologies needed for their manufacture. Other important research areas are to study the pharmacological, toxicological and therapeutic properties of medical drugs and to explore the social meanings of drugs. Pharmacy research favours a multidisciplinary approach in which problems are mainly addressed and analysed from the vantage point of applied natural sciences, but also from that of medical sciences, health sciences and social sciences. Indeed, the discipline can be described as an interdisciplinary microcosm.

Pharmacy is a broad and extensive field of research. In Finland, the first doctoral thesis in pharmacy was published in 1962 by Elna Nieminen. Over the past 25 years the field has continued to develop strongly, despite its expansiveness. In recent years, Tekes technology programmes, and the Drug 2000 programme in particular, have been highly instrumental in promoting the development of this field. Pharmacy provides high-level, research-based training programmes leading to the degrees of assistant pharmacist and pharmacist as well as postgraduate studies at two universities (Helsinki and Kuopio); programmes leading to the degree of pharmacist are also organised in the Swedish language at Åbo Akademi University. The universities in Helsinki and Kuopio also host separate drug research centres. The pharmacy field is well networked in Finland.

Established in 1998, the Graduate School in Pharmaceutical Research is a national graduate school run jointly by the universities of Helsinki and Kuopio. It represents an important additional resource for doctoral education in the pharmaceutical field, even though the number of student places is limited. Employment prospects in this field are excellent. All the young PhD graduates from the graduate school are well-equipped with the skills they will need in pharmaceuticals research, product development, monitoring and distribution. The graduate school is part of the FinPharmaNet network of graduate schools.

There is only a limited number of academic researchers in the pharmacy field. It is therefore quite vulnerable and dependent on the input of a few key personalities. Pharmacy PhDs in Finland have high employment rates, both within academia and industry. Pharmacists are well paid, and therefore researchers who choose to pursue an academic career feel they are in a vulnerable position. However, pharmacy could be applied more effectively in other fields of research, too, allowing for the growth of the necessary critical research mass.

The Tekes technology programme Drug 2000 ended in 2006. The funding of pharmaceuticals research has now reached a crossroads. At present, Tekes is primarily interested to finance research with the greatest potential for the fastest applications. On the other hand, the good level of Tekes funding has made researchers somewhat inactive in applying for new funding. Researchers in this field have had reasonably good success with their applications for EU funding, whereas funding from the Academy has been at a lower level, although rising.

Quality of research

The main areas of focus in the development of pharmacy are the integration of scientific and practical knowledge and the promotion of research-based education, which also serves as an important channel for recruiting doctoral students. Drug research centres have also attracted some foreign researchers into Finland. Research in the field is of high and to some extent very high international excellence: this assessment is based on international evaluations of university research during the 2000s (Haila, Holm & Niemelä 2006; Pellinen, Liikanen & Kalliokoski 2008), and confirmed by the results of citation analyses. Research into new drug-dispensing technologies (biotechnological drugs, genetic drugs) and new methods of administration is at a reasonably high level internationally. ADMET studies (absorption, distribution, metabolism, excretion, toxicology) enjoy international recognition. PAT (process analytical technology) and material studies are of high international standard. Research in the field of pharmaceutical chemistry is gathering momentum. Finland is a very strong player in the fields of pharmacognosy, (pharmaceutical) pharmacology and social pharmacy.

Since the number of researchers in this field is relatively low compared to its size, pharmacy has been unable to invest adequate research resources into such areas as the pharmacodynamics and pharmacokinetics of medical drugs for older people and children. Pharmacy should also have a more prominent role in studying the social impacts of medical drug treatments, for instance through the field of pharmacoeconomics.

Development needs

- A Nordic or even European assessment of pharmacy would be beneficial in providing a peer evaluation of this field's current performance in an international comparison. Pharmacy units have been evaluated on a number of occasions, but there are only two of those units in the whole country.
- Pharmacy researchers should be encouraged to participate in different national and international organisations and in organising international scientific meetings in order to increase the visibility and impact of this field.
- It is important that the funding base for pharmacy is expanded and that better use is made of EU funding.
- Cooperation between pharmacy and biomedicine should be stepped up at the translational stage of pharmaceuticals development with a view to facilitating progress to clinical studies. This would be easier if funding could be secured for one larger, multidisciplinary project from one domestic source.
- Further efforts are needed to develop and improve the postdoctoral system.
- Collaboration between social pharmacy and public health research should be stepped up.

Nursing science

Current state of the discipline 2008

In Finland nursing science developed into an independent line of research inquiry in the early 1980s. Now, nursing research is done at five university nursing departments and also in connection with the primary health care system. In 2003, the Academy conducted a discipline assessment of the discipline (Academy of Finland 2003a). It concluded that the field had managed to develop quite a versatile research structure within a short space of time. All nursing departments have growing research teams, doctoral programmes are nationally organised and international contacts are developing strongly. In 2005, the Academy's Research Council for Health allocated 600,000 euros in dedicated funding to nursing research. The evaluation of this research effort will be carried out in 2010.

Quality of research

According to the 2003 discipline assessment, a number of strong research teams are evolving in the field of nursing research. However, there still remain areas where there is a need for more senior researchers. These include mental health and gerontological nursing science.

The outlook for PhD education in the nursing science field is very positive in that PhD graduates have no difficulty finding employment. The main challenges for nursing science are related to the country's health care system and to enhancing cooperation within our research system.

Development needs

- For a young discipline such as nursing science, it is crucial that the number of graduates from doctoral programmes is high enough so that there is enough senior research staff to tackle key areas of national research.
- Measures are needed to further strengthen and develop the national graduate school.
- Nursing research depends crucially on clinical research and on the ability of the health care system to work closely with the research system. Further efforts are needed to strengthen existing national networks and to try and establish closer ties of cooperation with the Nordic and European research community.

Public health science

Current state of the discipline 2008

Finnish research in the public health field is internationally highly competitive. Its results have immediate social relevance, and the practices developed through research produce immediate health benefits. Public health research is funded not only by the Academy, but also through European research programmes and from the United States. Innovations in this field do not necessarily have commercial potential, and therefore funding from both Tekes (Finnish Funding Agency for Technology and Innovation) and Sitra (Finnish Innovation Fund) has remained insignificant. The same goes for EVO grants, and even the major end-users of public health research, such as the Ministry of Social Affairs and Health and the Association of Finnish Local and Regional Authorities, have provided only limited funding. For these reasons public health research is more dependent on Academy funding than many other fields of health research.

There is one graduate school in the public health field, which covers two universities and government research institutes. Public health subjects are also included in the curricula of the Graduate School in Environmental Health and the Graduate School in Social and Health Administration. Finland enjoys a high international reputation in this field, which has helped to attract some foreign researchers into the country. If senior researchers could be coaxed to work in Finland, that would help to boost research even more.

Quality of research

There are several internationally cutting-edge research teams in Finland that conduct epidemiological research focusing on the most common diseases in Finland. Population-level interventions are one important area of strength. Another area that has enjoyed good success is genetic epidemiology. Clinical epidemiology is still in its infancy in Finland, despite the strength of the tradition of intervention studies.

Finland should be well placed to conduct health care research and health economics studies, but despite recent advances this field still remains some distance from the international cutting edge. There is a scarcity of research on primary health care provision, and that is an area that needs to be developed. Research into the health and functional capacity of older people is continuing to gain in importance, and there are some high-level research teams in that field. Medical research on the causes of children's diseases is also of international excellence. There are a few high-level research teams in Finland that apply behavioural and social science approaches to studying public health issues. Changing people's health behaviour is an important area of current research interest. It is also an area that warrants further development because there has been a worrying growth of some well-known risk behaviours of late (e.g. lack of exercise, unhealthy diet, alcohol consumption and smoking).

Development needs

- Response rates in questionnaire and interview studies are traditionally very high in Finland, but are now falling. For public health research the problem lies in the Finnish interpretation of the ethical guidelines of research, according to which no payment can be made for participation in questionnaire studies. Several other countries allow for such payment in the case of studies that involve no risks.
- Public health research is often conducted at the intersection between different Research Councils,

for there are good experiences of cooperation between health sciences, behavioural sciences and social sciences. It is therefore important that in its review processes, the Academy continues to identify and encourage multidisciplinary and interdisciplinary research.

Sport science

Current state of the discipline in 2008

The main locus of Finnish research in the field of sport science is the Faculty of Sport and Health Sciences at the University of Jyväskylä. Research in sports medicine and sports physiology is additionally conducted at five sports medicine units that are supported by the Ministry of Education (Helsinki, Kuopio, Tampere, Turku and Oulu). Furthermore, research into the health effects of physical exercise is carried out at faculties of medicine and at some sectoral research institutes. The main areas of research interest in this field are the health effects of physical exercise, the biology of physical activity, sport sociology and physical education. The Research Council for Health has decided to commission a discipline assessment of sport science in 2010.

Quality of research

The 2005 evaluation of research at the University of Jyväskylä concluded that research in the fields of health science and the biology of physical activity is of a relatively high standard internationally. (University of Jyväskylä 2005). In recent years, medical faculties have conducted some highly valuable research on the health effects of physical exercise; examples include studies on how physical activity can help to prevent obesity and type 2 diabetes. With just a few exceptions, sport science research associated with social sciences and physical education has remained a national exercise.

Development needs

- The biggest future challenges for research in sport science have to do with the health effects of physical exercise and most particularly with research that helps to support interventions in health-promoting exercise among children and young people. Apart from health science and sports biology research, this will require a strong input from research in the fields of sport sociology and physical education.
- Another major challenge is presented by the development of various forms of health-sustaining physical exercise that people can adopt as part of their everyday life. In this case the integration of technological development needs and sound basic research in sport science could open up new opportunities to improve people's physical exercise habits and to create new high-tech jobs. One of the hardest challenges of all is to develop methods that genuinely measure the individual and social impacts of physical exercise.
- Responsibility for the conduct of basic research in the field of sport science currently rests with the Academy of Finland and the Ministry of Education's Sports Division. In the future, it is necessary to take a critical look at the advantages and drawbacks of this two-prongled system: this should most ideally be done in the context of a broad-based working group including representatives of both research and sports. This group should be charged with assessing the current state of research into the health and social effects of sport and physical exercise and develop a concrete plan on how to enhance the impacts of research.

Nutrition science

Current state of the discipline 2008

Nutrition science is taught as a major subject at two universities in Finland, i.e. the University of Helsinki and the University of Kuopio. In addition, nutrition science research is conducted at the University of Turku Functional Food Forum and at sectoral research institutes (e.g. the National Institute for Health and Welfare and the Finnish Institute of Occupational Health). Nutrition research is grounded in physiology, biochemistry, clinical research, public health research, molecular biology and food sciences. It also applies the approaches of behavioural sciences, social sciences and economics. In other words, the methods of nutrition research span from molecular medicine, biochemistry and metabolic research through clinical interventions and epidemiological studies to consumer studies and health economics.

One of the key objectives of nutrition research is to maintain the individual's and the population's health and to prevent and treat illnesses by means of nutrition. Although this is a small discipline, comprising no more than four professorships and a few lecturers at the universities of Helsinki and Kuopio, the increased availability of external funding has made possible the growth of nutrition research and allowed for the recruitment of increasing numbers of researchers in the field. Nutrition science does not have its own graduate school, but postgraduate students have been able to apply for doctoral student positions at the Applied Bioscience Graduate School or in Doctoral Programmes in Public Health – DPPH. Each year there are 5–10 new PhD graduates.

Quality of research

The Academy of Finland has conducted an assessment of nutrition science that covered the period from 2000 to 2004 (Academy of Finland 2006). In addition, the Clinical Nutrition Unit was evaluated in connection with the international assessment of research at the University of Kuopio in 2000–2006 (Pellinen, Liikanen & Kalliokoski 2008). Both these assessments concluded that the level of nutrition research is high and internationally competitive, and it was furthermore observed that the results of nutrition research had contributed to the development of nutrition recommendations in different countries. The assessments also drew attention to major population interventions, which have produced an abundance of information about reducing the risk of chronic diseases by means of nutrition. Finnish nutrition research was described as an innovative pioneer whose results have contributed significantly to the development of health promoting food products. Research into nutrition behaviour and the regulation of appetite was also rated very highly.

Research institutes have strong publishing activity, with publications often appearing in prestigious international journals. Nutrition research is involved in one Academy of Finland Centre of Excellence and two Nordic Centres of Excellence in Food, Nutrition and Health. Research teams are well networked both nationally and internationally. Furthermore, they have close cooperation with industry and work actively to put new research results and new knowledge to practical use in care practices and nutrition recommendations.

Development needs

- Nutrition research suffers from a scarcity of core budget funding: given their high level of teaching responsibilities, faculties do not have enough resources to engage in research. Other problems include a lack of research positions, shortcomings in research infrastructures, and the low mobility of PhD students and postdoctoral researchers in particular. Lack of international PhD education and experience from different research communities is not just a problem for postdoctoral researchers, but the same applies to senior nutrition researchers.
- In order to ensure a sufficient level of long-term funding for nutrition research it is necessary for all the funding bodies, including the food and the pharmaceuticals industry, to engage in honest dialogue. This will allow for serious testing of basic research observations in the context of clinical interventions, which in turn will pave the way to developing commercially viable products out of the most promising results of nutrition research for the maintenance and improvement of health.

Environmental health and occupational health

Current state of the disciplines 2008

Environmental health research is a relatively young field, but nonetheless one that has made a significant contribution over the forty or so years it has been conducted in Finland. Its main interests lie in the interactions between the environment and health, and its mission is to produce knowledge that can help maintain and improve the mental, physical and social health of both individuals and the population at large. Research is often concerned with minor shifts and changes that lead to phenomena with adverse health effects. In the health context, the 'environment' is defined as referring to everything outside the individual.

Environmental health research is interdisciplinary and multidisciplinary. With the profound global and local changes that are now taking place in our environment, it is currently in great demand. The research questions addressed in the field of environmental health research are often international in nature. The relationships between the environment and health are examined from a variety of different angles, over different time-spans and using different approaches. Another characteristic of research in this field is that while a particular contributing discipline may be highly advanced, the practical application of the knowledge it has produced to environmental issues might still be in its infancy.

Research in occupational health constitutes an independent line of inquiry in the broad and diverse field of environmental health research. Health and functional capacity are the most important conditions for working ability. The Finnish population of working age currently numbers around 2.5 million, the figure for the European Union is approximately 260 million. Research in occupational health, and preventive and health-promoting measures in particular, therefore has significant social impact.

Research in environmental health and occupational health is conducted at several universities around the country, but research traditions in these fields are particularly strong at sectoral research institutes. Environmental health researchers are very well networked both nationally and internationally, and there is much research cooperation.

Doctoral programmes in the environmental health field are provided among others through the Graduate School in Environmental Health, Doctoral Programmes in Public Health (DPPH) and the Finnish Graduate School in Toxicology. Some researcher training is provided in research teams that are not formally part of the Ministry of Education funded graduate school system. Doctoral education in occupational health is primarily organised in the context of research teams. Many of the PhD students are enrolled in DPPH, in the National Graduate School of Musculoskeletal Disorders and Biomaterials, or the Graduate School in Environmental Health. There is also a dedicated graduate school for occupational health physicians, but that has so far not been integrated as part of the Ministry of Education graduate school system.

Quality of research

Environmental health

Finnish research in the environmental health field has many areas of strength. This is reflected among other things in the EU funding received by Finnish researchers and in the large number of expert assignments they hold within the EU and the WHO. There is strong research expertise in the adverse health effects of various physical, chemical and biological factors. In particular, Finnish environmental health research concerned with the health-related risks of chemicals is at the international cutting edge. Finnish environmental health research on exposure and exposure routes is also of a high standard and enjoys international recognition.

Major population surveys that approach environmental health from a disease perspective represent one significant area of study in the environmental health field. Another focus is on mechanisms of impact, where environmental health research draws on the methods of modern biomedicine. Research focusing on health-promoting factors is still largely in its early stages, although studies on the health-promoting effects of dietary habits and factors have already made some substantial headway.

Research in the fields of environmental health and occupational health has begun to take advantage of the skills and knowledge built up in Finnish gene research. The rapid accumulation of genetic information coupled with extensive register data provides an excellent opportunity to study the interactions between the human genome and environmental factors. Cultural factors have so far received only scant attention in environmental health research.

