THE STATE OF SCIENTIFIC RESEARCH IN FINLAND 2016

SPECIAL THEME: BROADER IMPACT OF RESEARCH IN SOCIETY

ACADEMY OF FINLAND

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Broader impact of research in society

Background

The debate about the impact of research, about how to assess or monitor impact, and about the meaning of impact has intensified worldwide and in Finland over the last few years. The focus has partly been on the role of knowledge and innovation as underpinning factors of economic growth and renewal, but discussion has also developed around impact as a broader phenomenon and the importance of making it visible. The need for effectiveness and accountability in the use of tax revenue increased in all areas of society already before the economic downturn.

As a special theme in the State of Scientific Research in Finland 2016 review[1], we consider the different types of impact arising from research-based knowledge and expertise, and the pathways through which impacts come about. Research impact is a broad topic that cannot be covered completely in this review. The review is based on a comparative case study that combines qualitative and quantitative methods, as well as on the current understanding of research impact in the literature. The case study focuses on four different research fields that provide a reasonably inclusive picture of the ways in which academic research is linked and contributes to the surrounding society.

The impact of research has been studied since the 1950s, but monitoring and assessing it still presents a challenge. Impacts beyond academia are thoroughly diverse, as there is significant variation in the subjects and purposes of research as well as in its links to the surrounding society. Research is carried out within the wider scientific community and society, and the resulting impacts depend on many factors and activities. Hence, instead of quantitatively measuring or assessing impact, a recent trend has been to increasingly use qualitative methods.[2]

Attempts to address the broader impact of research, development and innovation activities have been made also in Finland since the 1990s. In the early 2000s, assessments were targeted mainly on specific fields or activities[3], and an indicator-based impact framework was developed.[4] More recently, the approach has been increasingly qualitative: the broader impact of higher education has been examined from different perspectives with a view to developing tools for identifying and promoting impact. A comprehensive assessment covering the various types of impact emerging from research-based knowledge and expertise has yet to be made.

An extensive assessment of the broader impact of research was performed as part of the UK Universities Research Excellence Framework (REF) assessment in 2014. The research units under assessment were asked to submit case descriptions (*narratives*) to showcase how research undertaken in the unit had made an impact beyond academia. Expert panels were then appointed to assess the impact described in each narrative for its *reach* and *significance*. The narratives (approximately 7,000 in total) are publicly available online, and they provide a comprehensive picture of the ways in which research contributes to society.[5]

The results of the REF assessment and their interpretation, as well as the added value of the assessment, have been widely discussed.[6] An independent review of the REF assessment includes observations and recommendations relating to the monitoring and assessment of impact in the future.[7]

Data and methods

For this review, the impact of research beyond academia was explored from the direction of research activities. The approach was a comparative case study, which enabled both the collection of detailed qualitative data and the drawing of conclusions at the level of the research system as a whole.

The study focused on four different research fields: *ecology, evolutionary biology and ecophysiology*[8]*; history; medical engineering and health technologies; and materials science and technology.* Together, these fields provide complementary views of

[1] The review as a whole is available in Finnish at www.aka.fi/tieteentila.

[2] A compact review of the issues relating to impact assessment is Bornmann, L. (2012): Measuring the societal impact of research. *EMBO Reports* 13 (8), 673–676. A more extensive synthesis of impact assessment is Greenhalgh, T., Raftery, J., Hanney, S. & Glover, M. (2016): Research impact: A narrative review. *BMC Medicine* 14 (78).

[3] For example, SIGHT 2006. *Publications of the Academy of Finland* 5–9/06 and 11/06.

[4] Ritsilä, M., Nieminen, M. & Sotarauta, M. (2007): Yliopistojen yhteiskunnallinen vuorovaikutus: Arviointimalli ja näkemyksiä yliopistojen rooleihin. *Reports of the Ministry of Education and Culture* 2007:22; Lemola, T., Lehenkari, J., Kaukonen, E. & Timonen, J. (2008): Vaikuttavuuskehikko ja indikaattorit. *Publications of the Academy of Finland* 6/08.

[5] King's College London & Digital Science (2015): *The nature, scale and beneficiaries of research impact: An initial analysis of Research Excellence Framework (REF) 2014 impact case studies.* HEFCE.

[6] For example, Telling stories, *Nature* 518 (2015), 37; Atkinson, P.M. (2014): Assess the real cost of research assessment. *Nature* 516, 145.

[7] *Building on success and learning from experience: An independent review of the Research Excellence Framework*, chaired by Lord Nicholas Stern. Department for Business, Energy & Industrial Strategy, Government of UK, 2016.

[8] Later in this document, this research field is referred to as ecology and evolutionary biology.

Box 1.

Roles of science in society.

Scientific research is expected to contribute to society, for example, in the following issues:

Human understanding and world view: Research-based knowledge and abilities build, sustain and develop individuals' and societies' understanding of the surrounding world and their part in it.

Wealth and prosperity: Research-based knowledge and abilities open material prospects for sustaining and increasing the wellbeing of people and societies.

Basis for decision-making: Research-based knowledge and abilities underpin societal decision-making, policies and problem-solving; they can also ease individuals' choices.

Practice development: Research-based knowledge and abilities generate, sustain and advance competencies and professional practices.

the diverse ways in which academic research is linked and contributes to the surrounding society. Other criteria for selecting the fields were the high scientific quality or societal significance of the research conducted in the field (including connections to national priority areas), the representation of the field in several Finnish universities or government research institutes, and the sufficient size and coherence of the research community working in the field in Finland.

A large survey and interview dataset was collected from the above mentioned research fields. The target group of the survey consisted of researchers active in these fields in Finland. Researchers were asked about the processes that are central for their research to have an impact beyond academia, and about the potential contributions of their research to society. On the basis of the survey responses, ten interview topics were constructed, and each theme was discussed in a small group consisting of both researchers and end-users or stakeholders.

The role of research-based expertise in society is reviewed also in the light of statistical data on doctoral degrees and doctoral degree holders' placement in working life, as well as based on a targeted survey for a sample of doctoral degree holders. The statistical analysis draws on the data of Statistics Finland and the Finnish Ministry of Education and Culture. The number and placement of doctoral degree holders are reviewed based on these data. The purpose of the survey, in turn, was to collect data on the careers of doctoral degree holders, the importance of research-based expertise in working life and the contributions of such expertise to society.

All data used in reviewing the broader impact of research in society is described in Appendix 1.

Roles of science in society

Academic research and training have significant impacts on society. In order to analyse these multiple impacts, it is useful to consider the different roles science has in society. Science develops human understanding and world views, generates wealth and prosperity, provides a basis for decision-making, and supports practice development (see Box 1). These roles capture, at a very general level, the functions science has become to serve in our societal system.[9]

The roles of science thus offer a possible starting point for understanding and assessing the broader impact of research. In Finnish research, development and innovation policy, science has often been considered from the perspective of the economic impacts emerging from natural science and technology, while discussion of its role across different policy sectors has been scant. The need to address broad, complex and unexpected problems is constantly increasing, however, and this requires wide-ranging utilisation of expertise from different fields.[10]

There are also other ways to define the different roles of science. Each role, as defined above, consists of a wide range of different research and its use by different stakeholders. The roles of science are also complementary to each other: For example, decision-making requires not only research-based knowledge of the issue under consideration, but also educated decision-makers and citizens. In a similar vein, the development of human understanding and world views would not be possible in the current scale without the wealth and prosperity that science has helped to bring about.

