Science Culture: Where Canada Stands

Expert Panel on the State of Canada's Science Culture

Council of Canadian Academies
Conseil des académies canadiennes

Science Advice in the Public Interest

SCIENCE CULTURE: WHERE CANADA STANDS

Expert Panel on the State of Canada's Science Culture

THE COUNCIL OF CANADIAN ACADEMIES
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The Council of Canadian Academies
Science Advice in the Public Interest

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Expert Panel on the State of Canada's Science Culture

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The Council also recognizes the important contribution to this assessment of Ian Hacking, C.C., FRSC, University Professor Emeritus in Philosophy at the University of Toronto.

Message from the Chair

Over 50 years ago, English physicist and novelist C.P. Snow gave his famous "Two Cultures" lecture in which he bemoaned the chasm between the sciences and society. If Snow were alive today he would be astonished at the changes that have taken place since then, principally driven by science, technology, and their application to society. In 1959 he could not have imagined the dawn of the information technology revolution, or the impact of biotechnology, modern medicine, and new materials on society. The pace of change, the mobility of people and resources, the speed and ease of communication, the rapid rise of emerging nations in a global knowledge-based economy, climate warming, and environmental stress — all of these developments underline that there has never been a time in history when science and technology have had a greater impact on citizens. Some understanding of science is now an integral part of being an informed citizen and almost every decision governments make has a scientific component.

Have we succeeded in bridging the chasm between the sciences and society that Snow referred to or has the gulf widened? That question is difficult to answer, but much evidence suggests that the gulf remains. It is abundantly clear that we must continue to strive for a society that is generally knowledgeable and literate about science and places a high value on science and its applications.

Over the course of the past year and a half, I was privileged to chair a panel charged with assessing the current state of Canada's science culture. The results of this investigation, presented here, are both encouraging and sometimes sobering. Canadians do benefit from a strong science culture in many respects and have much to be proud of. However, causes for concern remain and there is room for improvement.

On behalf of the Panel, I would like to extend my thanks to the Canada Science and Technology Museums Corporation, Industry Canada, and Natural Resources Canada for sponsoring this inquiry, and to the Council of Canadian Academies for expertly supporting the Panel throughout its deliberations. I would also like to thank the 10 external reviewers who took the time to review and critique an earlier draft of the Panel's report.

This assessment is a contribution to ongoing conversations about science, society, and culture in Canada. I look forward to continuing to participate in these conversations, and hope this Panel's study plays a useful part in informing future discussion and debate.

Arthur Carty, O.C., FRSC, FCAE
Chair, Expert Panel on the State of Canada's Science Culture

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Many individuals and organizations assisted the Expert Panel over the course of its deliberations, sharing information about Canada's science culture landscape that would have been difficult to obtain otherwise. The Panel would like to thank the following individuals in particular for their assistance: Penny Park at the Science Media Centre of Canada; Bonnie Schmidt at Let's Talk Science; Chantal Barriault at Science North; Lesley Lewis at the Ontario Science Centre; Kathryn O'Hara at Carleton University; Tracy Ross and Amber Didow with the Canadian Association of Science Centres; Derek Jansen and colleagues at EKOS Research Associates Inc.; Geoff Rayner Canham at Memorial University; Peter Calamai; and Paul Dufour.

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Report Review

This report was reviewed in draft form by the individuals listed below — a group of reviewers selected by the Council of Canadian Academies for their diverse perspectives, areas of expertise, and broad representation of academic, industrial, policy, and non-governmental organizations.

The reviewers assessed the objectivity and quality of the report. Their submissions — which will remain confidential — were considered in full by the Panel, and many of their suggestions were incorporated into the report. They were not asked to endorse the conclusions, nor did they see the final draft of the report before its release. Responsibility for the final content of this report rests entirely with the authoring Panel and the Council.