One of the principal areas of strength in environmental health research is the line of inquiry concerned with the health effects of air pollution. For example, there is a strong research tradition that focuses on the impacts of fine particles on cardiovascular and respiratory disease morbidity and mortality. Much work has also been done to shed light on the health hazards of exposure to indoor mildew and mould spores. Furthermore, exposure to biological and chemical factors through household water and to ionizing radiation has been widely and successfully studied from an environmental health point of view. Another important area of study focuses on exposure through nutrition and the assessment of related health risks. Studies concerned with land and water areas contaminated by various emissions are another important line of inquiry in Finnish environmental health research. There is strong research into ionizing and non-ionizing radiation, and the results are widely disseminated for use in society.

Occupational health

Important areas of research aimed at the maintenance and promotion of occupational health include the study of factors with adverse health effects in the workplace environment and the line of research that is aimed at maximising the functional capacity and working ability of the working-age population by means of preventive medicine. Occupational health services play a critical role in this effort, and for this reason it is necessary that the occupational health care system is constantly followed and researched so that it can be updated and adapted to the changing needs and requirements of the workplace.

Occupational health research is characterised by a strong multiprofessional research tradition, strong skills in the epidemiological and occupational medicine fields, and the extensive use of national health and population registers. Finland has a comprehensive occupational health care system that provides a sound basis for experimental studies designed to establish the impact of interventions targeted at the working-age population.

Important areas of occupational health research include mental health, musculoskeletal diseases, respiratory diseases, hypersensitivity diseases as well as psychosocial factors and associated diseases. Another challenging line of research is to identify the contribution of occupational factors to major public health diseases and to determine the potential of preventive interventions. There is strong and internationally recognized research competence in the area of risk factors for occupational cancer, both new and existing. A new and rapidly growing area of research is concerned with the health effects of synthetic nanoparticles, which draws heavily on the tradition of small particle research. Another example of research concerned with new risk factors is the line of inquiry that focuses on the impacts of complex information work on human cognitive capacity. In general, there is need for more information on the associations of brain diseases with environmental factors and major public health diseases.

Informed political decision-making and actions must be grounded in high-level and diverse research and development exploring the interactions between the environment and health. Two noteworthy examples include the anticipated global climate changes and their effects on environmental health and the shortage of labour that is expected to appear with the ageing of the Finnish population. High expectations are thus placed upon research in these fields, and the investment and inputs should match those expectations.

Development needs

- A good and comprehensive infrastructure is an important condition for successful research in environmental health and occupational health.
- Exposure and exposure routes are an important area of study that is in need of further development, especially in cases where measurements of very low concentrations require highly sophisticated and expensive research equipment.

- It is crucially important to have a strong knowledge base, especially comprehensive population and health registers. Up-to-date register data and extensive biological sample collections that are readily accessible to researchers are important among other reasons for studies into the interactions between the human genome and environmental factors.
- The upcoming generation change requires that doctoral programmes are delivered to the highest possible standards and that the wide range of knowledge and skills in this research tradition is handed down and further improved.
- Broad-based international cooperation and the necessary funding are crucial for the continued development of environmental health research.
- Research in the environmental health and occupational health fields needs the support and backing of competitive research funding as well as doctoral programmes that provide a sound skills and knowledge base, both at the PhD education and at the postdoctoral stages. Like public health research, however, this research often lies at the intersection of different Academy Research Councils, and therefore multidisciplinary evaluation practices are crucially important for securing the best possible framework conditions for environmental health and occupational health research.

2 Career Choice: Academic Research or Expert Assignment?

Doctoral education

In 2009, there are 16 Ministry of Education funded graduate schools in the health research field. The number of student places in these schools is 250, or 17 per cent of the total number of PhD student places.[4] A considerable number of students at graduate schools are funded from other than Ministry of Education sources (Table 1). In addition, many PhD students are researching their doctoral thesis outside graduate schools. In the 2003 report on the state and quality of scientific research in Finland, the Research Council for Health observed that the expansion of the graduate school system to as many different fields of health research as possible would support the development of the smaller fields of health research (Academy of Finland 2003b). Graduate schools that in 2008 were granted an extension to their funding for 2010–2013 included the Graduate School of Animal Wellbeing, the Finnish Post-Graduate School in Nursing Science, the Graduate School of Psychiatry and the Graduate School in Environmental Health. A new start-up is the Finnish Graduate School of Oral Sciences.

Table 1. PhD students (full-time n = 1,035) at Ministry of Education supported graduate schools in the health research field in 2007.

Gender	72% women	28% men
Nationality	86% Finnish nationals	14% foreign nationals
Funding	76% with other funding sources	24% graduate school places

Source: Graduate school reports for the 2008 graduate school call (reporting period 2006–2007), Academy of Finland.

Admission criteria for PhD programmes vary widely. As a rule the criteria for admission to MoE funded graduate school places are more rigorous, and student selection is based on competition. On the other hand, the threshold for admission into doctoral programmes outside the graduate school system can sometimes be noticeably low. This problem needs to be addressed by creating a harmonised set of criteria for admission into doctoral education. Another difficulty is that the most talented students do not necessarily even apply to PhD programmes.

PhD education reflects the standard of research more generally. The UK and the United States are strong research nations. In these countries the requirements for the PhD degree are clearly different from those in Finland. In Finland, research consists in large part of work undertaken by PhD students. One way of further improving the quality of research would be to bring the PhD thesis requirements in line with international practice (see Academy of Finland 2003b), which would leave PhD students with more time to spend on longer-term research projects outside of the formal requirements for the PhD thesis. This, however, must not happen at the expense of the quality of PhD education and the PhD thesis. In Anglo-American doctoral education programmes the main decisive criterion is the time limit, i.e. from three to four years, not the number of articles published as part of the PhD thesis. It should be possible to complete the PhD thesis within four to five years so that the average age at doctorate could be lowered in the medical and health sciences. However, it is important to bear in mind the differences between different fields, for in method sciences it may well be justified to take more time.

The development of the PhD process poses special challenges for supervision in doctoral education. A recent review of postgraduate students' assessments of doctoral education concluded that there is room for improvement most particularly in induction and supervision – and that this applies to medical and health sciences, too, even though students in these fields had the

4 In 2010, there will be 17 Ministry of Education and Academy supported graduate schools in health research fields with a total of 280 doctoral student places.

most positive overall assessment of their postgraduate studies (Hiltunen and Pasanen 2006). Another way of supporting students in the PhD process is through follow-up groups (Helve et al. 2007).

Demand for PhDs and placement

PhD graduates in the medical and health fields account for 28 per cent of all new PhDs in Finland.[5] The number of Doctor of Medical Science degrees

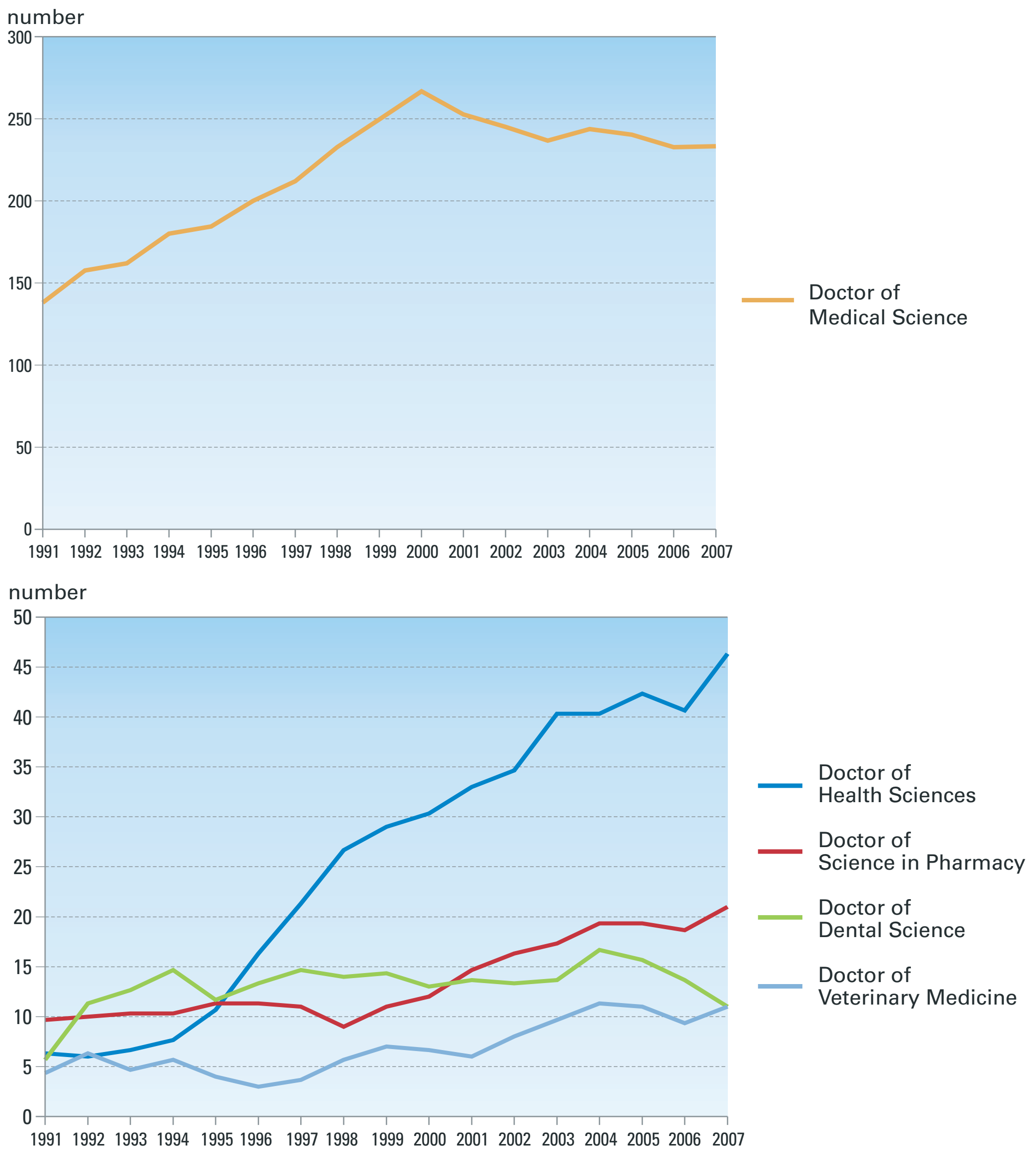


Figure 7. Number of doctoral degrees awarded in medical science, health sciences, pharmacy, dentistry and veterinary medicine in 1991–2007 (three-year moving averages, 1991 = average for 1990–1992). *Source: KOTA database, Ministry of Education 2009.*

5 Includes the following degrees: Doctor of Veterinary Medicine, Doctor of Dental Science, Doctor of Medical Science, Doctor of Science in Pharmacy, Doctor of Sport Sciences, Doctor of Health Sciences, and PhD awarded by a faculty of medicine.

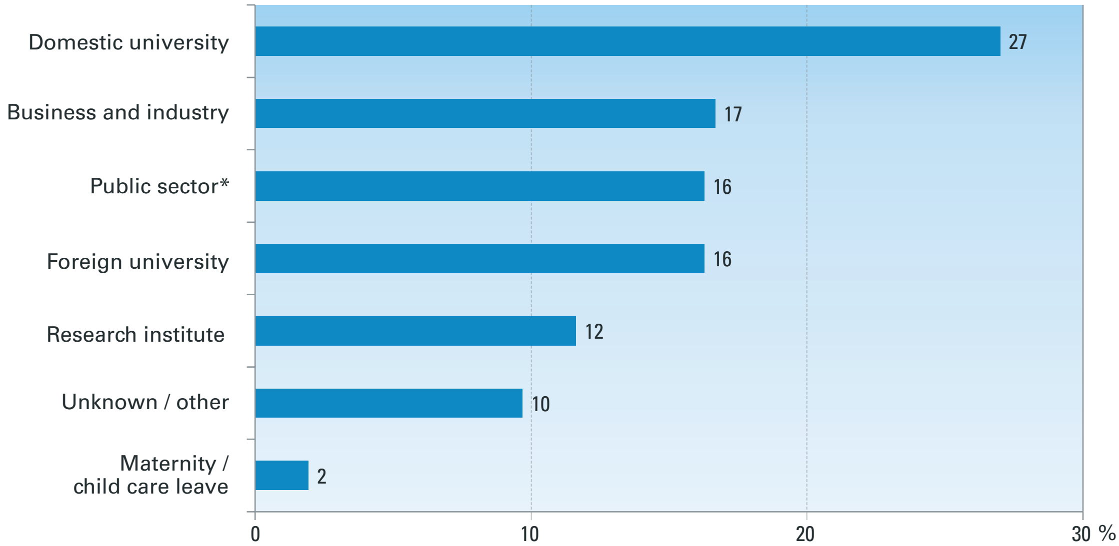


Figure 8. Placement (first employer after PhD graduation, %) of PhD graduates from Ministry of Education funded graduate schools in health research fields in 2006–2007 (n = 258).
Source: Graduate school reports for the 2008 graduate school call, Academy of Finland.

* Public sector includes public health care.

awarded has fallen in the 2000s (Figure 7)[6]. The number of Doctor of Health Sciences degrees increased fivefold during the 1990s, and the same trend has continued in the 2000s. In the pharmacy and veterinary medicine fields, too, the number of doctorates awarded has risen in the 2000s.

Some 40 per cent of PhDs graduating from graduate schools in health research fields in 2006–2007 found employment at a university or research institute immediately upon graduation (Figure 8). Around one in six PhDs were employed either in business and industry or in the public sector. The same proportion had moved to work at a university in some other country. Not a single PhD was out of work.

A recent review of the early career stages of PhD graduates in the job market examined PhD placement in different fields two to three years after graduation (Haapakorpi 2008). In the medical field the clear majority, 64 per cent, of Doctors were employed in social and health services, and 26 per cent in education and research. Among PhDs graduating from the health sciences, 68 per cent were in turn employed in education and research, for instance in teaching positions at polytechnics.

Well planned and systematic doctoral education that is sensitive to society's changing needs is extremely valuable to society. As regards the employment prospects of PhDs in the health research field, there are no major problems on the immediate horizon or over the next five years ahead. Employment prospects are very good in the fields of pharmacy, medicine, dentistry, veterinary medicine and nursing science, for instance. In the 2003 report on the state and quality of scientific research in Finland, the Research Council for Health concurred with the assessment made in the international evaluation of biotechnology regarding the demand for PhDs in the fields of pharmaceuticals development and bioinformatics (Academy of Finland 2003b). The evaluation included the recommendation that training and research programmes be launched in these fields (Academy of Finland 2002), and this recommendation is still valid.

6 In 2003–2004, 65 per cent of the doctorates awarded by medical faculties were Doctor of Medical Science degrees and 21 per cent PhDs. The corresponding averages for 2005–2007 were 60 per cent and 27 per cent (unpublished report by the Research Council for Health, 2008).

The postdoctoral career

In the 2003 review, the Research Council for Health stressed the importance of improving the position of young researchers seeking to assert their independence: this was identified as a priority area of development in health research (Academy of Finland 2003b). In 2006, the Academy revised and updated its funding opportunities for postdoctoral researchers, who can now apply for project funding that is intended primarily for purposes of improving recent PhD graduates' qualifications and supporting their independence as professional researchers. Research teams, on the other hand, may only apply for Academy funding for hiring postdoctoral researchers as part of other research funding.

In 2006–2008, women accounted for 45 per cent of all research funding applications filed with the Research Council for Health and for 46 per cent of all research grants awarded (Table 2). In earlier career stages the majority of applicants and funding recipients are women.

Table 2. Percentage of women among applicants and recipients of research funding in fields under the Research Council for Health in 2006–2008 (three-year average).

Applicants for Postdoctoral Researcher's project	67%
Recipients of Postdoctoral Researcher's project funding	74%
Applicants for Academy Research Fellowship	48%
Academy Research Fellows	53% (12/2008)
Applicants to Academy Professor positions	33%
Academy Professors	14% (v. 2009)
Applicants total all funding instruments	45%
Researchers funded total all funding instruments	46%

Source: Webfocus database, Academy of Finland 2009.

It does not make good sense for all PhDs to become team leaders. Indeed, doctoral education should be planned and designed with a view to the needs of those people who do not plan to continue their careers in academic research. Doctoral graduates from medical sciences said their main motives for seeking admission to doctoral education were their interest in research (72%) and their commitment to improve their professional qualifications (70%) (Haapakorpi 2008). By contrast only 14 per cent said they were interested in an academic research career. Among health science PhDs the interest in research and the improvement of professional qualifications were also mentioned most often as the leading motives (both at 67%). Among health science PhDs only 10 per cent indicated they were interested in an academic research career.