For the activities of individual researchers, research organisations and entire research fields, one particular role of science may be more important than others, and their identity and relations with the surrounding society may rest on that role. The public appreciation of science is also often founded on the understanding of the roles that science has in society.[11] In Finland, trust in science and education is relatively strong, which shows also in the recent Finnish Science Barometer.[12]

[9] Cf. Alastalo, M., Kunelius, R. & Muhonen, R. (2014): Evidenssiä eliitille ja kansainvälistä huipputiedettä? Tutkimuksen vaikuttavuuden mielikuvastot tiedepolitiikan resursseina. In Muhonen, R. & Puuska, H-M. (eds.), *Tutkimuksen kansallinen tehtävä,* 118–149. Vastapaino, Tampere; Muhonen, R. (2015): Yhteiskuntatieteet ja tutkimuksen moninainen vaikuttavuus. In Vastuullinen ja vaikuttava: Tulokulmia korkeakoulujen yhteiskunnalliseen vaikuttavuuteen. *Publications of the Ministry of Education and Culture* 2015:13, 101–118.

[10] For example, *The 5th Science and Technology Basic Plan,* Government of Japan, 2016.

[11] On the value of humanities, for example, see Crossick, G. & Kaszynska, P. (2016): *Understanding the value of arts & culture: The AHRC Cultural Value Project.* Arts & Humanities Research Council; Heikkilä, T. & Niiniluoto, I. (2016) *The value of humanities research in Finland.* The Finnish Institute in Rome, www.irfrome.org.

[12] *Summary of the Finnish Science Barometer 2016. A study of the Finns' attitudes towards science and their opinions on scientific and technological progress.* Tieteen tiedotus.

The objectives and societal contributions of research

Research activities and entire research fields vary significantly in terms of their quest for fundamental understanding, on the one hand, and their consideration for practical applications, on the other hand. These differences are often highlighted with the concepts of basic research and applied research. In practice, the distinction between basic and applied research is often ambiguous and not necessarily productive.

Analysis of the relations between science, technology and the economy has suggested that a significant part of research combines the motives of fundamental understanding and practical use. This type of research has been called use-inspired basic research.[13]

The types of research objectives can thus be illustrated with the quadrant model of scientific research, introduced by Donald Stokes.[14] The vertical dimension of the model stands for the advancement of humanity's collective knowledge and understanding, and the horizontal dimension stands for the advancement of practical applications. The upper left corner represents research that pursues fundamental understanding without particular interest in the usability of knowledge. This is exemplified by Niels Bohr's work on the foundations of quantum mechanics, which initially had no connections to practice.[15] The lower right corner represents the so-called pure applied research that aims at using scientific knowledge for solving a particular problem in the realm of practice. This is exemplified by Thomas Edison's inventive work on electric lighting systems. Use-inspired basic research is located in the upper right corner. It is founded on the evolving needs and problems of society, the resolution of which is pursued through scientifically ambitious research that focuses on the underlying phenomena. An example given for this type of research is Louis Pasteur's invention of heating milk products in order to kill bacteria.

Figure 1 illustrates the distribution of research objectives, pursued by researchers in the four research fields, in the Stokes' quadrant model of scientific research. Within each field, research is undertaken for different purposes: for either fundamental understanding or practical applications, or for both. The profiles of the four research fields, however, clearly differ from each other.

Research objectives make a major difference for the foreseeable impacts emerging from the research as well as the way in which they can be assessed. The more closely the research is coupled with some practical interests, the more straightforward it is to see it as responding to the expectations of society. A lack of practical goals does not mean, however, that the research has no broader impact in society.

All research can have an impact beyond academia both in the short term and especially in the long term. Research-based understanding, evidence or expertise may be a necessary condition for an undertaking to succeed, or for preventing or alleviating a problem. While it is sometimes impossible to demonstrate such contributions, let alone to know them in advance, they can be assessed. Figure 2 shows the types of contributions that research, undertaken in the four example research fields, can make according to the researchers' own assessments.[16]

[13] Stokes, D. (1997): *Pasteur's Quadrant: Basic Science and Technological Innovation*. Brookings Institution Press, Washington, D.C.

[14] Ibid., p. 73.

[15] Later on, quantum mechanics turned out to be very useful for practical applications.

[16] Contributions are presented in a similar way as in Figure 8, in King's College London & Digital Science (2015): *The nature, scale and beneficiaries of research impact: An initial analysis of Research Excellence Framework (REF) 2014 impact case studies*. HEFCE.

Figure 1.
Types of research objectives in four research fields.
Researchers' responses to two statements describing research objectives were placed in Stokes' quadrant model of scientific research. We asked respondents to assess the compatibility of the statements with their own research using a five-point scale. The area of the circle represents the proportion of responses (%) at the intersection of the two scales.

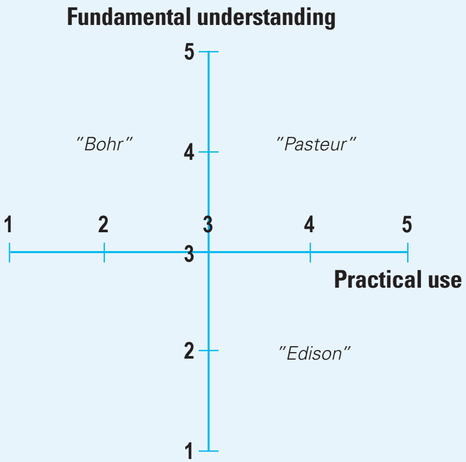
The horizontal axis shows the respondent's position to the statement "The research aims to solve some problems or find solutions in the realm of practice".

The vertical axis shows the respondent's position to the statement "The research aims to advance scientific understanding of some phenomena without obvious links to practical applications or societal needs".

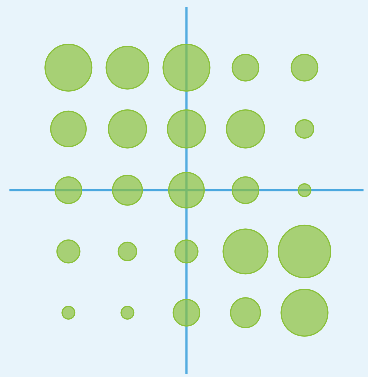
We asked: "Objective or purpose of your research: How compatible are the following descriptions with the purpose of your research?"

5 = very compatible
4 = fairly compatible
3 = neither compatible
nor incompatible
2 = fairly incompatible
1 = incompatible
IDK = I don't know

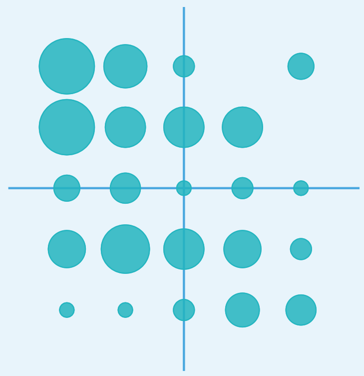
The figure does not include IDK answers. In the questionnaire, research objectives were described with four different statements. All statements and the response distribution in each research field is presented in Appended Figure 2.1.



