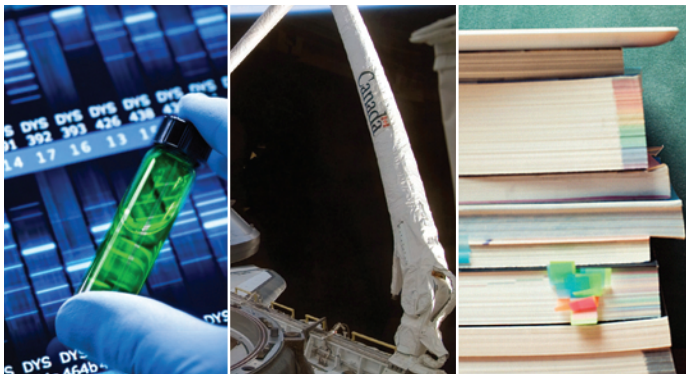
September 2012

Report in Focus

THE STATE OF SCIENCE AND TECHNOLOGY IN CANADA, 2012

Since the founding of this country, pioneering Canadians have contributed to significant advancements in aviation, medicine, engineering, telecommunications, and many other fields. For instance, the 1996 development of Sprinkles, a single dose sachet that delivers essential micronutrients, has benefitted four million children in 18 countries worldwide. The Canadarm, one of Canada's most recognized technological achievements, established this country's international reputation for robotics. More recently, the DNA barcoding initiative, conceived at the University of Guelph in 2003, has enabled scientists to better track and identify species through their discrete genetic codes. Innovations such as these have the potential to improve our quality of life and foster Canada's productivity and competitiveness.



To better understand what drives advancements in science and technology (S&T), governments regularly assess the three broad elements that characterize innovative societies: a world-class science and technology enterprise; a highly educated and skilled workforce; and a business, regulatory, and social environment that encourages entrepreneurship and creativity. With a comprehensive understanding of these elements, decision-makers are well placed to develop public policies that support science, technology, and innovation.

THE CHARGE TO THE EXPERT PANEL

Against a backdrop of a rapidly evolving and competitive global S&T environment, in 2010 the Government of Canada, through the Minister of Industry, asked the Council of Canadian Academies (the Council) to address the following question:

> What is the current state of science and technology in Canada?

In response to the charge, the Council assembled a multidisciplinary panel (the Panel) of 18 experts from Canada, the United States, and Europe, with backgrounds spanning numerous fields. The Panel was chaired by Dr. Eliot A. Phillipson, Sir John and Lady Eaton Professor of Medicine Emeritus at the University of Toronto and Former President and CEO of the Canada Foundation for Innovation.

The Panel developed a comprehensive assessment of the state of S&T in Canada, with a focus on research performed in the higher education sector, as well as in the not-for-profit and government sectors. Their report assesses Canada's overall S&T strengths, compared with international peers, and its strengths at the provincial and territorial level. The collective findings are comprehensive and represent one of the most in-depth examinations of Canadian S&T ever undertaken.

THEN AND NOW: S&T IN 2006 AND 2012

In 2006, the Council published its first report, *The State of Science and Technology in Canada*, providing a solid evidence base for policy decisions. The Council's 2012 report builds upon, updates, and expands on the previous report. It is also one in a new series of assessments by the Council that addresses various aspects of Canadian science, technology, and innovation. In particular, research in the private sector, is assessed in depth by another Council panel, the Expert Panel on the

State of Industrial Research and Development. The mandates of the two panels are complementary and taken together assess the entire research enterprise in Canada.

The 2006 report identified four key areas of S&T strength: natural resources, information and communication technologies (ICT), health and related life sciences, and environmental S&T. As a direct impact of the Council's report, the federal government identified these strengths as areas of priority in the 2007 federal S&T strategy, *Mobilizing Science and Technology to Canada's Advantage*.

The 2012 report demonstrates that Canadian S&T is healthy and growing in both output and impact, and highly regarded internationally.

The Panel identified six research fields in which Canada excels:

- Clinical Medicine;
- Historical Studies;
- Information and Communication Technologies (ICT);
- Physics and Astronomy;
- Psychology and Cognitive Sciences; and
- Visual and Performing Arts.

Collectively, these six fields of strength indicate the breadth of Canadian research excellence.

METHODOLOGIES FOR ASSESSING S&T STRENGTH

The concept of S&T strength is inherently complex and multi-dimensional and cannot be satisfactorily assessed using any single measure or indicator. Each methodology has strengths and limitations, and varying degrees of relevance to each of the specific fields of research. Therefore, the Panel's approach included multiple methodologies, incorporating both qualitative and quantitative measures. The Panel aimed for a balanced combination of techniques, including well-accepted methodologies such as bibliometrics and opinion surveys, and newer measurement approaches.