As a rule, a shorter PhD completion time would benefit both those who plan to pursue a career in academic research and those who decide to take some other career path. The former would no longer lose out in the international competition; we currently give Anglo-American PhDs a two-three year head start in this respect. Graduates opting to pursue a career outside academia, for their part, would be able to move into the workplace sooner.

The clinical research career

The challenges facing the clinical research career were already highlighted in the 2003 review of the state and quality of scientific research in Finland (Academy of Finland 2003b). In that report the Research Council for Health expressed its concern about the fact that growing numbers of clinical researchers no longer have a medical doctor's or dentist's education. That concern has not gone away. In the future, special health care will increasingly be concentrated in university hospitals. This will increase the demand for medical doctors in clinical positions, as senior physicians working at university hospitals must have the ability to critically assess clinical performance, and doctoral education provides the necessary skills to do just that. In addition to medical doctors, there is a need for doctors of dental science and veterinary medicine in research. There is a definite shortage of researchers in these fields, which already has caused problems in filling the university lecturer and professorial posts that require a doctoral degree.

The number of doctoral degrees awarded in medical science and dentistry has fallen in 2004–2007, while at the same time the number of PhDs awarded at medical faculties has risen.[7] This is also seen in funding decisions for Postdoctoral Researcher's projects and Academy Research Fellowships. In 2006–2008, 11 per cent of applicants to Postdoctoral Researcher's projects and 13 per cent of those who were awarded funding had a medical degree. In 2008, 37 per cent of the 49 Academy Research Fellows in health research fields had a medical degree (Doctor of Medical Science or Doctor of Dental Science).

In the 2003 report, the Research Council for Health recommended that steps be taken towards the closer coordination of research, specialist medical training and clinical work (Academy of Finland 2003b). The Research Council for Health has for its part sought to improve opportunities for clinical research by allocating funds for the promotion of the clinical research career as from the beginning of 2006. The purpose of these grants is to encourage doctors working in clinical practice to engage in research on a part-time basis so that they can continue to pursue their research career both during and after their specialist training.

Mobility

The number of foreign visits by university researchers and teachers in health research fields has dropped to less than one-quarter of the peak years in the mid-1990s (Figure 9). The average duration of these visits has also decreased from around five months to three months. From 1991 to 2007, the number of one-month or longer visits from abroad to Finnish universities has almost always exceeded

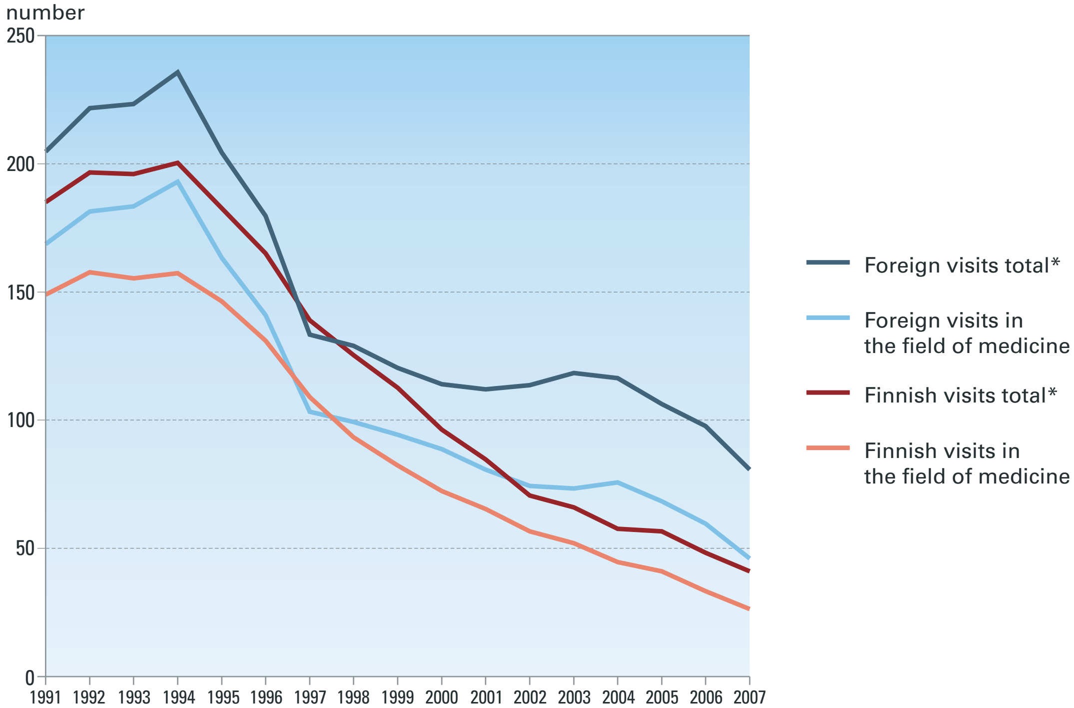


Figure 9. Number of visits lasting one month or longer by Finnish and foreign university teachers and researchers in health research fields in 1991–2007 (three-year moving averages, 1991 = average for 1990–1992).
Source: KOTA database, Ministry of Education 2009.

* Veterinary medicine, pharmacy, dentistry, sport science, medicine, health sciences; data not available for nutrition science.

7 Unpublished report by the Research Council for Health, 2008.

the number of visits by Finnish researchers to other countries. Finnish universities no longer hold the same appeal to foreign researchers and teachers as they did in the mid-1990s. However, this change has been less dramatic than the decline in the mobility out of Finland. In 1992-2006, the number of foreign postgraduate (licentiate and PhD) students in Finland has more than quadrupled in health sciences and more than tripled in medical science (Figure 10).

The Academy's 2006 impact assessment included an evaluation of the impacts of funding awarded by the Research Council for Health for researcher training (Suomen Akatemia 2006). Based on this assessment the Research Council concluded that measures are needed to further develop the funding mechanism for supporting research work abroad by facilitating the repatriation of researchers after their spells abroad. On the other hand, project grants for postdoctoral researchers are also a suitable funding instrument at the stage where postdoctoral researchers return to Finland and begin to set up their own research team, for instance.

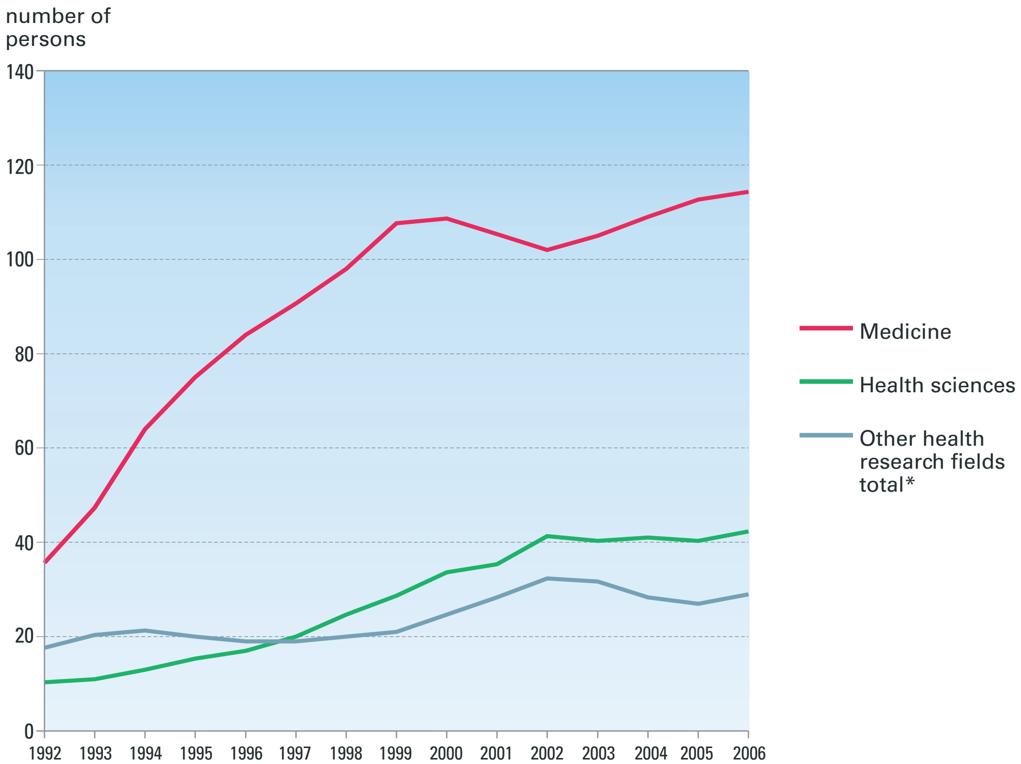


Figure 10. Number of foreign postgraduate (Licentiate and PhD) students in medical science and health research fields in 1992–2006 (three-year moving averages, 1992 = average for 1991–1993).
Source: KOTA database, Ministry of Education 2009.

* Veterinary medicine, pharmacy, dentistry, sport science; data not available for nutrition science.

3 Research Infrastructures

Biomedical research

For biomedical research, access to first-rate infrastructure is critical. Since research equipment is continuing to develop at an accelerating pace, it is crucial that universities and research institutes work constantly to upgrade and renew that equipment. This requires substantial investment in equipment, which has indeed been continued on the strength of dedicated biotechnology funding from the Ministry of Education. Many of the centralised service units supported with this funding require full-time personnel to keep the operation running smoothly. The best way to do this is through researchers who use the services of these units in their own work. One such area that requires special support is bioinformatics. Research facilities in the biomedicine field require constant investment if they are to keep up with international standards. Furthermore, steps are needed to safeguard research datasets that are of national significance and to make sure they are put to the fullest possible use.

A recent international assessment of the current state of research infrastructures in Finland concluded that infrastructures in the biomedical and life sciences have significant social impact since research results have immediate application in clinical practice and in preventive health care (Ministry of Education 2009). However, the panel also observed that in the biosciences field, more attention should be given to the commercial application of research results.

Recently established by the organisations hosting the biocentres, the *Biocenter Finland* network will contribute to further strengthening research and promoting the internationalisation of research in this field. Biocenter Finland is part of an international research network in biosciences, biomedicine and biotechnology designed to promote cooperation, deliver common services and to support networking with major infrastructure projects. The development of biocentres has contributed significantly to the ongoing structural reform of this field. The level of funding for biocentres is under constant threat, and any cutbacks would reflect adversely on their research infrastructure.

A significant new force in the biomedical research field is the *Institute for Molecular Medicine Finland (FIMM)*, a joint research institute of the University of Helsinki, the Hospital District of Helsinki and Uusimaa, the National Institute for Health and Welfare, and VTT Finland. Launched in 2007 and working closely with the European Molecular Biology Laboratory and the Norwegian and Swedish centres for molecular medicine, FIMM's mission is to coordinate Finnish research and research infrastructures in the fields of molecular medicine, genetics and epidemiology. The aim is to develop FIMM into a significant, high-profile international unit that will strengthen and further internationalise research and doctoral education in this field and advance the practical application of research results. The achievement of these goals is supported by the close cooperation between Biocenter Finland and FIMM.

Infrastructure issues are increasingly addressed not only locally and nationally, but also internationally through European projects. Finland contributes as a full member to funding the European Molecular Biology Laboratory (EMBL), and that funding is channelled via the Academy. In the health research field, the first roadmap developed by the European Strategy Forum on Research Infrastructures (ESFRI) includes infrastructures related to biobanks, biomolecular resources, genetically modified mice, bioinformatics, structural biology and translational medicine (Pihlajaniemi 2007). The international panel that reviewed Finland's research infrastructures observed that Finland has several areas of strength in the biomedical and life sciences, and that it is therefore well placed to host and take a leading role in some European research infrastructures (Ministry of Education 2009). In Finland, FIMM and the Ministry of Education are currently coordinating the European Advanced Translational Research Infrastructure in Medicine (EATRIS). The European Biobanking and Biomolecular Resources Research Infrastructure (BBMRI) is coordinated by the National Institute for Health and Welfare together with the Ministry of Social Affairs and Health. Finland is also involved through CSC – IT Center for Science in the European Life Sciences Infrastructure For Biological Information (ELIXIR), the mission of which is to develop methods for the storage and organisation of biological information, such as human genome information. Roadmap projects in the biosciences and health sciences also include the European infrastructure for phenotyping and archiving of model mammalian genomes (INFRAFRONTIER) and the A.I. Virtanen Institute for Molecular Sciences virus vector laboratory (AIV Vector Core).

Public health research

The main infrastructures in the field of public health research consist of data resources, which needs to be taken into account in the Academy's infrastructure policy. Successful research in this field requires access to comprehensive health care databases and registers, which are a critical infrastructure. Pathbreaking research requires that register data can be linked with other data sources, and therefore it is important that there is flexible access to those sources (see also Academy of Finland 2003b).

Access to register sources has clearly weakened in recent years. One underlying factor is the shortage of resources available to the register authorities in the face of increasing information needs. Furthermore, current procedures require an increasing number of permit applications, but the resources have not been made available to cope with this increased workload. One major infrastructure need is to ensure that the resources are available to process and deliver the necessary register data and to process the applications received with a view to facilitating research access to these sources. New legislation that is currently being drafted for the regulation of biobanks is predominantly well-conceived, but overly bureaucratic permit procedures will inevitably increase processing times. The Finnish Information Centre for Register Research, launched with support from the Academy of Finland, provides guidance to scientists and researchers, but is not in the position to address any grievances.

A critical infrastructure question for both public health research and clinical medicine is whether and to what extent they will have access to information on the proposed national electronic patient information system. If the data are not identifiable, they will have only limited research value. It is important that the science and research community is actively involved in the planning stages of this project so as to ensure it will have the maximum possible research uses. Data protection needs can be adequately satisfied without compromising the utility of register data.

4 Research to the Benefit of Society

Among the main challenges faced by health research are those that come from the population's changing age structure and the growth of the elderly population in particular. New research evidence must be generated and used to gain a better understanding of how the development of dementia and other memory disorders as well as decline in functional capacity can be slowed with a view to reducing the need for care. The growth of obesity and type 2 diabetes provide an example of a population-level health problem that can only be resolved by means of effective prevention and treatment that spans the entire life course. In addition to the chronic diseases just mentioned, the risk of global pandemics has also increased.

Health is the outcome of complex interactions between the individual (lifestyles, genome) and the environment (physical, social). However, it is only very rarely that people actually change their attitudes and lifestyles in response to the results of health research. The information produced in health research is communicated to the general public through the pharmaceuticals industry, partly through the food industry, the health care system, local and central government policies, organisations and the mass media (Table 3). The health care system obviously plays a very prominent role in the field of health research, but so too do the large number of organisations active in the field. Furthermore, health-promoting decisions affect various sectors to an exceptionally great extent in both central and local government.

Conditions for impact

A distinction can be made between two main types of impact from science and research. *Scientific impact* means that research results add to scientists' and the academic community's knowledge resources, improve university education and serve as a source of inspiration for other researchers (Figure 11). This kind of research is needed, and it is not always possible even to tell what research or which result will sometimes have *social impact*.

People's health and well-being, the productivity of society and industrial competitiveness are influenced by a wide range of factors that are independent of research and the use of knowledge. It would therefore be misleading to use the population's health, for example, as the only indicator of the social impact of science. In fact, the actions of the end-user of research knowledge and the changes in those actions often tell us more about the significance of science than very long-term impact assessments.

Four conditions must usually be met in order that research knowledge can be put to good use in society:

1. There is a social demand for that knowledge
2. The necessary knowledge is available at the right time
3. Scientists and researchers know how to communicate this knowledge to its end-users
4. The end-users of this knowledge know how to use the results of research.

Table 3. End-users of health research information: what can be achieved by research?