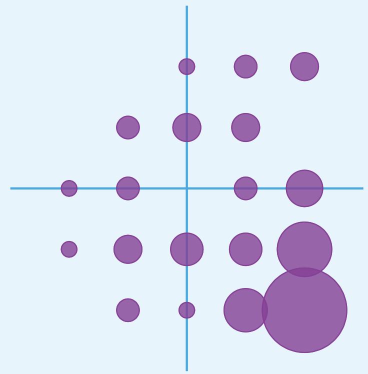
Stokes' quadrant model of scientific research (modified from Stokes, D. 1997: *Pasteur's quadrant: Basic science and technological innovation.* Brookings Institution Press, Washington, D.C.)



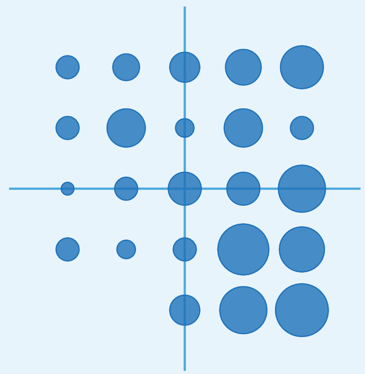
Ecology and evolutionary biology (N=153)



History (N=115)



Medical engineering and health technologies (N=83)



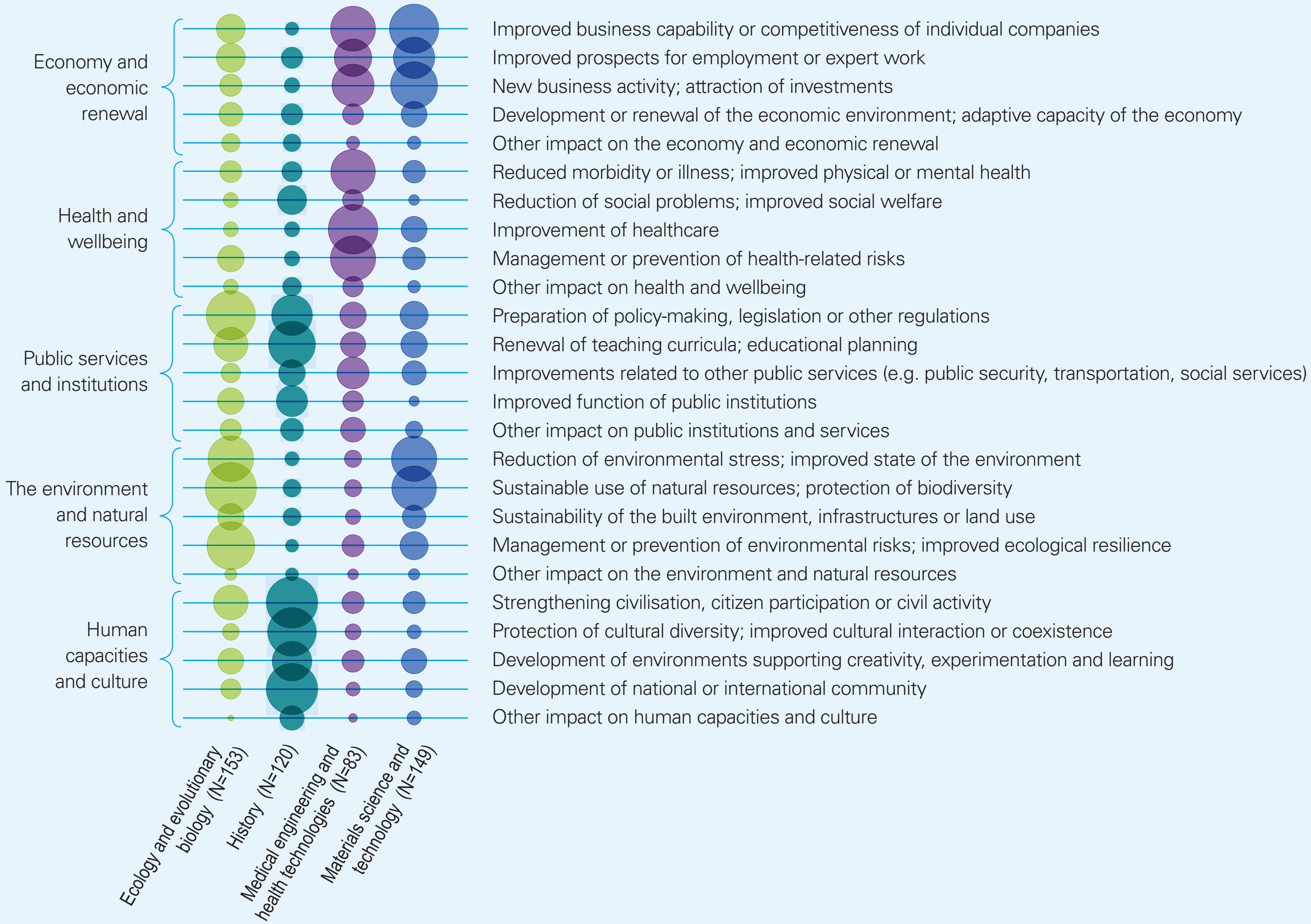
Materials science and technology (N=146)

Source: Academy of Finland's survey on the broader impacts of research on society, 2016.

Figure 2.
Contributions of research to society in four research fields.
The area of the circle represents the proportion of respondents in each research field (%) who selected the given type of contribution.

We asked: "Where will the potential impacts of your research be seen in the (short or) long run? Please select all developments to which your research, if successful, can make a contribution."

The largest circles represent some 70–80% of the responses of researchers working in the given research field.



Source: Academy of Finland's survey on the broader impacts of research on society, 2016.

Box 2.

Main routes to impact.

Transfer of research results: The results, inventions, methods or other outputs of research come into use beyond academia. There may be a lot of underpinning research and development in the background.

Cooperation and interaction: Researchers work alongside and discuss and exchange knowledge with stakeholders beyond academia, such as business and industry, public authorities, education, civic organisations or professional practitioners.

Proficient people: Research-based knowledge, expertise, vision and skills are conveyed by people who move and act beyond academia.

Routes to impact

The broader impact of research emerges as a result of someone taking up and using research-based knowledge or expertise, or as a result of the changes that take place in society by virtue of such knowledge and expertise. The first premise for impact to arise is that the new knowledge, technology, know-how, understanding or perspective produced by research is somehow being conveyed beyond academia. This process can be understood as occurring through three main routes: the transfer of research results, cooperation and interaction, and proficient people (see Box 2). In practice, the routes are used as different combinations, and their importance and time scales, among other things, may vary notably.

The routes to impact are linked to research topics and objectives, and especially to where, when and by whom the research is utilised. Science is part of society and thus constantly influenced by developments beyond academia. In many fields of the humanities and social sciences, for example, research undertakings and communications themselves may be interventions in society. Open science is also an important way to enable impact; it concerns all routes.

The main routes to impact are illustrated in Table 1 by providing examples of their meaning in the different roles of science.

The impact of research emerges through a complex process that involves not only researchers and research organisations but also other factors and stakeholders.[17] For furthering impact, it is thus helpful to identify the potential users and beneficiaries of knowledge and understand the environment in which they operate. Factors beyond the immediate control of academia, or beyond the means available for research policy-makers include the diffusion of ideas or products into wider usage; unpredictable changes in, among other things, economic or societal circumstances; timing and pace of needs for new knowledge; corporate IPR environments; political interests; and the relative importance of research-based knowledge in decision-making, which has recently raised much discussion.