The Council wishes to thank the following individuals for their review of this report:

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The report review procedure was monitored on behalf of the Council's Board of Governors and Scientific Advisory Committee by **Gregory S. Kealey, FRSC**, Professor, Department of History, University of New Brunswick. The role of the report review monitor is to ensure that the Panel gives full and fair consideration to the submissions of the report reviewers. The Board of Governors of the Council authorizes public release of an expert panel report only after the report review monitor confirms that the Council's report review requirements have been satisfied. The Council thanks Dr. Kealey for his diligent contribution as report review monitor.

Elizabeth Dowdeswell, O.C.
President and CEO, Council of Canadian Academies

Executive Summary

Science is a fundamental part of Canadian culture and society, affecting nearly every aspect of individual and social life. It is a driving force in the economy, catalyzing innovation and creating new goods, services, and industries. It has led to improvements in Canadians' physical health and well-being. It has made possible new forms of communication and learning, and changed how Canadians interact and relate to one another. It also provides opportunities for leisure and entertainment as Canadians visit science centres, pursue science-related hobbies, or tune in to such television programs as "The Nature of Things" or "Découverte". Science is also a systematic means of discovery and exploration that enriches our individual and collective understanding of the world and universe around us.

Most of the impacts of science on society are broadly welcomed as science has improved the quality of life in modern, industrialized societies in numerous ways. However, the applications of science and technology can also be a source of debate and controversy. Some individuals in Canada and other industrialized countries harbour reservations about science, worrying about its potentially disruptive influences or that the pace of scientific and technological change is "too fast" for society to cope with. Science also features prominently in public debates about politically divisive issues such as climate change, genetically modified foods, nuclear power, the use of embryonic stem cells, or the risks associated with biotechnology and nanotechnology. Concerns are raised that too few citizens have an understanding of science sufficient to grasp these issues and therefore lack the ability to participate in public debates in an informed manner. As a result, society's relationship with science can at times seem strained, characterized by a deep dependence on the one hand and by apathy or apprehension on the other.

THE CHARGE TO THE PANEL

In 2012 the Canada Science and Technology Museums Corporation, Industry Canada, and Natural Resources Canada asked the Council of Canadian Academies (the Council) to investigate the state of Canada's science culture. This request was driven by both the recognition of the role that science culture plays in maintaining Canada's demonstrated strengths in science and technology, and by concerns that Canada potentially lags behind other countries in terms of how deeply science is embedded in Canadian culture. The Council was tasked with forming an expert panel to address the following questions:

What is the state of Canada's science culture?

- *What is the state of knowledge regarding the impacts of having a strong science culture?*
- *What are the indicators of a strong science culture? How does Canada compare with other countries against these indicators? What is the relationship between output measures and major outcome measures?*
- *What factors (e.g., cultural, economic, age, gender) influence interest in science, particularly among youth?*
- *What are the critical components of the informal system that supports science culture (roles of players, activities, tools and programs run by science museums, science centres, academic and not-for-profit organizations and the private sector)? What strengths and weaknesses exist in Canada's system?*
- *What are the effective practices that support science culture in Canada and in key competitor countries?*

To address this charge, the Council convened a 14-member multidisciplinary panel of experts (the Panel). The Panel drew on three principal lines of research in exploring its charge: (i) a review of the existing literature on science culture in Canada and abroad, (ii) a new public survey of science culture in Canada commissioned by the Panel, and (iii) an inventory and analysis of the organizations and programs that support and promote science culture in Canada. The Panel's findings represent its collective judgment based on its review of the best available evidence.

ASSESSING CANADA'S SCIENCE CULTURE

As understood by the Panel, a society has a strong science culture when it embraces discovery and supports the use of scientific knowledge and methodology. Such a culture encourages the education and training of a highly skilled workforce and the development of an innovative knowledge-based economy. The concept of science culture is multidimensional, incorporating a number of distinct dimensions pertaining to how individuals and society relate to science and technology. The national context also influences how science culture develops and is expressed. The Panel's analysis of science culture in Canada focused on four key dimensions:

- public *attitudes* towards science and technology;
- public *engagement* in science;
- public science *knowledge*; and
- science and technology *skills* in the population.

Established indicators from surveys and other data sources can be used to assess these four dimensions with a reasonable degree of rigour and accuracy. International comparisons and trends over time can place these data in context and aid in their interpretation.