End-user	Examples of changes brought about by research
Health care system	Changes in care and other service practices
Political and public administration decision-making	Management-by-information: acts and decisions on the use of funds that take account of public health
Public health and sports organisations	New contents for campaigns and counselling, new service products
Pharmaceuticals and food industry	Development of new products, new marketing ideas
Media	Articles and programmes reporting on the results of health research

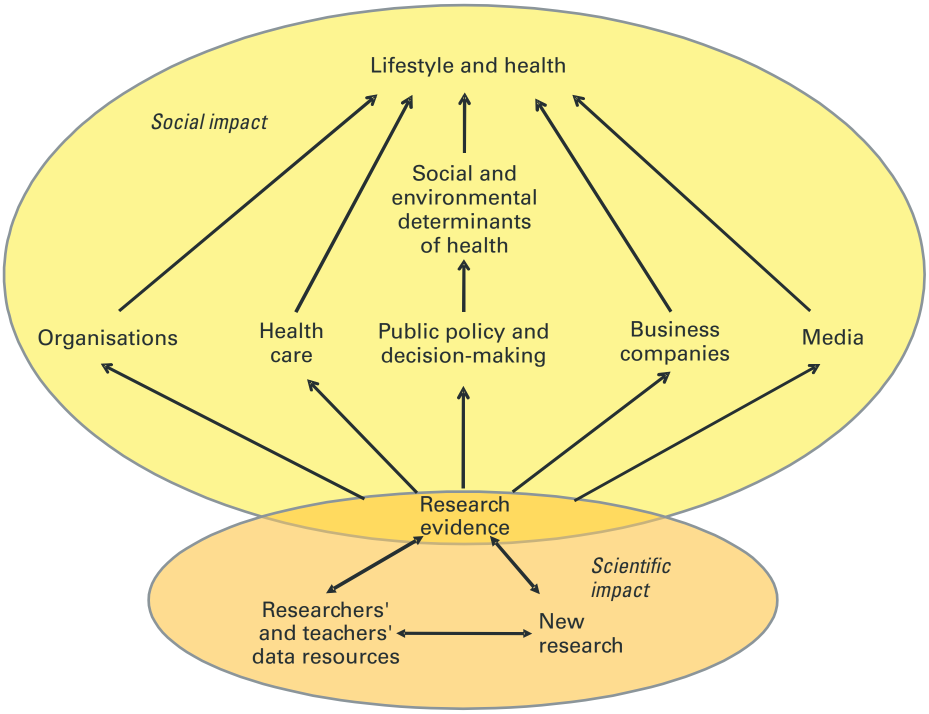


Figure 11. Scientific and social impact of health research.

The translation of new research discoveries into practical applications in society can take a very long time. Xylitol had been studied for at least 30 years before its first applications were introduced in functional foods with health effects. However, there may still be long delays even after the research evidence has been passed on from the world of research. This is most notably the case in the pharmaceuticals industry, where the development of a new drug can take several years. The same goes for the diffusion of a research result recommending a certain change in the health care system, especially if the political climate at the time is not conducive to making those changes.

Another question related to the utility of research results is timing. Sometimes research knowledge is in immediate demand. For example, the outbreak of the SARS epidemic and the discovery of acrylamide residues in food prompted an immediate need for information to support decision-making. On the other hand, the need for information may lie some years ahead in the future: for example, some information on the associations between food and health may be needed for purposes of drafting the nutritional recommendations published once every eight years by the Nordic Council of Ministers. Finally, there are the long-term research strategy objectives. Scientific basic research is the most typical representative of the latter. Some of the missions of sectoral research, on the other hand, have a shorter time span.

Apart from the timing of information and knowledge transfer, another important issue from an impact point of view is the interface between researchers and users: the transfer of knowledge into practice requires an active commitment and the necessary skills on the part of both researchers and end-users. A feature shared in common by the best examples of the impact of health information in recent years is a *structure or practice that brings together researchers and the end-users of information*.

End-users of health research

By virtue of their mission, sectoral research institutes take a more active approach than universities to developing structures and practices that support the practical application of research information. A good example is provided by the *Finnish Office for Health Technology Assessment* (Finohta) that was founded under the auspices of the National Research and Development Centre for Welfare and Health in 1995. Charged with the task of identifying and evaluating good practices of health care, Finohta serves as a bridge between research and practical health care and is capable of responding to both acute and medium-range information needs. The need for this kind of mediator organisation is clearly demonstrated by the fact that since 1995, Finohta's labour input has increased from three to 29 person-years.

The Finnish Medical Society Duodecim has developed two systems for translating scientific research results into health care practices. Working closely with the Academy of Finland, Duodecim has brought together scientists, health care professionals and other key players (e.g. NGOs, business and industry) to draft a consensus

Example 1: Consensus meeting on rehabilitation after acute brain damage

Duodecim and the Academy of Finland hosted a consensus meeting on rehabilitation after acute brain damage in October 2008.

Studies of brain damage are undertaken from the vantage-points of several different disciplines. Neurological research has shed much light on the plasticity of the brain and for instance the formation of new neural connections after brain damage. Clinical studies have investigated the combined effects of pharmaceutical and biological treatments. The efficiency and cost-effectiveness of rehabilitation has been studied among other things through register studies. Psychological and social-psychological approaches, then, are needed to understand how the rehabilitee's own resources can be put to the best possible use. Researchers in the field of sociology and social policy are interested in such issues as occupational rehabilitation and employment after brain damage.

The consensus meeting produced summaries of research on brain damage and subsequent rehabilitation. This information was compared with current rehabilitation practices and public support systems. The three-day event attracted the participation of the multidisciplinary panel that drafted the actual consensus statement, expert lecturers and an audience of some 200 people.

The meeting's key recommendations for the development of rehabilitation after acute brain damage were as follows:

1. Rehabilitation must be appropriately timed and sufficiently intensive.
2. Rehabilitation must be concentrated in large enough units to ensure access to the necessary skills and competencies.
3. Brain damage departments must be created at university hospitals.
4. Rehabilitation plans must be worked out together with each patient.
5. National statistics must be compiled of the rehabilitation provided, its costs and effectiveness.
6. Rehabilitation benefit must be made available to persons over 65.
7. Rehabilitation must be a seamless service chain.
8. Steps are needed to improve and strengthen cooperation between rehabilitation research and development.

As earlier consensus meetings, this conference combined research results and practical experiences and drew up concrete proposals. The practical implementation of those proposals depends mainly on the Ministry of Social Affairs and Health and local authorities.

statement on the treatment and/or prevention of a certain disease (see example 1). These *consensus meetings* have been held since 1997. The meetings held over the past five years have dealt with rehabilitation after acute brain damage (2008), psychotherapy (2006), obesity (2005) and hormone therapy in menopause (2004).

The *Current care recommendations* issued by Duodecim are designed to improve the quality of care and to minimise variation in care practices (www.kaypahoito.fi). Current care recommendations are based on a critical review of the latest scientific research evidence by a panel of experts. Based on the number and quality of the publications and the uniformity of their results, descriptions are attached to the different recommendations that rate the strength of the scientific evidence. The first current care recommendation (for coeliac disease) was published in 1997. Over the past five years, a total of 43 sets of current care recommendations have been issued. The recommendations completed and issued during 2008 are shown in Table 4.

Table 4. Current care recommendations published in 2008.

Palliative (symptomatic) care for (imminently) dying patients	Treatment of pneumonia
Borderline personality disorder	Third molar ('wisdom tooth')
Resuscitation of a newborn child	Physical activity and exercise training for adults in sickness and in health
Preoperative assessment	Bipolar disorder
Gestational diabetes	Adult epilepsy
Treatment of insomnia	

The biggest public health organisations in the country, such as the Finnish Heart Association and the Finnish Diabetes Association (see example 2), have long been putting scientific research results to practical use in their campaigns and programmes. In doing this they have relied on the skills and competencies of people with a background in medical science, nutrition science, sports science and behavioural sciences. For decades, Finnish research in the treatment of heart disease and related risk factors has provided valuable material for the Finnish Heart Association's information, training and health promotion campaigns.

One of the best applications of recent years has been the *Heart Symbol* introduced in food products. According to a survey in 2007, the symbol was recognized by 84 per cent of the adult population. Furthermore, 46 per cent of the respondents said they believed the symbol influenced their own choices. The symbol has also inspired the food industry. For example, one of the biggest food companies in the country has focused its development efforts specifically on its range of products that are sold under the heart label. In 2007, the symbol was further extended for use in connection with meals served at workplace canteens and other similar outlets.

Pharmaceutical companies have been highly active in the practical application of scientific information, and many of them also contribute to producing that information. According to Statistics Finland, the Finnish pharmaceuticals industry spent just over 200 million euros in R&D in 2007. In recent years the development of functional foods with beneficial health effects has emerged as another major area of product development and marketing. Food industry investment in scientific research, on the other hand, has remained at a lower level than in the pharmaceuticals industry, with just a few exceptions. Some companies have established scientific advisory boards to act as interpreters between the science and the company.

Funded by the Ministry of Social Affairs and Health, a project has been ongoing since 2005, under the coordination of the National Institute for Health and Welfare, to develop a *national health information portal* (www.tervesuomi.fi). This concept is designed to bring together the best health evidence produced by scientists, other experts, the authorities and associations. The purpose of the service is to help individual citizens, health promotion professionals and communities make informed decisions in the best interests of their health. The portal was opened in April 2009.

Example 2: From diabetes research to a prevention project

Some 200,000 people in Finland have type 2 diabetes, four times more than in 1970. In addition, it is thought that roughly the same number have type 2 diabetes without knowing it. Estimates are that 15 per cent of all health care resources go to the treatment of diabetes and associated diseases.

Finnish universities and the National Institute for Health and Welfare have been conducting research into diabetes for a long time. In recent years the focus of this research has been on the genetic and metabolic foundation of diabetes, the associations between diabetes and coronary heart disease and the prevention of diabetes by the promotion of healthy lifestyles. In 2001, Academy Professor (2000–2005) Jaakko Tuomilehto and his research team published an article in the New England Journal of Medicine on the prevention of diabetes by means of diet, physical exercise and weight control. The same research has provided material for dozens of other scientific articles.

Results from Finnish and international diabetes research have also been put to good use in the FIN-D2D project of the Development Programme for the Prevention and Care of Diabetes, which was launched under an initiative by the Finnish Diabetes Association in 2003. Both the National Institute for Health and Welfare and five hospital districts participate in the development work. The aim of the project is to improve the identification of people at risk of type 2 diabetes, to develop new prevention and treatment strategies, and to assess the feasibility, impacts and costs of these new strategies.

The active stage of the FIN-D2D project was completed in 2007. Research results have been put to practical use, despite the challenges identified by the reviewers in the process of knowledge transfer. Many of the health centres and occupational health units in the five hospital districts involved in the experiment have begun screening persons at risk on a routine basis. Lifestyle counselling in group settings has also increased significantly as a result of the FIN-D2D project. As yet no information is available on the impacts of the project on morbidity.

Another project that has made use of the results from diabetes prevention research is a joint programme among the University of Helsinki, the National Institute for Health and Welfare and the Hospital District of Päijät-Häme. The most visible impact has been the increased provision of group lifestyle counselling at health centres for middle-aged and older people.

5 Development Needs in Health Research

Research funding

Measures are needed to ensure the long-term continuity of public research funding at a high enough level. University budget funding must be established on a secure basis to provide the necessary framework conditions for research excellence. Funding bodies must step up their cooperation in supporting multidisciplinary research or the different stages of the research process.

Research career

In doctoral programmes, steps are needed to ensure more rigorous selection of postgraduate students; to harmonise doctoral thesis requirements with international standards; and to invest more resources in the supervision of the PhD process.

Improving long-term career paths in academic research remains one of the key development needs in the field of health research: more opportunities and more funding are needed for postdoctoral researchers and for scientists striving to establish their independence.

In the health research field it is necessary to develop flexible research career paths that take account of the need for scientists and researchers to work in hospital environments.

Continued efforts are needed to encourage young researchers to spend periods working abroad, especially in the postdoctoral stage. Mobility within Finland is also important.

Infrastructures

Research facilities in the biomedicine field require constant investment if they are to keep up with international standards. Many centralised service units require full-time personnel.

It is crucial that research environments in Finland continue to attract talented researchers from other countries, and on the other hand, that Finnish researchers of international excellence can be offered better opportunities to do research in Finland.

In the field of medical science in particular it is important to consider the needs of both academic research and health care when expensive patient examination equipment is purchased and used.

Legislative and other measures are needed to ensure the preservation of nationally valuable register-based research materials and their best possible use. As well as providing infrastructure funding for science and research, central government needs to take other steps to maintain databases that are used in the planning of health care provision and health policy, for instance.

Cooperation

Cooperation that cuts across disciplinary as well as national boundaries is by now widely recognized as an important factor for research excellence. Many of the challenges currently facing health research are such that the only way they can be tackled and resolved is through the seamless cooperation of different fields. Strong cooperation between those fields is also essential to further raising the quality standards of research. Many fields of health research are internationally very well networked, but in some smaller fields there is also need to further increase international cooperation.

Health care system and research

For the needs of both basic and postgraduate training it is crucial to ensure that universities and research institutes continue to work closely with the health care system. This will require increased investment is research and education within the health care system, too (through the EVO state subsidies system).

Measures are needed to develop university hospitals as research environments where it is possible to combine specialist medical training or clinical work with research.

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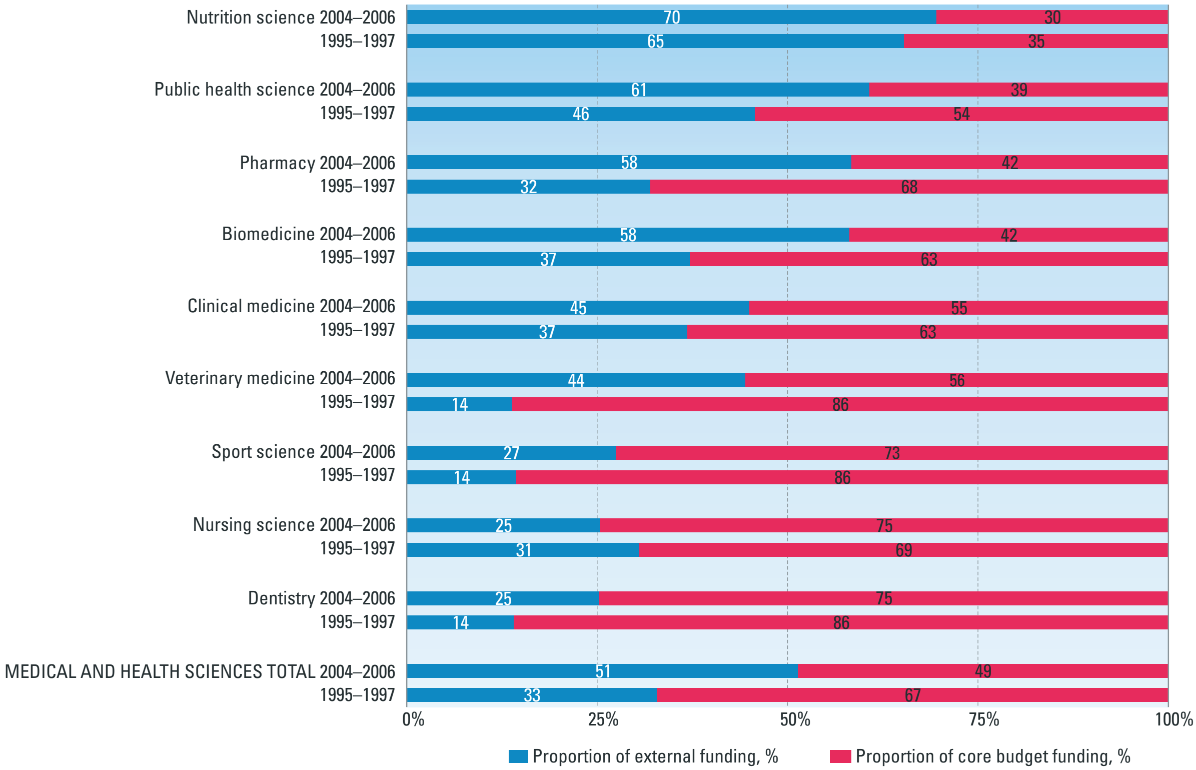
Appendix 1. Statistics on funding for health research in different fields



Appendix Figure. The percentage of external funding and core budget funding for medical and health research at universities in 2004–2006 and 1995–1997. *Sources: Statistics Finland; Unit for Science, Technology and Innovation (TaSTI), University*

Appendix Table. External funding for medical and health research at universities by sources of funding (%) 1995–1997 and 2004–2006. Personal grants awarded by private foundations not included in the statistics.