Many research fields have established practices that support the exchange and utilisation of knowledge beyond academia. The institutional mechanisms of generating and making use of new knowledge are, however, fundamentally different from each other. The institutional factors and dynamics within academia – such as the specialisation of disciplines and their mutual relationships; the professional accountability and responsibility of researchers; their international networks and mobility; and access to materials and methods – both enable and constrain the pursuit of impact.

Interaction between researchers and stakeholders outside academia, as well as the realisation of research impact, will be further analysed and additional material will be published on the Academy of Finland's website at www.aka.fi/en > State of scientific research in Finland.

The placement of doctoral degree holders in working life

Proficient people are an important route to impact. In this review, this is looked at from the perspective of the placement of doctoral degree holders in working life. Doctoral degree holders' placement is reviewed on the basis of statistical data, and the importance of research-based expertise for doctoral degree holders' careers is reviewed on the basis of a survey.

In Finland, doctoral degree holders' employment and career development have been reviewed on a regular basis. For example, the Aarresaari network has conducted nationwide career monitoring for doctoral degree holders since 2007; the latest report was published in 2016.[18] A report commissioned by the Ministry of Education and Culture, published in 2016, examined factors influencing the employment of doctoral degree holders.[19]

[17] Ks. esim. Spaapen, J. & van Drooge, L. (2011): Introducing productive interactions in social impact assessment. *Research Evaluation* 20 (3), 211–218; The Think Tank DEA (2016): *What lies beneath the surface? A review of academic and policy studies on collaboration between public research and private firms.* Commissioned by the Danish Council for Research and Innovation Policy.

[18] Sainio, J. & Carver, E. (2016): *Tavoitteidensa mukaisella työuralla – Aarresaari-verkoston tohtoriuraseuranta 2015, vuosina 2012–2013 valmistuneet.* www.aarresaari.net.

[19] Haila K., Karinen R., Kaihovaara A., Eronen A. & Haapakorpi A. (2016): Miten tohtorit työllistyvät. *Publications of the Ministry of Education and Culture* 2016:3.

Table 1.
Examples of the main routes to impact in different roles of science.

	Transfer of research results	Cooperation and interaction	Proficient people
Human understanding and world views	• Popular writings, incl. text books • Presentations and lectures	• Cooperation with education or culture institutes, organisations, archives, etc. • Social media • Citizen science	• As public debaters • In education and teaching • Science communication professionals
Wealth and prosperity	• Patenting and licensing • Technology transfer • Scientific publications in creating connections with companies	• Long-term collaboration with companies • Knowledge exchange with industry and commerce as well as with public service providers • Piloting, quick trials • Regional cooperation, ecosystems	• In product development • In business • Knowledge-based entrepreneurs • Public service reformers
Basis for decision-making	• Syntheses of results, e.g. policy briefs • Press releases of published results • Research on specific priority areas	• Expert panels and networks • Intermediary organisations • Public comments and statements	• In resolving complex questions • Experts • Assistants of decision-makers, decision preparers
Practice development	• Publication in professional journals • Recommendations and guidelines • Processes, practices, operation models	• Discussion on concrete problems in the realm of practice • Participatory research • Actor networks	• Professional practitioners • Experts

The number of doctoral degrees awarded annually in Finland was 300 on average in the early 1980s (see Figure 3). By the end of the 1980s, the number of degrees awarded annually had increased to about 400. The number of doctoral degrees increased heavily in the 1990s, rising above 1,000 degrees annually by the end of the decade. While the growth in the number of doctoral degrees has been slower in the 2000s than in the 1990s, the number of degrees awarded in 2015 was 56 per cent higher than in 2001. The number of doctoral degrees in the 2000s increased more strongly than the number of master's degrees: 15,513 master's degrees were awarded in 2015, which is 34 per cent more than in 2001.[20]

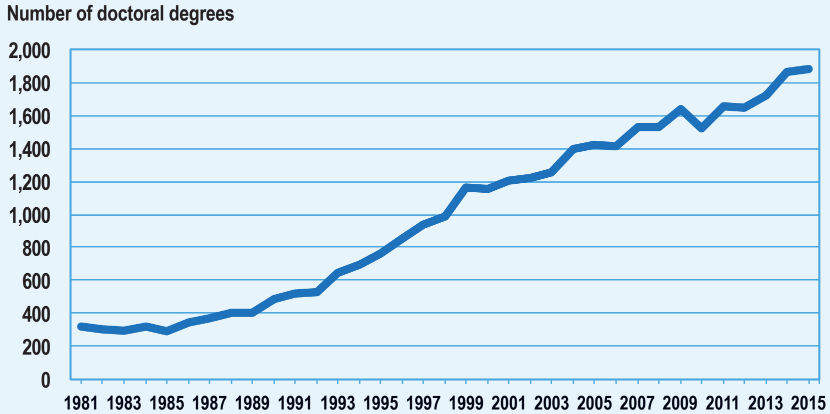
The doctoral degrees awarded in 2015 (a total of 1,881 degrees) were distributed almost evenly between women (52%) and men (48%). The median age of doctoral graduates was 35 years, and the average age was approximately 38 years. The median and average ages vary somewhat across disciplines.[21]

The number and growth of doctoral degrees awarded annually vary across disciplines (Appended Table 2.1). In some disciplines, the number of doctoral degrees, when comparing the three-year averages between 2007–2009 and 2013–2015, has even decreased.

In the Nordic countries, the number of doctoral degrees awarded annually in proportion to population was highest in Sweden in 1990–2008 (Figure 4). Finland overtook Sweden in 2009, when the number of doctoral degrees per capita decreased in Sweden. Overall, the increase in the number of doctoral degrees has been the strongest in Denmark, where the number of degrees per capita increased fivefold in 1990–2014. In Finland, the number of degrees tripled during the same period.

A doctoral degree gives qualifications, among other things, to work as a researcher or an expert in demanding research and development (R&D) activities. In 2013, there were approximately 24,300 doctoral degree holders in Finland's labour force, of which approximately 23,200 were employed. About half of the employed doctoral degree holders had gained their doctorate over the last ten years.[22] While the unemployment rate

Figure 3.
Number of doctoral degrees awarded in Finland in 1981–2015.



Source: Ministry of Education and Culture; Vipunen - Education Statistics Finland (available from 2005).

[20] Statistics Finland, University education.
[21] Vipunen – Education Statistics Finland > University education > Students and degrees.
[22] Vipunen – Education Statistics Finland > Korkeakoulutus ja t&k-toiminta > T&k-henkilövoimavarat (only in Finnish).

of doctoral degree holders has increased in 2000s, it is still lower than the unemployment rate of those with other levels of education.[23]

Sixty per cent (approx. 13,900 persons) of all employed doctoral degree holders worked in R&D[24] in 2013.[25] The full-time equivalents (FTEs) dedicated to R&D by doctoral degree holders, as well as their proportion of total FTEs in R&D, have increased since the late 1990s (Figure 5).