The Panel also surveyed the system of social and institutional support for science culture in Canada, reviewing the network of organizations, programs, and initiatives that provide opportunities for informal science learning and engagement (i.e., science learning and engagement occurring outside of the school system).

Although the Panel was charged to assess Canada's *science* culture rather than its *science and technology* culture, distinguishing between the two is often impractical as the public frequently does not differentiate between them. As a result, both terms are used in this report depending on the context.

THE CURRENT STATE OF SCIENCE CULTURE IN CANADA

The main findings from the Panel's analysis are summarized here. Table 1 presents data for selected indicators. The rankings should be regarded as an approximate indicator of Canada's international standing as data may be from different years and not all differences in rank are statistically significant.

Public Attitudes Towards Science and Technology

> Canadians have positive attitudes towards science and technology and low levels of reservations about science compared with citizens of other countries.

Like citizens of other industrialized countries Canadians hold both positive and negative attitudes about science and technology, though positive attitudes predominate. Approximately three-quarters of Canadians agree with statements such as "all things considered, the world is better off because of science and technology" and "science and technology are making our lives healthier, easier and more comfortable." On an index based on standard survey questions assessing beliefs about the promise of science and technology, Canada ranks 9th out of 17 industrialized countries. Relative to citizens of other countries, however, few Canadians express beliefs such as "it is not important for me to know about science in my daily life" or "we depend too much on science and not enough on faith." On an index based on standard questions assessing public reservations about science, Canada ranks 1st among the same 17 countries, indicating low levels of concern about any potentially disruptive impacts of science and technology. Public reservations about science in Canada have also declined on average since 1989.

Table 1

Summary Table of Selected Science Culture Indicators

Indicator	% or Score	Rank
Public Attitudes Towards Science and Technology		
Public views about the "promise" of science (index)[a]	7.3/10	9th out of 17 countries
Public reservations about science (index)[b]	3.0/10	1st out of 17 countries
% of pop. agreeing that even if it brings no immediate benefits, scientific research that adds to knowledge should be supported by government	76%	12th out of 35 countries
Public Science Engagement		
% of pop. that reports being very interested or moderately interested in new scientific discoveries and technological developments	93%	1st out of 33 countries
% of pop. that has visited a science and technology museum at least once in previous year	32%	2nd out of 39 countries
% of pop. that regularly or occasionally signs petitions or joins street demonstrations on matters of nuclear power, biotechnology, or the environment	23%	3rd out of 33 countries
% of pop. that regularly or occasionally attends public meetings or debates about science and technology	14%	5th out of 33 countries
% of pop. that regularly or occasionally participates in activities of a non-governmental organization dealing with science/technology-related issues	14%	1st out of 33 countries
% of pop. that regularly or occasionally donates to fundraising campaigns for medical research	63%	7th out of 33 countries

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Indicator	% or Score	Rank
Public Science Knowledge		
Estimated % of pop. that demonstrates a basic level of scientific literacy[c]	42%	1st out of 35 countries
Average score on OECD PISA 2012 science test[d]	525	10th out of 65 countries
Average score on OECD PISA 2012 math test[d]	518	13th out of 65 countries
Science and Technology Skills		
% of pop. aged 25–64 with tertiary education	51%	1st among OECD countries
% of first university degrees in science and engineering fields	20%	19th out of 29 countries
% of first university degrees in science fields awarded to women	49%	4th out of 28 countries
% of first university degrees in engineering awarded to women	23%	19th out of 28 countries
% of all doctoral degrees in science and engineering fields	54%	4th out of 37 countries
% of total employment in science and technology occupations	30%	22nd out of 37 countries

The table presents data for a selection of science culture indicators examined by the Panel. Canada's performance is ranked relative to other countries for which comparative data are accessible for each indicator. In cases of ties, both countries receive the same rank. [a]Index that combines responses to three science attitudes questions whereby a higher score represents more positive attitudes about the promise of science. [b]Index that combines responses to three science attitudes questions, with a lower score representing fewer reservations about science (/10). [c]Percentage of population that is identified as "civically scientifically literate" using Jon Miller's methodology, i.e., having the level of science knowledge necessary to comprehend the Science section of *The New York Times* (Miller, 2012). This rank should be interpreted with caution as the year of data collection varies by country. [d]Organisation for Economic Co-operation and Development (OECD) Programme for International Student Assessment (PISA) test scores are scaled so that the mean score is approximately 500 and the standard deviation is 100.