Source of funding (%)	Academy of Finland		Tekes		Other public funding (domestic, excluding Academy of Finland and Tekes)		Funds (domestic and foreign)		Universities' own assets		Companies (domestic and foreign)		EU funding		Other foreign funding		External funding total
Period	1995–1997	2004–2006	1995–1997	2004–2006	1995–1997	2004–2006	1995–1997	2004–2006	1995–1997	2004–2006	1995–1997	2004–2006	1995–1997	2004–2006	1995–1997	2004–2006	1995–1997 ja 2004–2006
Biomedicine	50	40	10	10	5	10	8	10	4	2	16	18	4	10	2	2	100
Veterinary medicine	21	11	7	5	48	13	0	53	10	4	9	9	4	5	0.3	0.3	100
Dentistry	36	32	16	25	17	15	3	5	4	2	16	21	8	0.4	1	0.04	100
Clinical medicine	32	32	6	12	7	10	12	12	7	2	21	15	7	11	8	6	100
Pharmacy	24	14	34	36	14	6	4	12	1	10	19	10	4	11	0.3	0.4	100
Nursing science	13	25	3	13	68	40	13	7	0.2	1	1	4	1	10	2	0	100
Public health science	33	23	0.4	2	35	18	4	5	2	0.4	8	36	0.1	10	18	5	100
Sport science	3	12	1	41	84	28	5	5	0	0	4	10	0	4	4	0.2	100
Nutrition science	15	27	5	14	12	16	2	6	1	2	63	14	0	22	2	0.4	100
MEDICAL AND HEALTH SCIENCES TOTAL	37	31	9	13	14	11	9	12	4	3	17	17	5	10	6	3	100

Sources: Statistics Finland; Unit for Science, Technology and Innovation (TaSTI), University of Tampere.

Appendix 2. Experts contributing to workshop discussions

In 2008, the Research Council for Health organised three workshop discussions on the following themes: research career, the strengths and weaknesses of health research, and the impacts of health research. Each expert participated in one workshop. The workshops were chaired by members of the Research Council for Health Anna-Elina Lehesjoki, Jorma Keski-Oja and Anssi Auvinen. In addition, several other members of the Research Council took part in the discussions (Appendix 3).

Hakulinen, Timo	Finnish Cancer Registry
Heikinheimo, Markku	University of Helsinki
Hemminki, Elina	National Research and Development Centre for Welfare and Health
Hovatta, Iiris	University of Helsinki
Härkönen, Pirkko	Lund University, Sweden
Jungman, Tor	Finnish Heart Association
Jylhä, Marja	University of Tampere
Jänne, Olli	University of Helsinki
Kajantie, Eero	National Public Health Institute
Kallioniemi, Olli	Institute for Molecular Medicine Finland, University of Helsinki
Kivelä, Sirkka-Liisa	University of Turku
Kujala, Urho	University of Jyväskylä
Kurki, Pekka	National Agency for Medicines
Lehenkari, Petri	University of Oulu
Leino-Kilpi, Helena	University of Turku
Lyly, Annina	University of Helsinki
Merikallio, Jussi	Association of Finnish Local Authorities
Mukala, Kristiina	Finnish Medical Society Duodecim, Centre for Military Medicine
Mustonen, Jukka	University of Tampere
Mutanen, Marja	University of Helsinki
Mäkelä, Sari	University of Turku
Mäkelä, Marjukka	National Research and Development Centre for Welfare and Health, Finnish Office for Health Technology Assessment
Mönkkönen, Jukka	University of Kuopio
Nupponen, Nina	University of Helsinki
Ollila, Eeva	Ministry of Social Affairs and Health
Paju, Susanna	University of Helsinki
Pelkonen, Jukka	University of Kuopio
Pihlajaniemi, Taina	University of Oulu
Pyörälä, Satu	University of Helsinki
Raivio, Kari	University of Helsinki
Salonen, Reijo	Orion Corporation Orion Pharma
Savolainen, Markku	University of Oulu
Syrjänen, Stina	University of Turku
Takala, Timo	Oulu Deaconess Institute
Tamminen, Tuula	University of Tampere
Tienari, Pentti	Helsinki University Hospital
Vartiainen, Terttu	National Public Health Institute
Visakorpi, Tapio	University of Tampere

Appendix 3. Research Council for Health in 2007–2009

Professor Kalervo Väänänen, chair	University of Turku
Professor Anssi Auvinen	University of Tampere
Professor Helena Gylling	University of Kuopio
Professor Kirsti Husgafvel-Pursiainen	Finnish Institute of Occupational Health
Professor Marja-Liisa Hänninen	University of Helsinki
Professor Tatu Juvonen	University of Oulu
Professor Jorma Keski-Oja	University of Helsinki
Professor Mikael Knip	University of Helsinki
Professor Anna-Elina Lehesjoki	University of Helsinki
Professor Tuula Salo	University of Oulu
Professor Pia Vuorela	Åbo Akademi University

Director Mikael Fogelholm and Science Adviser Anu Nuutinen from the Academy's Health Research Unit contributed to the preparation of this report.

III Directions for Development

1 Overview of current state and future outlook

The development of the Finnish research system from the 1960s to the present day is a good example of how a sustained development effort can yield internationally significant results. The main impetus for that effort has come from wider socio-economic development needs, such as regional policy considerations, the drive to raise skill levels in the population, growth policy, the diversification of the country's business and industry structure, innovation pressures and international relations. The system has brought in best practices from other countries and successfully adapted them to its own needs.

In order to understand the challenges of today, it is necessary to trace the development of the Finnish research system over the past 15 years and to compare it with developments in other countries.

In 1993 Finland's R&D expenditure as a proportion of GDP reached the OECD average level of 2.2 per cent, climbing further to 3.4 per cent in 2000 on the back of the additional research funding pledged by the Government. Since then, R&D investment has remained at this high level. The number of researchers has continued to increase particularly in the higher education sector, but in 2004 the number of person-years in research began to fall. In 2006 the number of R&D person-years also dropped in the private business sector for the first time since the recession in the early 1990s; as yet it is too early to assess the impacts of the current recession. In the space of a decade or so, Finland's research intensity increased sharply to become one of the highest in the world, and it has continued to remain so despite a downturn in recent years.

In 2008 the number of new doctoral graduates in Finland was twice as high as in 1993. During this period there has been a marked increase in the overall number of PhDs in the country. This has been one of the cornerstones of results-based management at universities, which have been forcefully encouraged to invest in the education of new PhDs. In 2005, Finland had by far the highest proportion of PhD graduates per thousand population aged 25–34 years, 3.1; Germany in second place lagged some way behind at 2.6. In Denmark and Norway, which were way ahead of Finland on the quality indicator of research publications, the figure was 1.3. Large amounts of R&D spending have been dedicated to doctoral education programmes, which has had a profound impact on professors' time use. The main focus in education has been to increase the number of new PhDs, although the quality of the recruitment base has not always been adequate. Intensive doctoral education has obviously brought many benefits to Finnish society and the Finnish economy, as many of the new PhD graduates (around 20–30% from graduate schools) have taken up employment outside academia. This significant investment in education may become an important asset for Finland in the future if it is properly used and managed. However, it has done little to improve the conditions for research at universities.

Finland's intensive investment in R&D and in increasing the size of its R&D workforce is clearly reflected in the corresponding statistics, which are at a considerably higher level than the average figures in other OECD countries. That investment has greatly boosted Finland's ranking in measurements of international competitiveness and produced an excellent education system. In the early 2000s, the number of scientific articles produced in Finland, relative to population and relative to GDP, was fourth highest among OECD countries. In the past couple of years the number of scientific publications in Finland has been falling.

Finnish indicators of scientific impact and quality (impact factors) have been on the decline since around 2000–2002. A Nordic comparison shows that the gap to Denmark has been widening very quickly for more than 10 years now, and Norway overtook Finland in the early 2000s. Sweden's impact factor has followed a roughly similar path to Finland's, albeit at a higher level. On this indicator the quality of scientific research in Finland is now at the OECD average. As around 70 per cent of all scientific publications in Finland are produced at universities, the challenge clearly is one of improving the conditions for research at universities and possibly their publishing strategies.

The emphasis in research funding and science and technology policy in Finland today is very much on encouraging applied research.

1. Tekes R&D funding exceeds university budget funding by an ever wider margin. University budget funding is now at the same level as in 2002.
2. Private business funding together with Ministry and Tekes funding for applied research and development at universities significantly exceeds the volume of funding from the Academy of Finland, the leading source of funding for scientific research in Finland. A recurring criticism in international evaluations commissioned by the Academy is that a disproportionate amount of research at universities focuses on application and product development at the expense of basic research. It is also necessary to note that the Academy funds research in all disciplines, while Tekes concentrates primarily on the natural sciences and engineering: the diversity of research is fundamentally important in all circumstances.
3. All of the Government's major policy documents in recent years – the Government Programme, the Government resolution on the structural development of the public research system and the Innovation Report – have placed scientific research primarily in a technological and economic context, without giving due consideration to the key importance of basic research and the diversity of research to innovation. As is stressed in the interim report to the OECD innovation strategy, "long-term, fundamental research remains critical to strong performance in innovation" (OECD Innovation Strategy, Interim Report 2009).

Research infrastructures are in several fields a necessary condition for scientific work, and they are always crucial to the international appeal of the country's research system. Finland's research infrastructures have eroded as a result of slow investment in their maintenance and development.

There are compelling reasons to conclude that the facilities and infrastructure for conducting high-level research at Finnish universities have not remained well-maintained and up-to-date. Acceptance of this fundamental condition lays the basis for the development of future measures.

Improvements are needed across the board and at various levels of the research system: steps are needed to strengthen the basic conditions for high-level scientific research (e.g. research infrastructures and funding), to improve the steering mechanisms of university research, to reduce fragmentation in scientific research (cooperation and profiling), and to develop new forms of competitive research funding to support the new approaches and strategies.

When the situation is viewed from the vantage-point of Finnish research teams and research environments, and when it is compared with that in other advanced science nations, it is possible to detect some factors that have a significant bearing on the output and quality of research. Perhaps the single most crucial factor is the very large number of doctoral students within the research community, which means that a significant proportion of scientific research publications in Finland consists of doctoral theses. It is very rarely that this work is of such a high calibre and so groundbreaking that it achieves very much visibility and impact in the international science community. In other advanced science nations there are more postdoctoral researchers and senior scientists in high-output and high-quality research teams.

In recent years the quality of research has inevitably suffered from the growth of administrative burdens and insufficient provision for auxiliary research staff.

Another significant difference between Finland and many other advanced science nations is that research environments in Finland have had some difficulty attracting foreign researchers into the country. Although researchers and research teams must contribute to addressing this challenge, this is ultimately an issue that has to be resolved at the level of the research system as a whole.

A third factor, and one that is harder to measure than the former two, is the dynamics of research environments. That is influenced by a number of factors, including funding principles, the structures of research environments and their management and intellectual ambitions. Building up an inspiring, dynamic, and creative environment is a hugely challenging task.

Finland is well placed for a quick return to a positive growth track in science and research, as there are a number of strengths that can be drawn upon. At the same time it is possible to look more closely at what others are doing better and where we can still improve our performance and produce higher-quality research.

- *Finland needs to develop a* ***national science strategy*** *to help raise the output and quality of its scientific research. The strategy shall set out 10-year development objectives and identify the means of achieving those objectives. All stakeholders responsible for improving the quality of scientific research shall contribute to this strategy work. One of the major challenges in this undertaking is how to bring together the different means and resources available into one integrated and effective strategy.*

2 The challenges of internationalisation

In the current global labour market, competition for good scientists and researchers and for the best research talent in particular is continuing to grow, and patterns of researcher mobility are in constant flux.

In view of its overall resources and current level of development, the Finnish research system – just as the country's innovation system – is characterised by a low level of international engagement. In this regard it may be assumed that the development of the research system reflects the degree of internationalisation in Finnish society as a whole. It is noteworthy, though, that for the science institution international engagement is one of the main key pillars: new ideas and new knowledge are disseminated via researchers' personal contacts.

In advanced countries the challenges of internationalisation are addressed by science policy instruments that are aimed first and foremost at raising scientific quality standards, enhancing the appeal of the research system, strengthening international research cooperation and increasing mobility.

Despite persistent efforts, the targets set for improving the quality and significance of scientific research have not been achieved, when measured using standard international indicators. This is also impacting adversely on the appeal of the Finnish research system.

- *The overriding goal must be to enhance the quality of scientific research in Finland. The attainment of that goal will also serve to increase the international appeal of our research system, both in the sense of mobility and the capacity for international cooperation. This is the platform from which the Academy of Finland works to develop its policies and funding instruments. Universities must be given further incentive to expand their international engagement.*

The appeal of the research system depends on a number of factors. Apart from the quality of research, other crucial factors include research career arrangements, the international visibility of the work and results produced by universities, research institutes and individual researchers in the country, the level of research infrastructures and the ability of research units and researchers to work with others.

The number of foreign researchers working in Finland is very low in comparison with other EU27 countries. In 2006, no more than 3 per cent of the country's research personnel were foreign-born, compared to the average of 10 per cent for EU27 countries and more than 10 per cent in Sweden, Austria, the Netherlands and Ireland, a group of countries that in many other respects are closely similar to Finland.

Since the late 1990s, the number of teacher and researcher exchange visits between universities has decreased sharply in all other fields except engineering. The number of foreign-born postgraduate students, on the other hand, has increased considerably, most particularly so in engineering and the social sciences. It seems that visits by Finnish postgraduate students to other countries have declined significantly since the early 2000s.

- *Urgent and effective measures are needed to increase the international appeal of the Finnish research system. In particular, research infrastructures should be improved and new incentives created to encourage universities to open up internationally.*
- *It is of paramount importance to advance the internationalisation of graduate schools so that students can start the process of international networking while they are still studying. The Academy contributes to advancing internationalisation through the selection of funding criteria for research projects.*

- *Working closely with Tekes, the Academy shall continue to strengthen and expand opportunities for foreign researchers to work in Finland by developing the Finland Distinguished Professor programme.*
- *New initiatives are needed to attract young scientific talent into Finland.*

There is a growing trend around the world to promote international research cooperation, particularly in the form of joint programming. For Finland, the most significant development is the growth of EU-coordinated programme cooperation. Regional cooperation has also gathered momentum within the European Research Area. Finland is involved in NordForsk cooperation. The Academy has signed agreements of programme cooperation among others with Japan, Canada, China, India, Russia, Brazil and Chile.

Finland's accession to the European Union and the increased use of EU instruments significantly enhanced the internationalisation of Finnish research. Today, however, Finnish involvement in EU Framework Programmes is at a strikingly low level. In European Research Council calls, Finnish researchers have had better than average success, and clearly better success than their colleagues in all other Nordic countries.

- *For reasons of networking it is important that Finnish researchers are more actively involved in EU coordinated programmes. The Academy encourages this involvement by awarding funding for purposes of project planning and preparation.*

3 PhD education and research careers

Doctoral education has been a keen area of development in Finnish university and science policy for the past 15 years. During this time the number of doctorates awarded has doubled. As most of the new graduates have taken up employment in research, Finland's researcher intensity has risen to become by far the highest in the world.

This has been achieved, firstly, through the creation of the graduate school system; and secondly, by rewarding universities based on the number of doctorates awarded. Research for doctoral theses has become an expanding part of scientific research at universities.

The proportion of women among new doctorates has climbed to 50 per cent, which is a significant achievement. By contrast there has been no noticeable drop over the past 15 years in the median age at doctorate, which continues to remain at an internationally high level. Since 1990 the median age at doctorate has fallen only in the engineering and natural sciences fields, where the figure currently stands at 32 years. In other fields the median age at PhD graduation is 37–40 years. Part of the reason for this is that efforts to accelerate the completion of the Master's degree have not been successful; in fact in recent years quite the opposite has happened.

The thinking behind the expansion of doctoral education was that increasing numbers of new PhDs would take up employment outside academia. Indeed, this has been the express objective. However, under the conditions of recession business companies are reluctant to take on more people, while in the public sector the Government's productivity programme is closing many doors. As a result of these failures, the number of research personnel in the higher university sector has increased by almost one-quarter in 2002–2007, but the number of person-years has dropped: an increasing proportion of new PhDs are employed on short-term contracts at universities.

- *The future demand for doctoral students in research and other positions in different fields and sectors must be carefully forecast in order that the nation can take full advantage of its major investments in education.*
- *The mean age at doctorate must be significantly lowered in order to improve the international competitiveness of Finnish researchers and to boost the output of the Finnish research system. Universities should adopt the best practices of graduate schools.*
- *The internationalisation of doctoral education continues to remain an important development focus: this means both increasing the number of foreign postgraduate students in Finland and increasing the number of Finnish postgraduate students abroad.*

In Finland the academic research career is far less predictable than in many other advanced science countries. Especially in its early stages the research career is often pieced together from a succession of fixed and short-term job contracts that are funded from different sources. In contrast to international practice, researchers in Finland cannot guarantee the continuity of their scientific career by producing good results. There is relatively limited intersectoral and international movement.