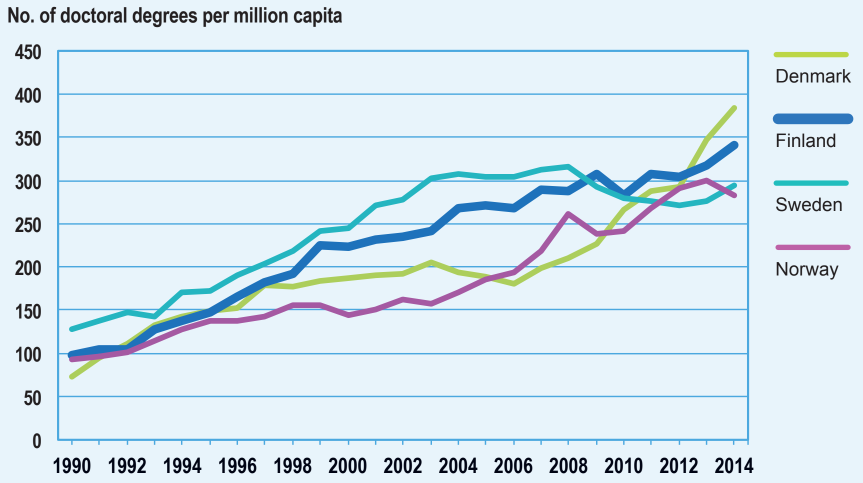
In 2015, the total FTEs in R&D were 50,400; the amount has increased by 22 per cent since 1997.[26] Doctoral degree holders accounted for approximately 9,100 FTEs in R&D; the amount has more than doubled since 1997. The higher education sector accounted for the majority of the FTEs performed by doctoral degree holders (approx. 5,900 FTEs). The FTEs performed by doctoral degree holders in the public sector (incl. private non-profit organisations) and the business enterprise sector added up to approximately 1,600 respectively.

The proportion of R&D FTEs accounted for by doctoral degree holders is still low in all employer sectors: 38 per cent in the higher education sector, 32 per cent in the public sector and 5 per cent in the business sector (Figure 5).

Doctoral degree holders also work in other tasks besides R&D. The placement of all employed doctoral degree holders in different employer sectors is reviewed in the following.

In 2013, half of all employed doctoral degree holders who had gained their doctorate in 2012 or earlier worked in higher education or government research institutes[27] (Table 2 and Figure 6).[28] The largest employer in almost all disciplinary groups was the university sector, accounting for nearly 37 per cent of all employed doctoral degree holders. Approximately one-quarter of doctoral degree holders worked in the private sector and approximately one-quarter in the public sector.

Figure 4.
Number of doctoral degrees per million capita in the Nordic countries in 1990–2014.



The figure does not include data on Iceland's doctoral degrees. The numbers in absolute terms are much smaller than in other Nordic countries.

Source: NIFU FoU-stastistikkbanken (www.foustatistikkbanken.no/nifu).

[23] Haila K., Karinen R., Kaihovaara A., Eronen A. & Haapakorpi A. (2016): Miten tohtorit työllistyvät. *Publications of the Ministry of Education and Culture* 2016:3, p. 23.

[24] Research and development personnel consists of people, who during the statistical year have spent at least 0.1 FTEs (or 10% of their time) in R&D work or in administrative, office or other support work that is directly linked to R&D projects in an R&D unit. R&D activities include the production of new knowledge and the development of new applications in product, process or other development work. In addition to researchers and product development engineers, R&D personnel includes people responsible for managing and planning the content of R&D projects, technical experts, other personnel carrying out R&D activities (e.g. laboratory technicians, computer programmers) and staff providing other support for R&D projects.

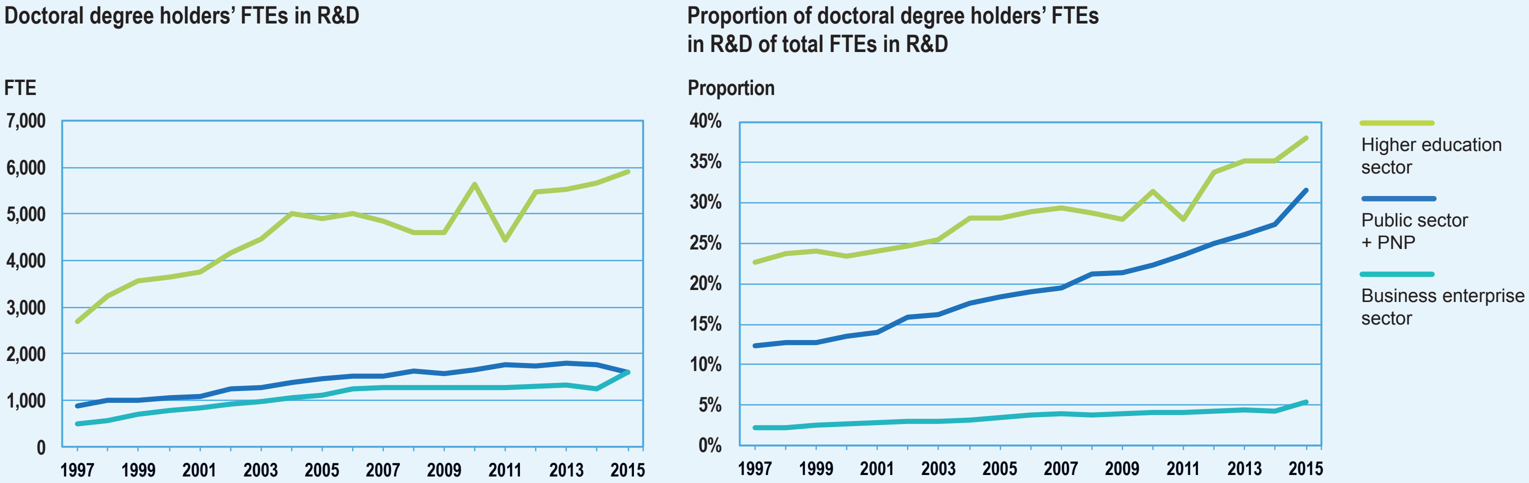
[25] Statistics Finland, Research and Development.

[26] Ibid.

[27] Higher education includes universities, universities of applied sciences and a few other higher education organisations. Government research institutes are as of 2013. Further information about the employer sectors is available in Appendix 1.

[28] Doctoral graduates who obtained their degree during the examined year were excluded from the analysis of placement by employer sector. This gives a more realistic view of placement after the doctoral degree. If doctoral graduates of 2013 are included in the analysis, the proportion of doctoral degree holders working in higher education organisations and government research institutes was 51%.

Figure 5.
Doctoral degree holders working in R&D in different sectors in 1997–2015.



FTE refers to full-time equivalent. The sectors are those used in the research and development statistics of Statistics Finland. The higher education sector includes universities, university hospitals and universities of applied sciences (as of 1999). The universities of applied sciences also include the Police University College. The public sector includes the administrative branches of the state, the municipalities (as of 2007) and other public institutions, as well as the National Defence University. PNP refers to the private non-profit sector.

Source: Statistics Finland, Research and Development.

In addition to the statistical analysis, we conducted a survey for doctoral degree holders. The target group of the survey consisted of doctoral degree holders who were living in Finland and who had been awarded a doctoral degree in one of the four research fields included in the assessment (i.e. ecology and evolutionary biology; history; medical engineering and health technologies; and materials science and engineering) from a Finnish university between 2005 and 2014 (see Appendix 1 for further information). In the survey, doctoral degree holders were asked about, among other things, the importance of research-based expertise in their careers. Across different employer sectors, respondents perceived the ability to piece together and solve problems, as well as skills related to searching for, adopting and critically examining knowledge, to be very important (Figure 7).