Canadians express above-average levels of support for public funding of scientific research, and a strong majority of Canadians view science and technology as important in pursuing a range of social objectives such as environmental protection and improving Canada's economic prospects. However, since 2004 Canadians have become slightly more skeptical about the ability of science and technology to achieve these objectives.

Public Engagement in Science

Canadians exhibit a high level of engagement with science and technology relative to citizens of other countries.

Ninety-three per cent of Canadians report being either very or moderately interested in new scientific discoveries and technological developments. Canada ranks 1st out of 33 countries on this measure. Canadians are also more likely to visit a science and technology museum than citizens of any other country except Sweden. Nearly one-third of Canadians report having visited such an institution at least once in the past year, and this share has increased over the past two decades. Canadians also show high levels of participation in scientific activities and organizations in other ways, such as donating money to medical research, taking part in activities of non-governmental organizations (NGOs) related to science or technology, and signing petitions or joining street demonstrations on nuclear power, biotechnology, or the environment.

Public Science Knowledge

Established, survey-based measures suggest that Canadians' level of science knowledge is on a par with or above citizens of other countries for which data are available.

Public surveys in the United States and Europe have used standard factual and open-ended questions to assess public science knowledge for several decades. Based on data from the Panel's survey, Canadians have a relatively high level of understanding of core scientific constructs and methods. Moreover, their level of science knowledge has increased since 1989. Canada ranks first on a science literacy index among countries for which data are available. Around 42% of the population in Canada, compared with 35% in Sweden and 29% in the United States, exhibits a sufficient level of science knowledge to grasp basic scientific concepts and understand general media coverage of scientific and technological issues. This ranking should be interpreted with caution, however, as Canadian data are more recent and science literacy has been improving over time in most countries. The survey data are consistent with findings from student assessments such as PISA (Programme for International Student Assessment) and TIMSS (Trends in International Mathematics and Science Study), which show that on average Canadian students excel in achievements in science and mathematics compared with students in most other countries. Canada's PISA scores in science and mathematics, however, have declined since 2006, raising the concern that Canada is failing to keep pace with other leading countries.

Science and Technology Skills

> Canada's performance on indicators of science and technology skills development is variable compared with other OECD countries.

While Canada ranks first among OECD countries in overall post-secondary educational attainment (the portion of the population aged 25–64 with college and university degrees), only 20% of first university degrees in Canada are in the sciences and engineering. Canada ranks 19th out of 29 countries on this measure, well behind leaders like Korea (32%) and Germany (30%). The proportion of students graduating with engineering degrees in Canada is particularly low. Despite this ranking, the sciences' share of first degrees in Canada has been relatively stable over the past decade while declining in the majority of developed economies. Immigration also plays an important role in determining the availability of these skills. Over half (51%) of individuals holding science, technology, engineering, and mathematics degrees in Canada are immigrants. Although Canada has a relatively low level of doctoral graduation, a large share of Canada's doctoral degrees are granted in the sciences and engineering. Similar patterns are evident in OECD occupational statistics. The share of Canada's workforce employed in areas relating to science and technology is near the OECD average, and particularly low in the manufacturing sector.

INSTITUTIONAL AND SOCIAL SUPPORT FOR SCIENCE CULTURE IN CANADA

Many types of organizations contribute to the advancement of science culture in Canada, including formal science education providers, informal science learning institutions like museums and science centres, a growing array of electronic and print science learning resources, and friends and family. The formal and informal science learning systems are linked, and experiences in formal science education are major drivers of national science culture. In this respect, Canada's science education system at the primary and secondary levels strongly contributes to Canadians' comparatively high levels of scientific knowledge and engagement.