- *In its funding decisions for Postdoctoral Researchers and Academy Research Fellows, the Academy shall give increasing weight to the criteria of international mobility and cooperation.*

Many of these problems can be resolved through the adoption of the proposed four-tier research career model. The key question that remains with regard to producing research excellence with international impact is whether and to what extent the focus of funding can be shifted towards senior researchers.

- *Incentives and funding criteria must be developed so that senior researchers take on a more prominent role in Finnish research teams at the expense of postgraduate students.*

4 Creative research environments and cooperation

A competitive and creative research team is characterised by a large enough size, good management and communication, a sound and balanced structure and its own distinctive culture. These characteristics have been promoted through measures taken by the organisations themselves as well as by science policy-makers and funding agencies.

A critical precondition is to have access to adequate resources. Funding must be sufficiently sustained and flexible, and there must be an appropriate balance between budget funding and competitive funding. In many fields a high-level research infrastructure is also a necessary condition for high-level research.

The fragmentation of research may be a major obstacle to research environments being able to make good enough use of the different types of expertise available and to apply different approaches in their research.

Centres of Excellence in research provide the clearest example of the Academy's commitment to building and supporting creative and competitive research environments. The CoE strategy has been a resounding success. An assessment is now needed to determine whether it is necessary to develop new funding instruments that would make it possible to provide longer-term funding for research teams that are at a creative stage.

Diversity of research team composition can be crucially important to team performance and output: strong and creative research environments have a balanced mix of researchers of different ages, researchers at different career stages, and men and women. Furthermore, several studies have shown that the involvement of researchers from different cultural backgrounds adds to the creativity of the team.

A major problem at the moment is that the composition of research teams is largely determined by ambitions of doctoral thesis research. For this reason research teams have large numbers of doctoral students and far too few senior researchers, who would be crucial to ensuring a high enough standard of scientific research.

- *The development of creative and competitive research environments is a key mission for science policy and research funding.*
- *The Academy shall conduct an assessment to determine what kinds of new funding instruments would allow for longer-term and more flexible funding for creative teams that have achieved a high scientific level.*
- *For funding and management by results purposes there are good grounds to emphasise the role of senior researchers as a key success factor in creative and competitive research environments.*

Communication and cooperation relations within research teams are set to gain ever greater importance. Science policy and research funding have provided strong encouragement for cooperation across national and organisational boundaries; this is one of the key criteria for Academy and Tekes funding. Cooperation across disciplinary boundaries and applications-oriented cooperation are encouraged most particularly in research and technology programmes, in CoE funding and in Strategic Centres for Science, Technology and Innovation. Graduate schools are an important science policy instrument for promoting cooperation among universities.

- *Mobility between organisations and different fields of science is important for the development of creative research environments.*

University research is an integral part of the national research and innovation system. Universities are in the process of profiling themselves as part of more sweeping changes to the university system: they may give different emphasis to research, undergraduate degree programmes, artistic activity, lifelong learning or innovation and regional activities. This requires ever closer cooperation and interaction with other stakeholders in the research and innovation system. Insofar as they adopt a research-oriented profile, universities will also have to decide on their cooperation with government research institutes, R&D in the private business sector, and centres of expertise.

Programme funding from the EU and the Academy and Tekes have contributed to promoting the cooperation of universities and research institutes. The further development of this cooperation is of vital importance to the success of the whole research system.

- *Cooperation between universities and research institutes must be developed on the basis of their respective scientific strengths.*

Research collaboration between universities and private businesses in Finland is highly advanced and flexible. The research agendas of Strategic Centres for Science, Technology and Innovation also contribute to developing this cooperation. Strategic Centres are business-driven. This may become a problem for long-term scientific research if companies fail to recognize the full potential of radical breakthrough research.

- *It is important to make the best possible use of Strategic Centres in the radical renewal of industry branches by means of scientific research.*

5 Research infrastructures

Finland has not made sufficient investment in research infrastructures and equipment. In an international comparison, infrastructure investment in the Finnish higher education sector has shown weak development. It is important that infrastructures are incorporated as an integral part of universities' and research institutes' development strategies.

In many fields the number and level of infrastructures is crucial to the appeal of the research system. The absence of high-level infrastructures seriously undermines the system's appeal, for instance with respect to the availability of top research talent and opportunities for cooperation.

- *The Academy considers it essential that the investments set out in the Finnish national infrastructure roadmap are completed by 2016.*

In contrast to many other advanced science countries, Finland does not have a funding mechanism for research infrastructures that could provide a centralised assessment of the required resources, prioritise the necessary investments and make the funding decisions.

- *For reasons of improving the standards of Finnish science, the attractiveness of the research system and rational decision-making, the Academy considers it important that a coordinated funding system is created for scientific infrastructures.*
- *International experience has shown that the proposed national infrastructure council is the most workable model. The funding system will require cross-sectoral cooperation and joint investments. The most natural solution would be for the council to be based at the Academy.*
- *Apart from funding, the council's tasks shall include the development of practices and procedures concerning such areas as joint use, maintenance, and the foresighting of new infrastructure needs.*
- *The Academy considers it important that the development of infrastructures is a joint effort to find the best solutions, with special emphasis on quality.*

6 Science in society

The prevailing view in Finland is that, in contrast to many other advanced science nations, young talented people here are very keen on making a career in research. PISA results show that science achievement among Finnish schoolchildren is excellent, providing a firm foundation for later studies. Finland has more researchers in its labour force than any other country in the world.

However, young people in Finland may not be quite as enthusiastic about a career in research as has been believed. According to the PISA survey, young people in Japan have the lowest expectations of a career in research among all advanced science nations, while young people in Finland have the second lowest expectations. It is also evident that young people are less attracted than before to natural science programmes at university.

- *It is important that the education and research system is considered as a whole. This highlights the importance of critical thinking and scientific literacy in secondary education.*

People in Finland are better informed about science and they show a much more positive attitude towards the opportunities it offers than Europeans and Americans on average. The reasons for this lie no doubt in the high level of education in the country as well as in the relative absence of cultural obstacles to the public acceptance of scientific knowledge.

The relationship between public policy preparation and decision-making and the research field has varied over time. Today, this relationship is in transition.

In many countries central government in particular has adopted the principles of evidence-based policy-making. Its cornerstones are the evaluation of the existing research evidence, the collection of new research data if necessary, the consultation of experts and stakeholders, and the submission of alternative policy measures and their knowledge-based evaluation.

- *As well as continuing to pursue the path of structural development, Finland must adopt the principles and practices of evidence-based policy-making. This will promote the use of research evidence in decision-making and thereby improve the quality of decision-making. To this end it is necessary to strengthen the role of scientific expertise in the policy planning process at government ministries.*
- *In the development of sectoral research it is imperative to ensure that government research institutes continue to have access to the necessary expertise based on high-level scientific research.*

Preparations for the structural development of the Finnish research system and the associated decision-making have not always progressed in a unilinear fashion, or at a measured pace. It is natural that, as is the case with any policy changes in society, this process produces not only intended outcomes but also unforeseen changes.

- *The Academy considers it important that the outcomes and changes resulting from the structural development of the research system are constantly monitored and analysed. The Academy shall contribute to this monitoring in line with the Government resolution.*

In a knowledge-based society it is a natural part of science, technology and innovation to demonstrate their social impacts. In Finland, the Academy and Tekes have worked closely to develop a coherent representation of impact in the form of an impact framework. Within this framework the analysis of impact and the development of impact indicators is concentrated in four key areas of society: economy and renewal, learning, education and culture, Finnish welfare and well-being, and the environment.

- *Long-term scientific research remains the key to strong performance in technological development and innovation. This is also one of the key conditions for society's capacity for renewal, education and culture.*
- *The Academy is committed to promoting the impact of research primarily on the basis of scientific quality. At the same time, it will continue to facilitate networking and the involvement of different stakeholders as the most effective channel of generating impact.*

Appendices

Appendix 1. Individuals contributing to the report on the state and quality of scientific research in Finland 2009

Aalto	Mika	Finnish Funding Agency for Technology and Innovation Tekes
Aaltola	Mika	University of Tampere
Absetz	Ilmari	Finnish Funding Agency for Technology and Innovation Tekes
Ahonen	Paavo-Petri	Gaia Consulting Oy
Ahopelto	Jouni	VTT Technical Research Centre of Finland
Ainamo	Antti	Finnish Society for Science and Technology Studies
Airaksinen	Matti S.	University of Helsinki
Alasuutari	Pertti	University of Tampere
Alatossava	Tapani	University of Helsinki
Alén	Raimo	University of Jyväskylä
Andersson	Harri	University of Turku
Annila	Arto	University of Helsinki
Arajärvi	Mirja	Ministry of Education
Arjas	Elja	University of Helsinki
Arjava	Antti	Finnish Cultural Foundation
Aro	Eva-Mari	University of Turku
Astala	Kari	University of Helsinki
Astola	Jaakko	Tampere University of Technology
Auranen	Otto	University of Tampere
Autio-Sarasmo	Sari	University of Helsinki
Auvinen	Anssi	University of Tampere
Bamford	Jaana	University of Jyväskylä
Björkroth	Johanna	University of Helsinki
Buchert	Johanna	VTT Technical Research Centre of Finland
Bäckman	Jan	Academy of Finland
Carlsson	Sanna	Academy of Finland
Castren	Eero	University of Helsinki
Chen	Ruizhi	Finnish Geodetic Institute
Dammert	Ritva	Academy of Finland
den Hollander	Daphne	NWO, Netherlands
Donner	Kristian	University of Helsinki
Ekman	Kalevi	Helsinki University of Technology
Eloranta	Eero	Helsinki University of Technology
Engeström	Ritva	University of Helsinki
Ervelä-Myréen	Eili	Academy of Finland
Fogelholm	Mikael	Academy of Finland
Forsman	Tiina	Academy of Finland
Friberg	Ari	Helsinki University of Technology
Gyllenberg	Mats	University of Helsinki
Gylling	Helena	University of Kuopio
Haapala	Pertti	University of Tampere
Haaparanta	Leila	University of Tampere
Hagelin	Aila	Academy of Finland
Haggren	Henrik	Helsinki University of Technology
Haila	Yrjö	University of Tampere
Hakala	Johanna	University of Tampere
Hakulinen	Timo	FInnish Cancer Registry
Halinen	Petri	University of Helsinki

Hannula	Simo-Pekka	Helsinki University of Technology
Hanski	Ilkka	University of Helsinki
Hansteen	Thomas	RCN, Norway
Harlin	Ali	Tampere University of Technology
Hattula	Raija	Academy of Finland
Haukioja	Jussi	University of Turku
Hedvall	Maj-Britt	Hanken School of Economics
Heikinheimo	Markku	University of Helsinki
Heikinheimo	Riikka	Finnish Funding Agency for Technology and Innovation Tekes
Heikkinen	Erja	Ministry of Education
Heikkinen	Pekka	University of Helsinki
Heinonen	Marina	University of Helsinki
Heinonen	Pertti	Finnish Funding Agency for Technology and Innovation Tekes
Helander	Eila	University of Helsinki
Hemming	Samuli	Academy of Finland
Hemminki	Elina	National Research and Development Centre for Welfare and Health
Hentilä	Helka-Liisa	University of Oulu
Hiidenmaa	Pirjo	Academy of Finland
Himanen	Laura	University of Tampere
Hjelt	Kari	Nokia Research Centre
Hjelt	Mari	Gaia Consulting Oy
Hokkanen	Heikki	University of Helsinki
Holm	Liisa	University of Helsinki
Holmbom	Bjarne	Åbo Akademi University
Holopainen	Heikki	Academy of Finland
Holopainen	Irma	University of Turku
Hovatta	Iiris	University of Helsinki
Hovi-Wasastjerna	Päivi	University of Art and Design Helsinki
Hughes	Mark	Helsinki University of Technology
Huhtala	Anni	MTT Agrifood Research Finland
Hukkanen	Veijo	University of Oulu
Hukkinen	Janne	Helsinki University of Technology
Huovelin	Juhani	University of Helsinki
Hupa	Mikko	Åbo Akademi University
Husgafvel-Pursiainen	Kirsti	Finnish Institute of Occupational Health
Husso	Kai	Science and Technology Policy Council
Hytönen	Sanna	Academy of Finland
Hyvärinen	Jari	Finnish Funding Agency for Technology and Innovation Tekes
Häggman	Hely	University of Oulu
Häkli	Jouni	University of Tampere
Häme	Tuomas	VTT Technical Research Centre of Finland
Hämäläinen	Keijo	University of Helsinki
Hänninen	Hannu	Helsinki University of Technology
Hänninen	Marja-Liisa	University of Helsinki
Hänninen	Pekka	University of Turku
Härkönen	Pirkko	Lund University, Sweden
Högnäs	Göran	Åbo Akademi University
Höijer	Laura	MTT Agrifood Research Finland
Ikonen	Eeva	Academy of Finland
Ilmoniemi	Risto	Helsinki University of Technology
Isotalus	Pekka	University of Tampere
Ivaska	Ari	Åbo Akademi University
Jacobsson	Carl	Swedish Research Council
Jokinen	Kimmo	University of Jyväskylä
Jukola	Saana	Academy of Finland

Julin	Rauno	University of Jyväskylä
Julkunen-Tiitto	Riitta	University of Joensuu
Jungman	Tor	Finnish Heart Association
Juvonen	Riitta	Chemical Industry Association
Juvonen	Tatu	University of Oulu
Jylhä	Marja	University of Tampere
Jänne	Olli	University of Helsinki
Jääskeläinen	Timo	University of Joensuu
Kahlos	Maijastina	University of Helsinki
Kaila	Kai	University of Helsinki
Kajantie	Eero	National Public Health Institute
Kallioniemi	Olli	Institute for Molecular Medicine Finland
Kangasjärvi	Jaakko	University of Helsinki
Kankaanpää	Paula	Arctic Centre
Kanto	Kimmo	Finnish Funding Agency for Technology and Innovation Tekes
Karhu	Juha	University of Helsinki
Karhumäki	Juhani	University of Turku
Karjalainen	Juha	University of Jyväskylä
Karlsson	Markku	UPM Kymmene
Karppinen	Maarit	Helsinki University of Technology
Karppinen	Soile	Academy of Finland
Katajamäki	Hannu	University of Vaasa
Katko	Tapio	Tampere University of Technology
Kaukonen	Erkki	University of Tampere
Kaukovirta-Norja	Anu	VTT Technical Research Centre of Finland
Kauppi	Lea	Finnish Environment Institute
Kauppi	Pekka	University of Helsinki
Kauppinen	Esko	Helsinki University of Technology
Kauranen	Martti	Tampere University of Technology
Kautonen	Mika	University of Tampere
Keinonen	Turkka	University of Art and Design Helsinki
Keinänen	Kari	University of Helsinki
Keski-Oja	Jorma	University of Helsinki
Ketola	Mikko	University of Helsinki
Kivelä	Sirkka-Liisa	University of Turku
Kivikuru	Ullamaija	University of Helsinki
Kivinen	Markku	University of Helsinki
Kivinen	Osmo	University of Turku
Knip	Mikael	University of Helsinki
Koistinaho	Jari	University of Kuopio
Kokkala	Matti	VTT Technical Research Centre of Finland
Kolu	Timo	Academy of Finland
Kononen	Kaisa	BONUS EEIG
Kontinen	Vesa	National Public Health Institute
Koponen	Juhani	University of Helsinki
Korhonen	Hannu	MTT Agrifood Research Finland
Korkeala	Hannu	University of Helsinki
Korpimäki	Erkki	University of Turku
Koskela	Pekka	University of Jyväskylä
Koskenlinna	Markus	Finnish Funding Agency for Technology and Innovation
Koskinen	Hannu	University of Helsinki
Koskinen	Jari	VTT Technical Research Centre of Finland
Koskinen	Kari	Helsinki University of Technology
Kostamovaara	Juha	University of Oulu
Kotilainen	Jari	University of Turku