Table 2.
Doctoral degree holders working in different employer sectors by disciplinary group in 2013.
The table shows employed doctoral degree holders who were awarded their degree in 2012 or earlier.

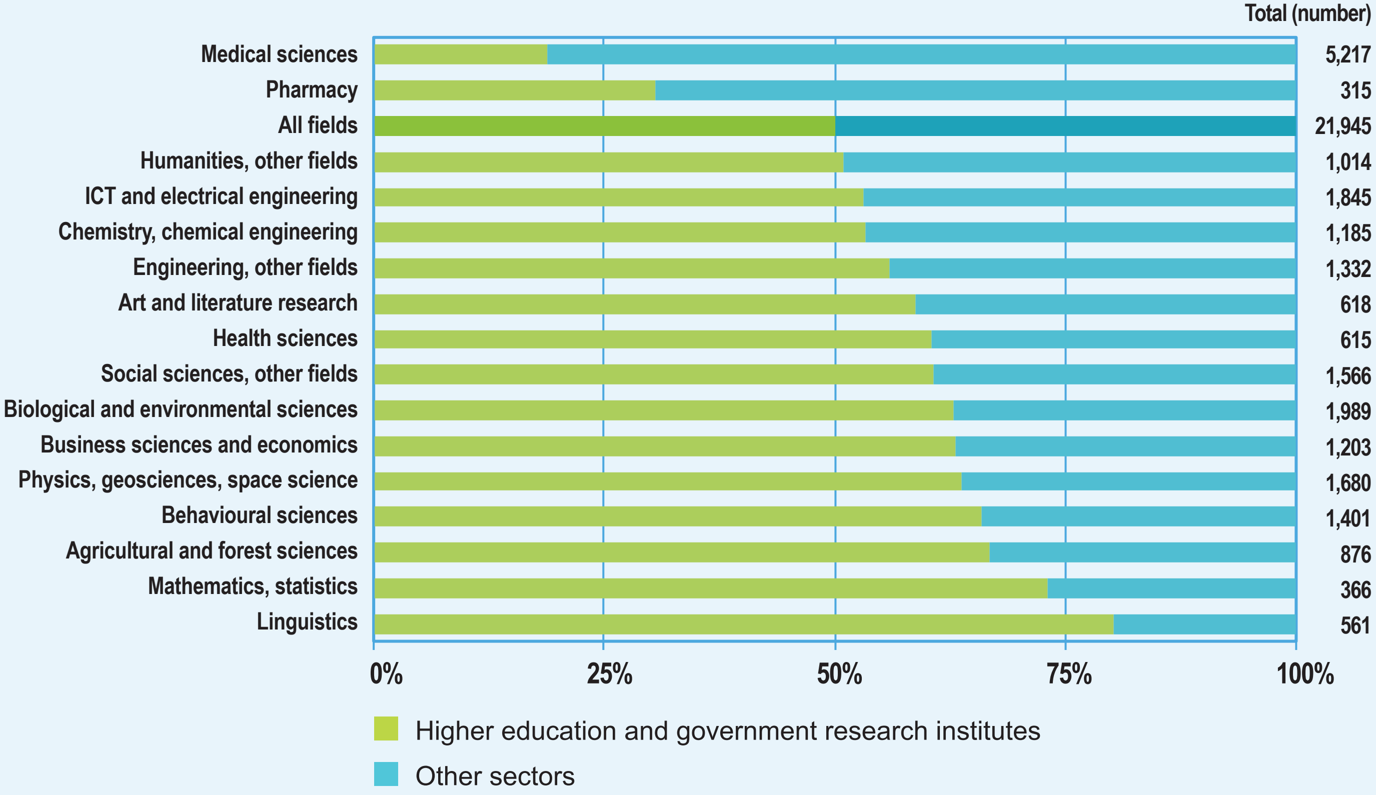
Disciplinary group	Private	Public	University	Univ. of applied sciences*	Government research institute	Total	Proportion of higher education and research institutes
Mathematics, statistics	63	36	228	21	18	366	73%
Physics, geosciences, space science	417	189	678	57	336	1,680	64%
Chemistry, chemical engineering	453	99	456	33	144	1,185	53%
ICT and electrical engineering	774	93	765	57	156	1,845	53%
Engineering, other fields	483	105	522	72	150	1,332	56%
Business studies and economics	294	144	582	129	48	1,203	63%
Biological and environmental sciences	435	300	846	48	357	1,989	63%
Agricultural and forest sciences	195	96	273	27	285	876	67%
Medical sciences	1,194	3,042	789	24	165	5,217	19%
Pharmacy	171	48	84	0	12	315	30%
Health sciences	99	141	174	150	48	615	60%
Behavioural sciences	192	282	717	156	51	1,401	66%
Social sciences, other fields	270	345	750	114	87	1,566	61%
Linguistics	72	39	414	18	18	561	80%
Art and literature research	156	99	315	45	3	618	59%
Humanities, other fields	369	129	483	27	6	1,014	51%
All fields	**5,730**	**5,211**	**8,106**	**978**	**1,899**	**21,945**	**50%**

** Includes a few other higher education organisations. Further information about the employer sectors is available in Appendix 1.*

Doctoral degree holders whose graduation year is unknown are included in the analysis (177 people). Higher education includes universities and universities of applied sciences. The universities of applied sciences also include the Police University College. University hospitals and the National Defence University are included in the public sector. Government research institutes are as of 2013. The column "Total" includes 21 doctoral degree holders whose employer sector was "other or unknown". The row "All fields" includes 162 doctoral degree holders whose detailed field of research was unknown.

Source: Data collected by Statistics Finland, Vipunen – Education Statistics Finland.