Recognizing that bibliometric measures are less relevant for the humanities, arts, and social sciences where research advances are often disseminated by means other than peer-reviewed journal articles, the Panel made considerable attempts to evaluate more relevant measures such as books and book chapters, presentations and exhibitions, and international awards. However, hampered by lack of available data, the evidence did not meet the standards required for this assessment and was not used.

Comparisons among and synthesis of the various methodologies were facilitated by consistent use of a 22-field classification system covering all S&T. Although the best available, a key limitation of all field-based systems is that scientific publications are classified on the basis of the journals in which the research is published, which may differ from the actual discipline of the authors or traditional academic departments. Responding to this challenge the Panel also undertook an analysis based on co-citations and keywords to identify research clusters.

The Panel also assessed the global reputation of Canadian S&T through a survey of the authors of the top one per cent of the most highly-cited research papers in the world. With more than 5,000 respondents, the survey represented the first time the opinions of the world's top researchers were analyzed in this manner.

Figure 1. Research Elements of the 2006 and 2012 Reports

The figure above illustrates the differences between the methodologies used for the 2006 report and those used for this report. Three of the four methodologies used in 2006 were repeated in 2012, and several new methodologies were used as well. Bibliometrics refers to the study of patterns in peer-reviewed journal articles. "Advanced" bibliometrics refers here to the use of additional techniques to study clusters of related research as well as patterns in research collaboration. Technometrics is the analysis of intellectual property (i.e., patents).

Over five thousand leading international scientists ranked the quality of Canada's scientific research enterprise fourth highest in the world, after the United States, the United Kingdom, and Germany.

Assessing the Current State of S&T in Canada

MAIN FINDINGS

Canadian S&T in a Global Context

Canadian S&T is healthy and growing in both output and impact. With less than 0.5 per cent of the world's population, Canada produces 4.1 per cent of all scientific papers and nearly 5 per cent of most frequently cited papers. Canada produced 59 per cent more papers in 2005-2010 than in 1999-2004 – the only G7 country with an increase in output above the world average.

Canada is ranked sixth in the world for overall impact of its S&T, as measured by the frequency of citation of publications (the Average Relative Citations (ARC)). It is among the 5 leading countries in 7 of 22 fields of research, and among the 10 leading countries in another 14 fields.

Canada's strong performance in research impact and output contributes to high international regard for the quality and rigour of Canadian S&T. Thirty-seven per cent of respondents to a survey of the world's top-cited researchers identified Canada as one of the five leading countries in their field. This placed Canada fourth overall behind the United States, the United Kingdom, and Germany. Sixty-eight per cent of respondents rated Canadian S&T as strong compared with the rest of the world.

In three-quarters of fields, the majority of the world's top-cited researchers surveyed thought Canada had world-leading research infrastructure or programs. Canadian S&T experts surveyed identified the Canada Research Chairs program, Canada's universities and research hospitals, and Canada's national research funders as S&T advantages for Canada.

In contrast to its strength in knowledge generation is Canada's weaker performance in patents and related measures. Despite producing 4.1 per cent of all scientific papers, Canada holds only 1.7 per cent of patents. But Canada excels in international comparisons of quality with citations to patents (ARC scores), ranking second in the world behind the United States.

Canada's Fields of Research Excellence

The Panel determined two measures of quality to be the most relevant in determining a field's position relative to other advanced countries: the field's international ARC rank and its rank in the international survey. The six research fields (in alphabetical order) in which Canada excels indicate the breadth of Canadian research excellence:

- Clinical Medicine
- Historical Studies
- Information and Communication Technologies (ICT)
- Physics and Astronomy
- Psychology and Cognitive Sciences
- Visual and Performing Arts

These six fields show strength by many measures. Citation indices ranked Canada among the top five countries in the world in all six fields with the exception of ICT. Similarly, leading international researchers ranked Canada among the five leading countries in all these fields except Physics and Astronomy. Three of the fields (Clinical Medicine, ICT, and Physics and Astronomy) are among the five largest research enterprises in Canada in terms of output of scientific papers. Further, Canada's share of publications in all fields, with the exception of ICT, grew in the 2005-2010 period compared with the 1999-2004 period. ICT, however, is responsible for 44 per cent of Canada's patents. Finally, three of the six fields (Historical Studies, Psychology and Cognitive Sciences, and Visual and Performing Arts) are at least partly, if not completely, within the humanities, social sciences and creative arts, notwithstanding the challenge of assessing research strength in these areas.