Kovalainen	Anne	Turku School of Economics
Kujala	Urho	University of Jyväskylä
Kukkonen	Ilmo	Geological Survey of Finland
Kulmala	Markku	University of Helsinki
Kulomaa	Markku	University of Tampere
Kumpulainen	Kristiina	University of Helsinki
Kurki	Hannele	Academy of Finland
Kurki	Pekka	National Agency for Medicines
Kutinlahti	Pirjo	Ministry of Employment and the Economy
Kyrölä	Erkki	Finnish Meteorological Institute
Kämäri	Juha	Finnish Environment Institute
Kärenlampi	Sirpa	University of Kuopio
Kärkkäinen	Asta	Nokia Oyj
Kärkkäinen	Katri	Finnish Forest Research Institute (Metla)
Käyhkö	Jukka	University of Turku
Kääriäinen	Helena	National Public Health Institute
Laaksonen	Leo	Federation of Finnish Technology Industries
Laasonen	Mauri	Tampere University of Technology
Lahti	Reijo	University of Turku
Laine	Ilpo	University of Joensuu
Laitinen	Risto	University of Oulu
Lajunen	Lauri	University of Oulu
Lammasniemi	Jorma	VTT Technical Research Centre of Finland
Latikka	Juha	Academy of Finland
Lauri	Sari	University of Helsinki
Lavonen	Jari	University of Helsinki
Lehenkari	Janne	Advansis Oy
Lehenkari	Petri	University of Oulu
Lehesjoki	Anna-Elina	University of Helsinki
Lehtinen	Ari	University of Joensuu
Lehtinen	Maaria	Academy of Finland
Lehvo	Annamaija	Academy of Finland
Leino-Kilpi	Helena	University of Turku
Leiviskä	Kauko	University of Oulu
Lemmetyinen	Helge	Tampere University of Technology
Lemola	Tarmo	Advansis Oy
Lepistö	Toivo	Tampere University of Technology
Lepola	Janne	University of Turku
Leskelä	Markku	University of Helsinki
Lindström	Kai	Åbo Akademi University
Lindström	Miia	University of Helsinki
Linko	Susan	Academy of Finland
Lunabba	Johan	Gaia Consulting Oy
Lundell	Taina	University of Helsinki
Luomi	Jorma	Helsinki University of Technology
Luukkanen	Jyrki	Turku School of Economics
Lyly	Annina	University of Helsinki
Lyytikäinen	Pirjo	University of Helsinki
Lönnberg	Harri	University of Turku
Löppönen	Paavo	Academy of Finland
Majahalme	Tapio	Tampere University of Technology
Makarow	Marja	ESF
Manninen	Matti	University of Jyväskylä
Markkola	Pirjo	Åbo Akademi University
Markku	Reijo	Design Reform Oy

Matikainen	Raija	Academy of Finland
Mattila	Markku	Academy of Finland
Mattila	Pertti	University of Helsinki
Merikallio	Jussi	Federation of Local and Regional Authorities
Miettinen	Marita	University of Tampere
Miettinen	Reijo	University of Helsinki
Muinonen	Karri	University of Helsinki
Mukala	Kristiina	Finnish Medical Society Duodecim, Centre for Military Medicine
Muona	Jyrki	University of Helsinki
Mursula	Kalevi	University of Oulu
Mustonen	Jukka	University of Tampere
Mustonen	Riitta	Academy of Finland
Mutanen	Marja	University of Helsinki
Mykkänen	Jussi	Vaisala Oyj
Myllylä	Raili	University of Oulu
Mäkelä	Marjukka	National Research and Development Centre for Welfare and Health
Mäkelä	Sari	University of Turku
Mäkinen	Kristiina	University of Helsinki
Mälkki	Anssi	Academy of Finland
Mänttäri	Mika	Lappeenranta University of Technology
Mäntylä	Hans	Helsinki School of Economics
Mönkkönen	Jukka	University of Kuopio
Mönkkönen	Mikko	University of Jyväskylä
Neuvo	Yrjö	Helsinki University of Technology
Nevalainen	Terttu	University of Helsinki
Nevanlinna	Olavi	Helsinki University of Technology
Niemelä	Pauli	University of Kuopio
Nieminen	Mika	University of Helsinki
Nieminen	Risto	Helsinki University of Technology
Nikinmaa	Mikko	University of Turku
Nordenstreng	Kaarle	University of Tampere
Nordlund	Kai	University of Helsinki
Nousiainen	Kevät	University of Helsinki
Nuolijärvi	Pirkko	Research Institute for the Languages of Finland
Nuorteva	Jussi	National Archives of Finland
Nuotio	Kimmo	University of Helsinki
Nupponen	Nina	University of Helsinki
Nurmi	Hannu	University of Turku
Nurmi	Jari-Erik	University of Jyväskylä
Nuutinen	Anu	Academy of Finland
Näätänen	Risto	University of Helsinki
Oinas	Päivi	Turku School of Economics
Oja	Erkki	Helsinki University of Technology
Oja	Hannu	University of Tampere
Oksman-Caldentey	Kirsi-Marja	VTT Biotechnology
Ollikainen	Markku	University of Helsinki
Ollila	Eeva	Ministry of Social Affairs and Health
Paalanen	Mikko	Helsinki University of Technology
Paasi	Anssi	University of Oulu
Paasikivi	Nelli	Konecranes Oyj
Paavilainen	Leena	Finnish Forest Research Institute (Metla)
Paju	Susanna	University of Helsinki
Palmroth	Minna	Finnish Meteorological Institute
Paloheimo	Heikki	University of Tampere
Palonen	Kari	University of Jyväskylä

Palva	Tapio	University of Helsinki
Pantzar	Mika	National Consumer Research Centre
Panula	Pertti	University of Helsinki
Parkkari	Tuomas	Science and Technology Policy Council
Partanen	Jarmo	Lappeenranta University of Technology
Pauli	Anneli	European Commission
Pehkonen	Jaakko	University of Jyväskylä
Pekkanen	Jukka	Confederation of Finnish Construction Industries RT
Pelkonen	Jukka	University of Kuopio
Pelkonen	Paavo	University of Joensuu
Pellinen	Terhi	Helsinki University of Technology
Peltonen	Laura	Finnish Funding Agency for Technology and Innovation Tekes
Peltoniemi	Markku	Helsinki University of Technology
Penttilä	Merja	VTT Technical Research Centre of Finland
Pesonen	Hanna-Leena	University of Jyväskylä
Pesonen	Pekka	Finnish Funding Agency for Technology and Innovation Tekes
Pessa	Markus	Tampere University of Technology
Pietikäinen	Matti	University of Oulu
Pietikäinen	Petteri	Academy of Finland
Pietola	Kyösti	MTT Agrifood Research Finland
Pihlajaniemi	Taina	University of Oulu
Piirainen	Tatu	University of Tampere
Piironen	Vieno	University of Helsinki
Polla	Matti	University of Helsinki
Poropudas	Olli	Ministry of Education
Poutanen	Kaisa	VTT Technical Research Centre of Finland
Poutanen	Markku	Finnish Geodetic Institute
Pouttu	Ari	University of Oulu
Pulkkinen	Pentti	Academy of Finland
Pulkkinen	Tuija	Finnish Meteorological Institute
Puttonen	Jari	Helsinki University of Technology
Puuska	Hanna-Mari	University of Tampere
Pyykkö	Pekka	University of Helsinki
Pyysiäinen	Ilkka	University of Helsinki
Pyörälä	Satu	University of Helsinki
Päivärinta	Lassi	University of Helsinki
Pörhölä	Maili	University of Jyväskylä
Raaska	Laura	Academy of Finland
Raento	Pauliina	University of Helsinki
Raivio	Kari	University of Helsinki
Raivola	Vera	Academy of Finland
Rantanen	Jorma	Finnish Institute of Occupational Health
Rautiainen	Anna-Maija	Finnish Funding Agency for Technology and Innovation Tekes
Rauvala	Heikki	University of Helsinki
Reuter	Martina	University of Helsinki
Rinne	Risto	University of Turku
Riska	Dan-Olof	Helsinki Institute of Physics
Rissanen	Kari	University of Jyväskylä
Ritsilä	Jari	University of Jyväskylä
Roivainen	Merja	National Public Health Institute
Rojola	Lea	University of Turku
Romantschuk	Martin	University of Helsinki
Roos	Jaana	Academy of Finland
Rosenholm	Jarl	Åbo Akademi University
Rouvinen	Juha	University of Joensuu

Rummukainen	Kari	University of Oulu
Ruohotie	Pekka	University of Tampere
Ruskoaho	Heikki	University of Oulu
Ryhänen	Eeva-Liisa	MTT Agrifood Research Finland
Saarikangas	Kirsi	University of Helsinki
Saarinen	Jukka	Nokia Oyj
Sairinen	Rauno	University of Joensuu
Salmela-Aro	Katariina	University of Jyväskylä
Salmenkivi	Erja	University of Helsinki
Salminen	Seppo	University of Turku
Salo	Tuula	University of Oulu
Salonen	Reijo	Orion Pharma
Saris	Per	University of Helsinki
Satka	Mirja	University of Jyväskylä
Savilahti	Harri	University of Turku
Savolainen	Markku	University of Oulu
Savolainen	Outi	University of Oulu
Savunen	Liisa	Finnish Council of University Rectors
Schulman	Alan H.	MTT Agrifood Research Finland, University of Helsinki
Seppälä	Esko-Olavi	Science and Technology Policy Council
Seppälä	Jukka	Helsinki University of Technology
Sere	Kaisa	Åbo Akademi University
Serimaa	Ritva	University of Helsinki
Setälä	Maija	University of Turku
Sievi	Eeva	Academy of Finland
Sihvola	Ari	Helsinki University of Technology
Sihvola	Juha	University of Helsinki
Simpura	Jussi	National Research and Development Centre for Welfare and Health
Sipilä	Jorma	University of Tampere
Sistonen	Lea	Åbo Akademi University
Skurnik	Mikael	University of Helsinki
Smolander	Heikki	Finnish Forest Research Institute (Metla)
Sorvari	Sanna	University of Helsinki
Stigell	Pauli	Finnish Funding Agency for Technology and Innovation Tekes
Strand	Kari	University of Oulu
Sundström	Liselotte	University of Helsinki
Suni	Ilkka	VTT Technical Research Centre of Finland
Suominen	Kalle-Antti	University of Turku
Syrjänen	Mikko	Gaia Consulting Oy
Syrjänen	Stina	University of Turku
Säteri	Helena	Ministry of the Environment
Taavitsainen	Jussi-Pekka	University of Turku
Tahvonen	Risto	MTT Agrifood Research Finland
Taipale	Jussi	University of Helsinki
Takala	Timo	Oulu Deaconess Institute
Talvitie	Antti	Helsinki University of Technology
Tamminen	Tuula	University of Tampere
Taurio	Ritva	Academy of Finland
Teeri	Teemu	University of Helsinki
Tenhunen	Hannu	University of Turku
Tenhunen	Sirpa	University of Helsinki
Tienari	Pentti	Hospital District of Helsinki and Uusimaa
Tiensuu	Paul	Academy of Finland
Tilli	Kari	Finnish Funding Agency for Technology and Innovation Tekes
Timonen	Juhani	SWOT Consulting

Tirronen	Mika	Academy of Finland
Toivanen	Hannes	Ministry of Employment and the Economy
Toivanen	Otto	University of Helsinki
Toivanen	Reetta	University of Helsinki
Toivonen	Heikki	Finnish Environment Institute
Tokola	Timo	University of Joensuu
Tolonen	Marja-Leena	Finnish Funding Agency for Technology and Innovation Tekes
Torkkola	Sinikka	University of Tampere
Tuominen	Marja	University of Lapland
Tuominen	Markku	Lappeenranta University of Technology
Tuunainen	Juha	University of Helsinki
Tuusa	Heikki	Tampere University of Technology
Törmä	Päivi	Helsinki University of Technology
Uotila	Minna	University of Lapland
Ursin	Jani	University of Jyväskylä
Uusitalo	Olavi	Tampere University of Technology
Vaahtera	Kaisa	Academy of Finland
Vaattovaara	Mari	University of Helsinki
Vainio	Martti	University of Helsinki
Vainio-Korhonen	Kirsi	University of Turku
Vainiotalo	Pirjo	University of Joensuu
Valkeasuo	Laura	Academy of Finland
Valtonen	Heli	University of Jyväskylä
Valtonen	Tellervo	University of Jyväskylä
Vanhala	Jukka	Tampere University of Technology
Vartiainen	Maria	University of Helsinki
Vartiainen	Perttu	University of Joensuu
Vartiainen	Terttu	National Public Health Institute
Vattulainen	Ilpo	Tampere University of Technology
Weckström	Matti	University of Oulu
Vestala	Leena	Ministry of Education
Westerlund-Wikström	Benita	University of Helsinki
Viemerö	Janne	Finnish Funding Agency for Technology and Innovation Tekes
Vihma-Purovaara	Tiina	Academy of Finland
Viisanen	Yrjö	Finnish Meteorological Institute
Viitanen	Kauko	Helsinki University of Technology
Viitasalo	Markku	Finnish Institute of Marine Research
Vilkki	Suvi	Academy of Finland
Vilkko	Risto	Academy of Finland
Visakorpi	Tapio	University of Tampere
von Bonsdorff	Pauline	University of Jyväskylä
von Wright	Atte	University of Kuopio
Vuolanto	Pia	University of Tampere
Vuorela	Pia	Åbo Akademi University
Vuorinen	Tapani	Helsinki University of Technology
Välimaa	Jussi	University of Jyväskylä
Väänänen	Kalervo	University of Turku
Väänänen	Keijo	University of Oulu
Ylijoki	Oili-Helena	University of Tampere
Ylikarjula	Janica	Confederation of Finnish Industries EK
Ylänne	Jari	University of Jyväskylä
Åkerman	Karl	Biomedicum Helsinki
Ämmälahti	Erja	Finnish Funding Agency for Technology and Innovation Tekes
Östman	Jan-Ola	University of Helsinki

Appendix 2. Bibliometrics

A) Bibliometric analyses for the 2009 report

Bibliometric science indicators

Number and share of scientific publications	• Background indicator • Changes in publication numbers are studied by country and field of science.
Relative citation impact	• Provides a rough indication of the scientific impact and quality of research compared to world level. • Relative citation impact is calculated as follows: ***A/B*** ***A*** = number of fractionalised citations received by publications / fractionalised publications ***B*** = world average citations for each field of science and type of publications World average citations for a field of science or type of publication can be determined for a major field of science, a category of science or for all Finnish publications during a certain period of time. • Citations received by, for example, all Finnish publications or Finnish publications within a certain field as a percentage more or less than citations received by all world publications during a certain period.
Highly cited publications	• Provides a rough indication of leading edge research. • Proportion of Finnish publications that rank among the most highly cited world publications. • Proportion of Finnish publications within a certain field that rank among the most highly cited world publications in that field. • Proportion of publications among the 1%, 5% or 10% most highly cited world publications.
International publishing cooperation	• Describes the level of international research cooperation through the number of publications co-authored with researchers from different countries. • Number of international co-publications and share of all publications by country. Examination can focus for instance on Finnish co-publications in different fields of science.

Bibliometric data

- The bibliometric data are compiled by the Swedish Research Council and consist of three databases produced by Thomson Reuters (http://scientific.thomson.com): Science Citation Index Expanded, Social Science Citation Index and Arts & Humanities Citation Index. These databases are available from 1982 onwards. (Database coverage is extremely limited for the humanities and largely for the social sciences.)
- The data comprise original articles and reviews. Other types of publication included under the same heading with original articles include notes and letters. Conferences proceedings are not included.
- The bibliometric data and methods are described in closer detail in part B of this Appendix.

Field of science classifications

- The field of science classification for a particular scientific article is determined based on the field of the journal in which the article is published.
- The three databases mentioned above comprise a total of 255 fields. In recent years Finnish researchers have published in 240 of those fields (e.g. Biochemistry & Molecular Biology; Environmental Sciences; Endocrinology & Metabolism; Engineering, Electrical & Electronics).

- Chapter 2 in the first section of this report presents bibliometric analyses for 12 different fields of sciences. These fields have been formed by combining a number of Thomson Reuters classifications (Appendix Table 1). Publications in the social sciences and humanities are not included in these analyses because the Thomson Reuters data offer only a fragmentary picture of developments in these fields. The Research Council report on health research in second section includes bibliometric analyses of three out of these 12 fields.
- The field of research classifications used in the bibliometric analyses in the Research Council reports on biosciences and the environment and on natural sciences and engineering in second section are described in Appendix Tables 2A and 2B.