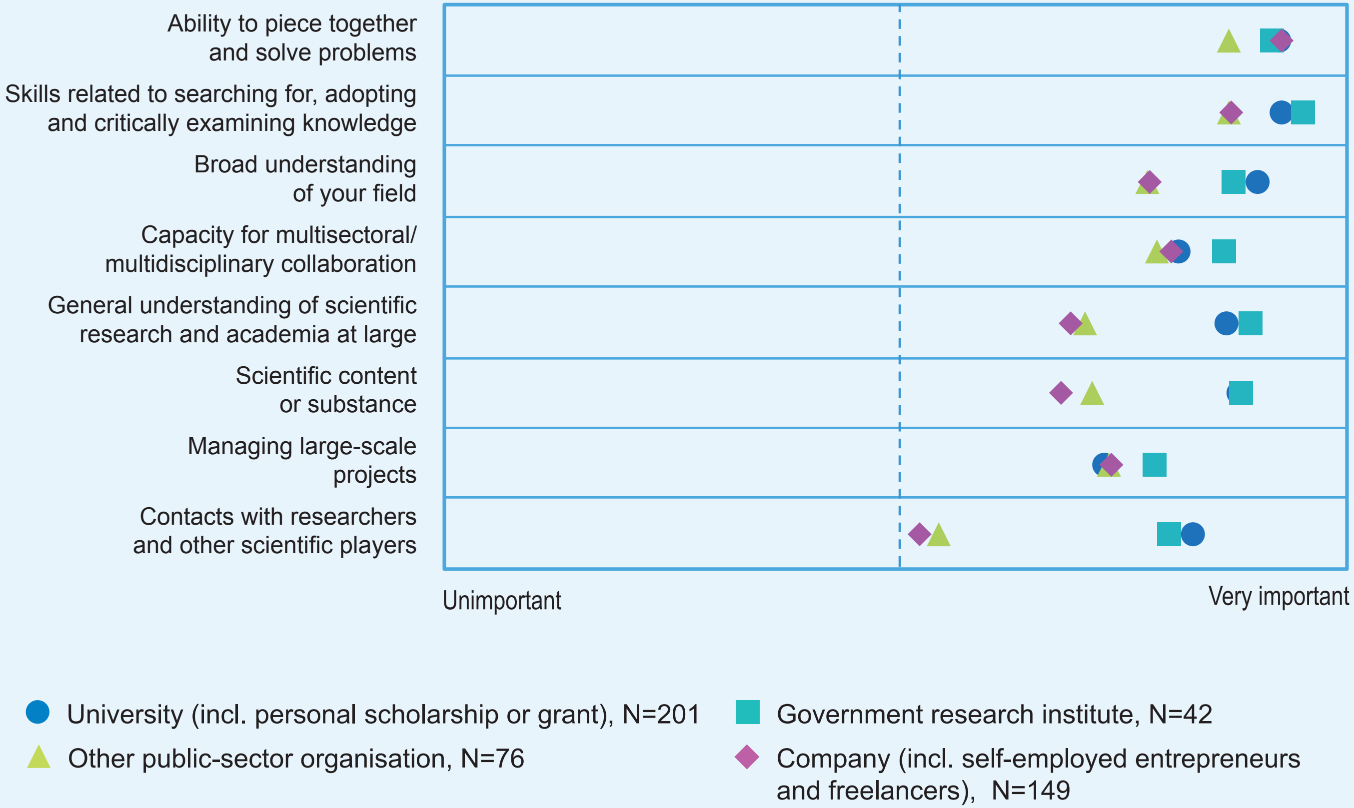
Figure 6.
Doctoral degree holders working in higher education and government research institutes vs other employer sectors in 2013.
The figure shows employed doctoral degree holders who were awarded their degree in 2012 or earlier. The disciplinary groups are arranged in ascending order according to the proportion of higher education and research institutes.



Doctoral degree holders whose graduation year is unknown are included in the analysis (177 people). Higher education includes universities and universities of applied sciences and a few other higher education organisations. Government research institutes are as of 2013. Other sectors include the private and public sectors and the sector "other or unknown". Further information about the employer sectors is available in Appendix 1. The row "All fields" includes 162 doctoral degree holders whose detailed field of research was unknown.

Source: Data collected by Statistics Finland, Vipunen – Education Statistics Finland.

Figure 7.
Importance of research-based abilities in the career of doctoral degree holders working in different employer sectors.
The figure shows the average of responses, given on a five-point scale, of doctoral degree holders working in different employer sectors.



We asked: "Which research-based abilities have been important in your career? Please assess the importance of the following abilities in terms of your career."

5 = very important
4 = fairly important
3 = neither important nor unimportant
2 = fairly unimportant
1 = unimportant
IDK = I don't know

The averages do not include IDK answers. The employer choices given in the questionnaire were as follows: university; government research institute; other public-sector organisation; private or state-owned company/enterprise; independent entrepreneur, self-employed or freelancer; personal scholarship/grant; non-profit organisation; parental leave; unemployed; and other employer or work situation. Doctoral degree holders who selected any of the last four choices are not included in the figure.

Source: Academy of Finland's survey on the role of doctoral degree holders in society, 2016.

Appendix 1.
Data collection

Surveys

The broader impact of research was explored in four different research fields (ecology, evolutionary biology and ecophysiology; history; medical engineering and health technologies; and materials science and technology). A large survey and interview dataset was collected from these fields.

The survey on the broader impacts of research on society was open from 26 January to 10 February 2016. The target group of the survey consisted of researchers active in the above mentioned fields in Finland. Potential participants were identified by using data on funding applications for the Academy of Finland over the last five years as well as the expertise and networks of Academy staff.

The survey on the role of doctoral degree holders in society was open from 9 May to 1 June 2016. The target group of the survey consisted of Finnish residents who had been awarded a doctoral degree in one of the above mentioned fields from a Finnish university between 2005 and 2014. Potential participants were identified by gathering degree information from relevant universities.

Both surveys were conducted in Finnish and in English in parallel. The target groups of the two surveys partly overlapped, but the datasets were collected and analysed separately. The numbers of invited participants and responses received are shown in Appended Table 1.1. Both surveys contained structured multiple-choice questions as well as open-ended questions. The questionnaires and the summary of results can be found on the Academy of Finland's website (www.aka.fi/en > State of scientific research in Finland). The data generated in these surveys will be opened for broader use in 2017. They can be found in a research data service provided by the Ministry of Education and Culture (etsin.avointiede.fi/en).

Appended Table 1.1.
Surveys in four research fields, conducted for the State of Scientific Research in Finland review

Survey	Invited	Responses	Response rate
Survey for researchers	1,587	584	37%
Survey for doctoral degree holders	1,723	566	33%

Survey for researchers	Invited	Responses
Ecology, evolutionary biology and ecophysiology	441	153
History	395	120
Medical engineering and health technologies	209	83
Materials science and technology	542	149
In total	**1,587**	**505**

If the respondents did not identify with any of the four research fields, or if they were no longer active in research, they were automatically taken to the end of the questionnaire. These responses (94 in total) were included in the response rate calculation but excluded from the analyses.

Respondents could also identify themselves as representing more than one of the research fields. There were 15 respondents who selected two research fields (in most cases, medical engineering and health technologies together with materials science and technology). The responses of these persons were included in the analyses of both research fields.

Survey for doctoral degree holders	Responses
Ecology, evolutionary biology and ecophysiology	154
History	125
Medical engineering and health technologies	68
Materials science and technology	183
None of the above mentioned fields	36
In total	**566**

A total of 79 responses were received from persons who reported that their doctoral degree or dissertation had no relevant connection to any of the four research fields examined. Some of these respondents were allocated to the research fields on the basis of how they described their research field in an open-ended question. Figure 7 based on this survey, however, did not take account of disciplinary differences and thus did not exclude any responses on this ground.

Interviews

Drawing on the survey for researchers, we constructed ten different interview themes that covered the most typical impacts emerging from the research fields examined. The themes were constructed primarily on the basis of who uses the research (outcomes), and for what purpose. Each theme was discussed in a focus group of 5–9 persons, including a few respondents from one or several research fields, and a few relevant users or beneficiaries of knowledge whom the researchers helped us to identify. The purpose of the focus groups was to deepen and complement the survey data on the interactions, influences and impacts of research beyond academia. The focus group interviews were organised in March–May 2016 and involved a total of 70 participants. The list of participants is available on the Academy of Finland's website (www.aka.fi/tieteentila; only in Finnish).