The science culture support system is also dynamic. New organizations, programs, and initiatives are continually created while older ones are discontinued. A 2011 inventory of science culture and communication initiatives in Canada identified more than 700 such programs or organizations. These include over 400 initiatives related to museums, science centres, zoos, or aquariums; 64 NGOs or associations; 49 educational initiatives; 60 government policies and programs; 27 media programs; and a variety of other organizations and programs. These organizations fulfil a range of different functional roles within the system of informal science interventions in Canada.

Given a lack of internationally comparable data, there is no scientifically rigorous way of evaluating the strengths and weaknesses of Canada's system of informal science engagement and learning interventions relative to that of other countries. However, a number of informed observations can be made based on the available evidence:

- The success of Canada's network of science centres and museums is reflected in their strong international reputations and relatively high numbers of annual visitors.
- Several long-standing, iconic Canadian science media programs (in French and English) contribute to informal science learning.
- General science coverage in the English-language Canadian press is limited by few dedicated science reporters, a function of the decline of print media in general. However, television and radio continue to have well-recognized and established science programming. Canadians also increasingly rely on the internet for information on science and technology topics.
- Private industry and research institutes also support science culture in Canada, and research organizations play an active role in some forms of public outreach and engagement.
- Federal, provincial, and municipal governments in Canada support science culture through a range of programs, though the federal government has not been as active as some of its peers in articulating a national vision or strategy for science culture. Some provincial governments, most notably Quebec and Ontario, have been more active in supporting public science outreach and engagement.
- Concerns about how federally employed scientists are allowed to communicate with the media have been widely reported in the Canadian and international media in recent years, raising questions about the extent to which current policies limit opportunities for public communication and engagement.
- Canada also lacks a dedicated funding program for research on informal science learning like the one provided by the National Science Foundation in the United States. The lack of such a program limits resources for informal science learning initiatives in Canada and curtails the development of knowledge about the effectiveness of existing programs and institutions.

CULTIVATING A STRONG SCIENCE CULTURE

The Panel's research on cultivating a strong science culture identified relevant interventions under five broad themes. The quality of the evidence available to evaluate these interventions is variable. While science education and learning have been the subject of extensive academic research over the years, other types of practices reviewed by the Panel have received less study and could benefit from more research.

Supporting Lifelong Science Learning: Exposure to science in the formal school system is a critical determinant of the level of science knowledge in the adult population. At the same time, individuals spend a small portion of their lives in formal school settings, and will continue to encounter new needs for scientific information throughout their lifetimes. Effective strategies for promoting science knowledge therefore recognize the importance of formal educational settings in providing a foundation of knowledge and skills, while, at the same time, offering a variety of channels through which the adult population can continue to seek out information on science.

Making Science Inclusive: Tailoring science learning and engagement opportunities to the social and cultural contexts of groups traditionally underrepresented in the sciences can make science more inclusive. Such strategies will vary depending on the group. Young women are more likely to develop interest and pursue science learning when they can see the social relevance of the subject matter and when given the opportunity to engage with scientists and mentors. For Aboriginal populations, recognizing and incorporating aspects of traditional knowledge into curricula and instruction can be effective.

Adapting to New Technologies: All organizations involved in activities related to science culture need to adapt to a rapidly changing technological environment. New technologies are threatening the viability of traditional models of instruction and communication and changing the ways in which people seek information on scientific topics. New technologies can be used to augment science education and engagement strategies in many ways. Internet-based resources may allow learners to tailor learning to their own style and interests. Technology can also enhance a variety of science outreach activities, and offer new modes of public engagement (e.g., citizen science) and communication (e.g., social media and blogs).

Enhancing Science Communication and Engagement: Scientists who are encouraged to communicate with the public and equipped with the tools to engage successfully can build support, knowledge, and interest across the population. A careful framing of science communication will factor in the social and cultural context of the audience, and how messages will resonate with diverse groups. Engaging the public in certain areas of science decision-making can also make science more relevant to society and increase science knowledge of participants. Other approaches to facilitating public engagement in science include acknowledging debate and controversy and linking science with other aspects of culture such as the arts.