Bibliometric methods

Fractionalisation	• Fractionalisation by country is performed when a publication is co-authored by persons from different countries. For instance, a co-publication by Finnish and Swedish researchers produces 0.5 publications for each country. Based on authors' addresses. • Fractionalisation by field of science is performed when a publication is classified in more than one field. This eliminates overlap when different fields are grouped into larger clusters. • Each publication is calculated in the analysis once only, and the ratio of fractions is always one. • Citations are fractionalised in the same way as publications. • Articles receiving the most citations do not dominate the citation analysis.
Normalisation	• Normalisation allows for a more balanced analysis of different fields of science and different types of publication in the same dataset. In addition, normalisation allows for a more reliable analysis of time series. • The method takes account of the differences in citation practices between different fields of science and different types of publication.
Citation window*	• Citations accumulate over time, and therefore citations are calculated for specified periods (3-year citation window: year of publication + 2 following years).
Removal of self citations	• Based on mechanical identification of self citations according to the authors' surname and initials. • If the author of both the citing and cited work is the same, this is interpreted as a self citation. • This method involves a risk of error if the citing and cited researcher have exactly the same surname or initials. It may cause distortion in fields of science where publications are based on the cooperation of very large research teams.

* The 2007 citation statistics are incomplete, comprising the year of publication plus one year. The 2006 and 2007 analyses presented for individual fields of science in the Research Council reports on biosciences and the environment and on natural sciences and engineering in the second section of the report are incomplete, 2006 citation statistics cover the year of publication plus one year, and 2007 citation statistics the year of publication.

Appendix Table 1. Field of science classification used in Chapter 2 of the first part of the report.

Field of science	Thomson Reuters categories	
Biology	Biodiversity Conservation	Limnology
	Biology	Marine & Freshwater Biology
	Biology, miscellaneous	Mycology
	Ecology	Ornithology
	Evolutionary Biology	Reproductive Biology
	Developmental Biology	Plant Sciences
	Entomology	Zoology
Biosciences and biomedicine*	Anatomy & Morphology	Genetics & Heredity
	Biochemical Research Methods	Immunology
	Biochemistry & Molecular Biology	Microbiology
	Biophysics	Microscopy
	Biotechnology & Applied Microbiology	Neurosciences
	Cell Biology	Pharmacology & Pharmacy
	Chemistry, Medicinal	Physiology
	Cytology & Histology	
Physics	Acoustics	Physics, Atomic, Molecular & Chemical
	Astronomy & Astrophysics	Physics, Multidisciplinary
	Thermodynamics	Physics, Condensed Matter
	Nuclear Science & Technology	Physics, Nuclear
	Optics	Physics, Particles & Fields
	Physics, Applied	Physics, Mathematical
	Physics, Fluids & Plasmas	
Geosciences	Geochemistry & Geophysics	Meteorology & Atmospheric Sciences
	Geography, Physical	Mineralogy
	Geology	Oceanography
	Geosciences, Multidisciplinary	Paleontology
Chemistry	Chemistry, Applied	Chemistry, Physical
	Chemistry, Multidisciplinary	Crystallography
	Chemistry, Analytical	Electrochemistry
	Chemistry, Inorganic & Nuclear	Polymer Science
	Chemistry, Organic	Spectroscopy
Clinical medicine*	Allergy	Neuroimaging
	Andrology	Obstetrics & Gynecology
	Anesthesiology	Oncology
	Cardiac & Cardiovascular System	Ophthalmology
	Clinical Neurology	Orthopedics
	Critical Care Medicine	Otorhinolaryngology
	Dentistry, Oral Surgery & Medicine	Parasitiology
	Dermatology	Pathology
	Emergency Medicine	Pediatrics
	Endocrinology & Metabolism	Peripheral Vascular Disease
	Gastroenterology & Hepatology	Psychiatry
	Geriatrics & Gerontology	Psychology, Clinical
	Gerontology	Radiology, Nuclear Medicine & Medical Imaging
	Hematology	Rehabilitation
	Infectious Diseases	Respiratory System
	Integrative & Complementary Medicine	Rheumatology
	Medical Ethics	Substance Abuse

Field of science	Thomson Reuters categories	
Clinical medicine continues*	Medical Informatics	Surgery
	Medical Laboratory Technology	Toxicology
	Medicine, General & Internal	Transplantation
	Medicine, legal	Tropical Medicine
	Medicine, miscellaneous	Urology & Nephrology
	Medicine, Research & Experimental	Virology
Agricultural sciences	Agriculture, Dairy & Animal Science	Food Science & Technology
	Agricultural Engineering	Forestry
	Agricultural Economics & Policy	Horticulture
	Agriculture, Multidisciplinary	Soil Science
	Agricultural experiment station reports	Veterinary Sciences
	Agronomy	Water Resources
	Fisheries	
Mathematics	Mathematical & Computational Biology	Mathematics, Interdisciplinary Applications
	Mathematics, General	Mathematics
	Mathematics, Applied	Statistics & Probability
Engineering	Construction & Building Technology	Materials Science, Biomaterials
	Energy & Fuels	Materials Science, Ceramics
	Engineering, Aerospace	Materials Science, Characterization, Testing
	Engineering, Biomedical	Materials Science, Coatings & Films
	Engineering, Chemical	Materials Science, Composites
	Engineering, Civil	Materials Science, Multidisciplinary
	Engineering, Environmental	Materials Science, Paper & Wood
	Engineering, Geological	Materials Science, Textiles
	Engineering, Industrial	Mechanics
	Engineering, Manufacturing	Metallurgy & Metallurgical Engineering
	Engineering, Marine	Metallurgy & Mining
	Engineering, Mechanical	Mining & Mineral Processing
	Engineering, Multidisciplinary	Nanoscience & Nanotechnology
	Engineering, Ocean	Operations Research & Management Science
	Engineering, Petroleum	Transportation
	Ergonomics	Transportation Science & Technology
Health sciences*	Health Care Sciences & Services	Public, Environmental & Occupational Health
	Nursing	Sport Sciences
	Nutrition & Dietetics	
Computer Sciences (ICT)	Automation & Control Systems	Computer Science, Software Engineering
	Computer applications & Cybernetics	Computer Science, Theory & Methods
	Computer critical reviews	Engineering, Electrical & Electronic
	Computer Science, Artificial Intelligence	Instruments & Instrumentation
	Computer Science, Cybernetics	Remote Sensing
	Computer Science, Hardware & Architecture	Robotics
	Computer Science, Information Systems	Telecommunications
	Computer Science, Interdisciplinary Applications	
Environmental Sciences	Environmental Sciences	

* Publishing in this field is also discussed in the health research section of the second part of the report.
Certain data included herein are derived from the Science Citation Index Expanded® prepared by Thomson Reuters®, Philadelphia, Pennsylvania, USA.

Appendix table 2A. Classification of research fields used in the bibliometric analyses of biosciences and environmental research in appendices 1–4.

The classifications used in the bibliometric analyses have been chosen with a view to maximum correspondence with the workshop fields referred to in the text. The classifications of the databases used impose some restrictions in this regard.

Appendices 1 and 2

Research fields	Database classifications
Biochemistry	Biochemistry & Biophysics Cell & Developmental Biology Molecular Biology & Genetics
Ecology	Environment / Ecology
Food sciences	Food Science / Nutrition
Plant sciences	Plant Sciences
Agriculture and forestry	Agricultural chemistry Agriculture / Agronomy
Microbiology	Microbiology
Neurosciences	Neurosciences & Behavior Physiology

Database used: Thomson Scientific, National Science Indicators 1981–2005 (Deluxe).

Appendices 3 and 4

Research fields	Science Citation Index Expanded Database: Subject Categories	
Biochemistry	Biochemistry & Molecular Biology Biochemical Research Methods Biophysics Cell Biology	Developmental Biology Genetics & Heredity Mathematical & Computational Biology
Ecology	Biodiversity Conservation Ecology	Evolutionary Biology
Food sciences	Food Science & Technology	Nutrition & Dietetics
Plant sciences	Biotechnology & Applied Microbiology	Plant Sciences
Geography	Geography	Geography, Physical
Agriculture	Agricultural Economics & Policy Agricultural Engineering Agricultural Experiment Station Reports Agriculture, Dairy & Animal Science Agriculture, Multidisciplinary	Agronomy Fisheries Horticulture Soil Science Water Resources
Forestry	Forestry	
Microbiology	Microbiology	Virology
Neurosciences	Neurosciences	Physiology
Environmental research	Environmental Sciences	Environmental Studies

Appendix table 2B. Classification of research fields used in the bibliometric analyses of natural sciences and engineering research.

Field of research	Science Citation Index Expanded Database: Subject Categories	
Space sciences and astronomy	Astronomy & Astrophysics	
Physics	Acoustics Physics, Applied Physics, Fluids & Plasmas Physics, Atomic, Molecular & Chemical Physics, Multidisciplinary Physics, Condensed Matter	Physics, Nuclear Physics, Particles & Fields Physics, Mathematical Nuclear Science & Technology Thermodynamics
Geosciences	Geochemistry & Geophysics Geography, Physical Geology Geosciences, Multidisciplinary Meteorology & Atmospheric Sciences	Mineralogy Oceanography Paleontology Remote Sensing
Chemistry	Chemistry, Applied Chemistry, Multidisciplinary Chemistry, Analytical Chemistry, Inorganic & Nuclear Chemistry, Organic	Chemistry, Physical Crystallography Electrochemistry Polymer Science Spectroscopy
Mathematics and statistics	Mathematical & Computational Biology Mathematics, Applied Mathematics, Interdisciplinary Applications	Mathematics Statistics & Probability
Materials Science	Materials Science, Ceramics Materials Science, Multidisciplinary Materials Science, Biomaterials Materials Science, Characterization, Testing Materials Science, Coatings & Films	Materials Science, Composites Materials Science, Textiles Nanoscience & Nanotechnology Optics
Energy technology and environmental engineering	Energy & Fuels	Engineering, Environmental
Mechanical engineering and manufacturing technology	Engineering, Aerospace Engineering, Manufacturing Engineering, Mechanical	Ergonomics Mechanics
Process technology	Engineering, Chemical Metallurgy & Metallurgical Engineering	Mining & Mineral Processing
Pulp and paper technology	Materials Science, Paper & Wood	
Construction technology and municipal engineering, architecture	Architecture Construction & Building Technology Engineering, Civil	Transportation Transportation Science & Technology
Electrical engineering and electronics	Automation & Control Systems Engineering, Electrical & Electronic Instruments & Instrumentation	Robotics Telecommunications
Computer science (ICT)	Computer Science, Artificial Intelligence Computer Science, Cybernetics Computer Science, Hardware & Architecture Computer Science, Information Systems	Computer Science, Interdisciplinary Applications Computer Science, Software Engineering Computer Science, Theory & Methods
Industrial management	Engineering, Industrial	Operations Research & Management Science

B) Data source, definitions and computation formulas

Data source

- The statistics are compiled using the publications database at the Swedish Research Council (Vetenskapsrådet). This database contains all publications from international journals indexed in the following Thomson Reuters products: *Science Citation Index Expanded*, *Social Science Citation Index* and *Arts & Humanities Citation Index.*
- Any report based on these data is required to include the following statement: Certain data included herein are derived from the Science Citation Index Expanded®, Social Science Citation Index and Arts & Humanities Citation Index prepared by Thomson Reuters®, Philadelphia, Pennsylvania, USA© Copyright Thomson Reuters® 2009. All rights reserved.

Definitions

- *Publication types included.* All statistics are based on articles and reviews only. However, the definition of article has been expanded to include the publication types note and letter. The types note and article were merged by Thomson Reuters in 1996, but the Swedish Research Council has also merged them before this year.
- All *citation statistics* are based on field normalised citations using a 3-year citation window (i.e. citations received during the publication year +2 following years). For the year 2007, the 3-year citation window is not complete and therefore the statistics may change when the database is updated. Volume and citation statistics may also change concerning previous years when the database is updated, since new journals are continuously added to the database contents. Updates usually also include back issues of new journals.
- *Self citations* are always removed based on author names. All citations where the same surname and initial(s) occur among the authors in both the citing and cited work are ignored.
- *Multidisciplinary publications* are, whenever possible, reclassified into other subject fields based on (a) the subject profile of the reference list of each multidisciplinary publication and (b) the subject profile of the publication citing the publication. A publication remains classified as multidisciplinary only when the reclassification algorithm has failed to reclassify it. After the year 2000, approximately 10% of the publications originally classified as multidisciplinary remain in this group.

Computations

Number of (fractionalised) publications per subject field

$$P_{s,\,frac} = \sum_{i=1}^{P} \frac{A_i}{T_i S_i}$$

where

P = the number of publications the unit has participated in

A_i = the number of author addresses from the analysed country or region in publication *i*

T_i = the total number of author addresses in publication *i*

S_i = the number of subject fields publication *i* is assigned to.

For example, if a publication has five addresses of which two belong to Finnish organisations and the publication is assigned to two subject fields, Finland is credited 2/(5*2) = 0.2 fractionalised publications to *each* of the two subject fields. All statistics on number of publications are based on fractionalised numbers according to this definition.

Field normalised citation rate (c_f)

The field normalised citation rate is one of what is called ‘state-of-the-art’ bibliometric indicators. The general idea of the indicator is to relate the number of citations made to a publication or a group of publications to average citations to a group of comparable publications of the same publication type, publication year and scientific field.

The Swedish Research Council calculates its c_f indicator using a fraction-oriented method, which means that the citation rate of each subject fraction for a publication is normalised against an average citation rate for the same publication type, publication year and subject field that the fraction in question belongs to. When the average normalised citation rate for the analysed unit's publication is calculated, each publication fraction is weighted according to the inverse of the number of subject fractions, so that the resulting average is a weighted average.

The average c_f is calculated according to the following formula:

$$C_f = \frac{\sum_{i=1}^{R} \frac{C_i}{S_i * A_i * \mu_{f(i)}}}{\sum_{i=1}^{R} \frac{1}{S_i * A_i}}$$

where

R = the number of publication fractions attributed to the analysed unit

C_i = the number of citations to the publication of fraction *i* (according to a separately specified citation window, self-citations removed)

S_i = the number of subject fields that the publication of fraction *i* has been classified as belonging to

A_i = the total number of addresses in the publication of fraction *i*

$\mu_{f(i)}$ = the field reference value for the field of fraction *i*

Proportion of top 10% (or 5%, or 1%)

$$P_{f10\%} = \Sigma(x_i) / P$$
$$x_i = p_{frac} \text{ if } C_i > \tau_{f10\%},$$
$$\text{else } x_i = 0$$

where

P = the unit's number of fractionalised publications for the same year and subject field

C_i = the number of citations to publication *i*

$\tau_{f10\%}$ = the 90th percentile of the number of citations to publications of the same type, published the same year in the same subject field.

Comments to this index:

- The number of citations must be *greater* than the corresponding percentile for a publication to be included in any of these groups. The proportion of publications included in the group in question is therefore less than the percentage indicated by the group title. The exact proportion included varies by year and subject field. Typically 7% of all publications are included in the top 10% group and 0.7% in the top 1% group.
- The *proportion of top 5% and top 1%* is calculated in the same way using the 95th and 99th percentiles respectively.
- It is possible for a publication assigned to several subject fields to belong to a group of highly cited publications in one subject field but not in another.

Moving averages

The 3-year average for number of publications (P) for year *y* is calculated as:

$$(P_{y-1} + P_y + P_{y+1})/3.$$

The 3-year average for field normalised citation rate for year y (c_{fy}) is calculated as:

$$(\Sigma c_{y-1} + \Sigma c_y + \Sigma c_{y+1}) / (P_{y-1} + P_y + P_{y+1})$$

Where Σc_y is the sum of field normalised citations for year *y*.

The Academy of Finland conducts a review of the current state of science and research in Finland once every three years to coincide with its Research Councils' terms. The 2009 report is divided into three parts.

The general overview describes the development of the Finnish research system over the past few decades, with special reference to science and research activities within universities. In addition, it discusses the development of the international operating environment, the internationalisation of Finnish science and the Finnish research system, and the role of science in society.

In the second part of the report, the Academy's four Research Councils discuss the strengths, weaknesses and opportunities of Finnish science and research in their respective fields. Furthermore, they deal with the state of doctoral education and research careers, research infrastructures and questions of scientific and social impact.

The third part of the report provides a general assessment of the state of scientific research in Finland and the country's research system and outlines future directions for development.

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