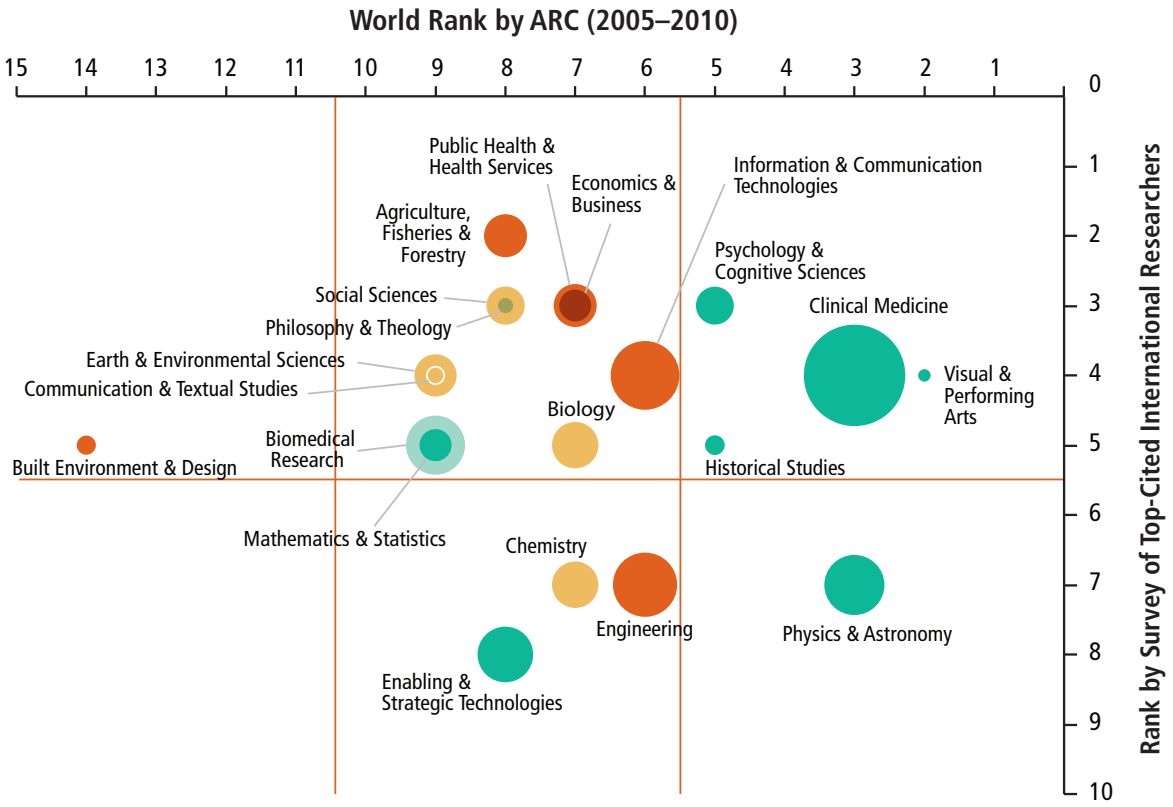


Figure 2. Survey Rank versus ARC Rank of 20 Fields

This figure shows Canada's rank in each field by Average Relative Citations (ARC) in the period 2005-2010 on the x-axis, and ranking in terms of the reputation of Canadian research in the survey of top-cited international researchers on the y-axis. The size of the bubble is proportional to the number of papers produced in 2005-2010. Bubbles are coloured according to whether Canada's share of world papers in that field increased (green), decreased (red), or remained approximately the same (yellow – defined as an increase or decrease of less than 0.2 per cent) compared with 1999-2004. ARC rank is out of the top 19 countries by total number of papers produced in that field of research.

The data related to strengths in technological applications are less comprehensive, but indicate that Canadian patents related to ICT, Chemicals, and AgriFood have a greater impact than the world average.

Drilling Down: Nine Sub-Fields of Strength

Much of the nuance of Canadian S&T strength is at the sub-field level. Canada leads the world in scientific impact, as measured by bibliometrics (ARC scores), in nine sub-fields:

- Anatomy and Morphology
- Astronomy and Astrophysics
- Business and Management
- Classics
- Criminology
- Dermatology and Venereal Diseases
- General and Internal Medicine
- Nuclear and Particles Physics
- Zoology

In a further 56 (of 176) sub-fields, Canada is ranked among the top five countries in the world, based on its ARC rank.