The focus groups were organised around the following themes:

- Interaction and impact across disciplinary boundaries in natural sciences and engineering
- Impact of research through education and civilization
- Interaction between academia and civil society
- Scientific research and the renewal of industrial business
- New research-based businesses
- Impact of ecological research on public administration
- Impact of ecological research on the use of natural resources
- Impact of historical research on international affairs
- Impact of humanities research on professional practices
- Impact of medical engineering and health technologies research on healthcare practices

Statistical data on the placement of doctoral degree holders in Finland

Doctoral degrees

The statistical information on doctoral degrees was obtained from the Ministry of Education and Culture. The statistics as of 2005 are available through the education administration's reporting portal Vipunen (see https://vipunen.fi/en-gb/). The numbers of doctoral degrees by research field were calculated from the Statistic Finland data of doctoral degrees classified by education code. The research fields of doctoral degree holders were defined on the grounds of the education code (e.g. "Doctor of Philosophy, Physics" would be classified into "Physics"), and grouped into broader disciplinary groups. The statistics on doctoral degrees in the Nordic countries are available in the R&D statistics bank of NIFU (Nordic Institute for Studies in Innovation, Research and Education; see www.foustatistikkbanken.no/nifu).

Placement of doctoral degree holders

The data concerning doctoral degree holders working in R&D are based on the statistics on research and development generated by Statistics Finland (see www.stat.fi > Statistics > Science, Technology and Information Society > Research and Development).

The data concerning the placement of employed doctoral degree holders are based on material number 5.5 of the information service contract of the education administration and Statistics Finland. The population in the data includes persons aged 16–74 with a tertiary-level degree or working in expert tasks. The latest statistical year is 2013.

In this review, the placement of doctoral degree holders is analysed in terms of employer sectors. The information is based on Vipunen's statistics on doctoral degree holders' placement in terms of both employer sector and field of industry (see Appended Table 1.2). The classification of employer sectors in Vipunen is modified from Statistics Finland's classification of employer sectors. The classification of fields of industry in Vipunen is modified from the Standard Industrial Classification used by Statistics Finland.

The terms and conditions of using the placement data requires securing the data so that individuals cannot be identified. Therefore, the numbers of individuals have been rounded: if the number of individuals in a category is 1–4, the number has been rounded to three, and if the number is 5 or more, the number has been rounded to the nearest number divisible by three.

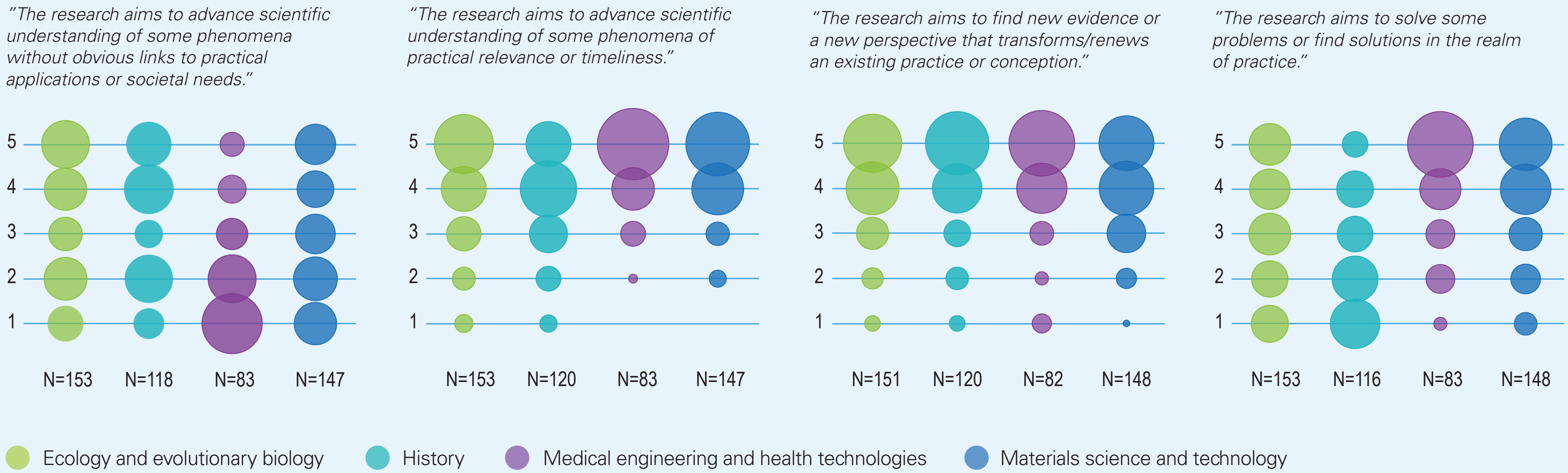
Appended Table 1.2.
The classification of sectors used in reviewing the placement of doctoral degree holders, compared to the classifications in the source data.

State of scientific research in Finland 2016	Statistics Finland's data in Vipunen
Private	Private (excl. those working in the field of industry of "other higher education")
	Entrepreneurs
	State-majority corporate enterprises
Public	State (excl. those working in the field of industry of "other higher education")
	Municipalities (excl. those working in the field of industry of "other higher education")
University	University
University of applied sciences	Those working in the field of industry of "other higher education" in the private or public sector have been classified under the category of "university of applied sciences". This category includes also a few other higher education organisations in addition to universities of applied sciences.
Government research institutes	Research institute
(Other or unknown)	Other or unknown

Non-profit institutions, religious communities and foundations, as a rule, are included in the private sector. University hospitals and the National Defence University are included in the public sector. The universities of applied sciences also include the Police University College.

Source: Statistics Finland, Ministry of Education and Culture.

Appended Figure 2.1.
Types of research objectives in four research fields.
The figure shows researchers' responses to four statements describing research objectives. We asked respondents to assess the compatibility of the statements with their own research using a five-point scale. The area of the circle represents the proportion of responses (%) at the different points of the scale.



We asked: "Objective or purpose of your research: How compatible are the following descriptions with the purpose of your research?"

5 = very compatible
4 = fairly compatible
3 = neither compatible nor incompatible
2 = fairly incompatible
1 = incompatible
IDK = I don't know

The figure does not include IDK answers.

Source: Academy of Finland's survey on the broader impacts of research on society, 2016.

Appended Table 2.1.
Three-year average and change (%) of the number of doctoral degrees awarded in different disciplinary groups in 2007–2009 and 2013–2015.

Disciplinary group	2007–2009	2013–2015	Change in the no. of doctoral degrees in the disciplinary group (%)
Mathematics, statistics	27.0	29.3	9%
Physics, geosciences, space science	120.7	148.0	23%
Chemistry, chemical engineering	73.3	102.7	40%
ICT and electrical engineering	163.0	219.3	35%
Engineering, other fields	105.0	146.7	40%
Business studies and economics	107.7	118.0	10%
Biological and environmental sciences	152.7	134.7	-12%
Agricultural and forest sciences	57.3	71.3	24%
Medical sciences	265.3	288.3	9%
Pharmacy	20.3	28.3	39%
Health sciences	56.7	54.0	-5%
Behavioral Sciences	114.3	121.7	6%
Social sciences, other fields	120.0	143.7	20%
Linguistics	46.0	54.3	18%
Art and literature research	57.7	65.3	13%
Humanities, other fields	76.3	93.3	22%
All fields	**1,564.7**	**1,823.3**	**17%**

The three-year average has been rounded to one decimal place. The change has been calculated using actual three-year averages. The row "All fields" also includes doctoral degree holders whose doctoral degree's research field was other natural sciences (2007–2009 on average 1.3 and 2013–2015 on average 4.3 doctoral degrees per year).

Source: Statistics Finland, Ministry of Education and Culture.

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