Geographic Distribution of S&T Strength

Collectively, Ontario, Quebec, British Columbia, and Alberta are the major drivers of Canadian S&T, accounting for 97 per cent of total Canadian output in terms of scientific papers, compared with 86 per cent of the national population. Ontario produces 46 per cent of Canada's research publications, in keeping with the 45 per cent of Canada's gross domestic expenditure on research and development (GERD) spent in the province. British Columbia leads in terms of impact as measured by ARC indices. The same four provinces are most often identified as provinces of strength by Canadian experts. These provinces also have the best performance in patent-related measures, and the highest per capita numbers of graduates from doctoral programs.

Canadian S&T experts identified Ontario, Quebec, British Columbia, and Alberta as Canada's strongest provinces for research, with Ontario ranked highest in nearly all sub-fields.

The geographic distribution of the six fields of strength is difficult to determine with precision because of the diminished reliability of data below the national level and the vastly different size of the research enterprise in each province. Using provincial ARC scores, the most reliable data independent of size, the leading provinces in each field are as follows:

- Clinical Medicine: ON, QC, BC, AB
- Historical Studies: NB, ON, BC
- ICT: BC, ON
- Physics and Astronomy: BC, AB, ON, QC
- Psychology and Cognitive Sciences: BC, NS, ON
- Visual and Performing Arts: QC

Notwithstanding the dominant position of the four large research-intensive provinces, several fields of particular specialization were also identified in the other provinces – examples include: Agriculture, Fisheries, and Forestry in Prince Edward Island and Manitoba; Biology in Saskatchewan; Historical Studies in New Brunswick; and Earth and Environmental Sciences in Newfoundland and Labrador and Nova Scotia. Diversity among provinces often aligns with local economic strengths and contributes to local and regional clusters of innovation.

Improving and Declining S&T Fields

Since the 2006 report on S&T, improvements have occurred in the magnitude and quality of Canadian S&T in several fields, including Biology, Clinical Medicine, ICT, Physics and Astronomy, Psychology and Cognitive Sciences, Public Health and Health Services, and Visual and Performing Arts.

Two of the four areas identified as strengths in the 2006 report – ICT and health and related life sciences – have improved by most measures since 2006. The other two areas of strength – natural resources and environment – have not experienced the same improvement as Canadian S&T in general. In the current classification system, these broad areas are now represented primarily by the fields of Agriculture, Fisheries, and Forestry; and Earth and Environmental Sciences. The Panel mapped the current classification system for these fields to the 2006 system and is confident that the overall decline in these fields is real, and not an artifact of different classifications. Scientific output and impact in these fields was either static or declined in the 2005-2010 period compared to 1999-2004. In addition, of the 10 sub-fields with the greatest declines in publication volume, half are in these two fields. Both fields, however, maintain considerable strength and reputation: Canadian research in Agriculture, Fisheries, and Forestry ranked second in the world in the survey of international researchers, and Earth and Environmental Sciences ranked fourth.

Emerging Areas

Although robust methods of identifying emerging areas of S&T are still in their infancy, the Panel used innovative bibliometric techniques to identify research clusters and their rates of growth. Rapidly emerging research clusters have keywords relating, most notably, to wireless technologies and networking, information processing and computation, nanotechnologies, and digital media technologies.

Further, Canadian experts identified personalized medicine and health care, several energy technologies, tissue engineering, and digital media as areas in which Canada is well placed to become a global leader in development and application.

Canada is producing high-impact research related to several clusters in medicine and physics, and is highly active in clusters related to geology and mineral extraction. Canada's interdisciplinary research clusters include several related to environmental science and remediation technologies, and biomedical technologies.

The Panel noted the many changes that have occurred in the Canadian S&T enterprise since the first Council report in 2006. Overall, Canadians have much to be proud of. This assessment provides another snapshot in time of a dynamic, rapidly evolving, and highly competitive environment. The report can also serve to inform policy formulation and decision-making related to science, technology, and innovation by governments, academic institutions, and industry.

Figure 3. Key S&T Indicators for 20 Fields

Field	MAGNITUDE/INTENSITY			QUALITY/IMPACT		
	# of Papers (2005–2010)	Share of World Pubs. (2005–2010) (%)	SI (2005–2010)	ARC Score (2005–2010)	ARC Rank (2005–2010)	Share of Top 1% Cited Papers (%)
Agriculture, Fisheries & Forestry	15,880	5.33	1.38	1.25	8	7.90
Biology	18,227	5.23	1.18	1.34	7	5.45
Biomedical Research	31,326	4.96	1.12	1.18	9	4.22
Built Environment & Design	3,152	4.94	1.36	1.17	14	4.81
Chemistry	17,653	2.56	0.63	1.27	7	2.62
Clinical Medicine	88,354	4.09	0.98	1.59	3	6.15
Communication & Textual Studies	2,686	5.16	1.73	1.04	9	1.87
Earth & Environmental Sciences	15,788	5.79	1.23	1.29	9	4.53
Economics & Business	10,161	4.80	1.21	1.11	7	3.96
Enabling & Strategic Technologies	26,896	2.96	0.75	1.36	8	3.77
Engineering	34,927	3.92	1.01	1.37	6	4.44
Historical Studies	3,512	4.76	1.26	1.28	5	3.74
Information & Communication Technologies	40,529	4.35	1.12	1.30	6	4.27
Mathematics & Statistics	8,951	4.18	0.91	1.11	9	3.29
Philosophy & Theology	2,024	5.90	1.94	0.93	8	3.31
Physics & Astronomy	30,890	3.03	0.60	1.42	3	2.57
Psychology & Cognitive Sciences	12,319	7.64	1.96	1.13	5	5.39
Public Health & Health Services	15,298	6.88	1.82	1.24	7	8.00
Social Sciences	12,355	4.69	1.44	1.10	8	4.05
Visual & Performing Arts	286	3.71	1.37	2.09	2	4.55

	QUALITY/IMPACT			TRENDS				
	Canada's rank in survey of top-cited international researchers	% of top-cited researchers identifying Canada in top 5	% of Canadian S&T experts rating field as strong	Change in share of world pubs (%)	Change in ARC	Change in SI	Gaining Ground (Canadian survey) (%)	Falling Behind (Canadian survey) (%)
	2	57	78	-0.98	0.00	-0.31	7	19
	5	37	57	-0.08	0.16	-0.11	5	16
	5	37	62	0.36	0.07	0.03	8	18
	5	29	50	-0.81	0.09	-0.26	10	7
	7	20	53	-0.04	0.04	-0.03	6	29
	4	43	55	0.40	0.10	0.04	7	16
	4	58	55	0.09	0.13	-0.03	21	14
	4	41	71	0.16	-0.02	-0.07	10	26
	3	63	66	-0.23	0.05	-0.12	14	6
	8	17	62	0.31	-0.05	0.06	13	21
	7	27	70	-0.47	0.16	-0.16	8	17
	5	35	53	0.21	-0.13	0.04	9	15
	4	42	64	-0.71	0.13	-0.20	5	12
	5	27	76	0.07	0.02	-0.01	24	15
	3	79	65	0.73	0.05	0.20	12	6
	7	19	56	0.34	0.16	0.05	8	10
	3	69	67	0.52	0.04	0.03	15	4
	3	58	65	0.78	0.07	0.18	26	10
	3	54	60	0.18	-0.05	0.05	12	11
	4	55	68	1.04	0.66	0.27	22	6

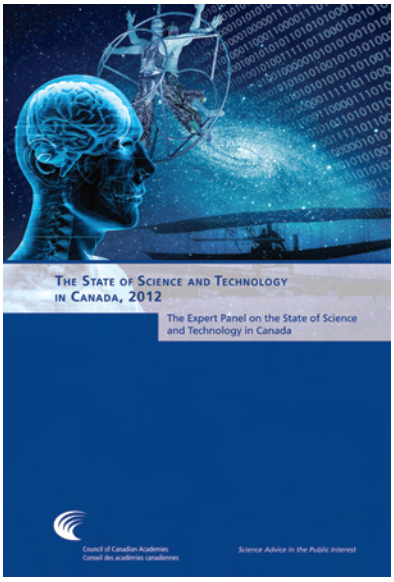
Notes: SI = Specialization Index; ARC = Average Relative Citations; ARC rank = Canada's rank by ARC for 2005–2010. Other variables are drawn from the Survey of Top-Cited International Researchers and the Survey of Canadian S&T Experts. "Trends" are for the period 2005–2010 compared with 1999–2004, except for "Gaining Ground" and "Falling Behind" which are for the past five years.

Inside the Full Report

The Panel's report represents one of the most in-depth examinations of Canadian S&T ever undertaken. Within the report, readers can find:

- The full data set for the 22 fields and 176 sub-fields of Canadian S&T
- Advanced bibliometric analysis of Canadian S&T
- The results of the survey of top-cited international researchers and the survey of Canadian S&T experts
- Regional analysis of S&T strength
- Data on the migration of researchers to and from Canada
- Analysis of Canadian research collaborations

Comprehensive appendices – which include additional data as well as copies of the original surveys – is available online at www.scienceadvice.ca.



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This Report in Focus was prepared by the Council based on the Report of the Expert Panel on The State of Science and Technology in Canada, 2012.

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