Providing National or Regional Leadership: Governments can play a role in supporting science culture by articulating a vision for science culture that provides a framework for action across organizations and a foundation for coordination. Governments can also promote the value of science, incorporate science into policy-making, strengthen science learning through the formal education system, provide leadership, and share information.

THE IMPACTS OF A STRONG SCIENCE CULTURE

Many claims have been advanced about the impacts of a strong science culture. Such claims are often plausible given the extent to which science and technology feature in most aspects of individual and social life. However, there is limited empirical evidence to substantiate these claims, and in some cases that evidence points to more complexity in the way these impacts are manifested than is typically acknowledged. Much of this evidence suggests that, while a stronger science culture may contribute to a range of personal or social benefits, it is not always in itself sufficient to ensure the realization of those benefits. The Panel explored these impacts in relation to four domains: impacts on individuals, impacts on democracy and public policy, impacts on the economy, and impacts on scientific research.

Impacts on Individuals: Improving scientific knowledge can help individuals better differentiate between fact and opinion, make more informed consumer choices, and better evaluate personal and public health risks. However, it is not a guarantee of more effective individual decision-making, which can be affected by many other factors, including underlying cultural values and common cognitive biases and heuristics (i.e., innate or ingrained decision-making rules). Different forms of scientific knowledge (i.e., knowledge of scientific processes versus scientific facts) are also not necessarily of equal value or relevance in informing individual decisions in daily life.

Impacts on Democracy and Public Policy: Science plays a defining role in many policy debates faced by current governments. Some level of knowledge of science is therefore critical to enabling informed public participation in policy issues involving science and technology. However, increasing knowledge does not ensure higher levels of participation or more effective policy-making. The types of public engagement opportunities available to citizens and the institutional mechanisms for incorporating science advice into policy-making also determine the nature of any impacts on policy outcomes.

Impacts on the Economy: As understood by the Panel, a strong science culture is one that supports the development of advanced science and technology skills in the population. A strong science culture can therefore reasonably be expected to bolster an economy's capacity for innovation through increasing the supply of these skills. However, the relationships between the supply of skills and economic outcomes are complex, and there are many other determinants of both innovation performance and aggregate economic outcomes. As a result, a greater supply of science and technology skills will not necessarily lead to improved economic outcomes in all contexts.

Impacts on Scientific Research: Increased public engagement in science can benefit research through greater public support of and participation in different kinds of research activity such as clinical trials or provision of medical samples or health data. Online platforms are also creating novel opportunities for public engagement in scientific research.

FINAL REFLECTIONS

Much of the evidence reviewed by the Panel speaks to the relative strength of Canada's science culture. Canadians exhibit high levels of science knowledge and of engagement in scientific activities relative to their peers abroad. However, it remains an open question whether Canada's science culture is sufficiently robust for a technologically advanced, democratic society in the 21st century. Despite Canada's high international standing, more than half of Canadians lack the understanding of basic scientific concepts needed to make sense of major public debates on scientific issues. Based on the Panel's research, 54% of Canadians cannot describe what it means to study something scientifically, which compromises the ability of Canadians to meaningfully engage in public discussions involving science. Similarly, the 72% of Canadians unable to describe a molecule will struggle to make sense of public debates on the safety of nanotechnology, and the 49% of Canadians with little understanding of DNA cannot fully comprehend the possibilities or risks associated with new genetic research and technologies. Persistent gender disparities with respect to science knowledge, interest, and attitudes also indicate that Canada's science culture is not equally well established across all segments of the population.

There are many rationales for cultivating a strong science culture. One of the simplest is that doing so helps foster a fuller, richer experience of science itself. As a systematic means of discovery and exploration, science enables individuals to more fully understand and appreciate the world around them. A strong science culture is also one that celebrates the experience of science in this light, and works to ensure that all individuals (and all segments of society) have opportunities to share in the wonder and excitement of science. Canadians are fortunate to have many such opportunities, but science and society are both constantly evolving, and developing a stronger science culture in Canada — one with a nuanced understanding and appreciation of the myriad ways in which science is deeply ingrained in society — remains a work in progress.

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1 Introduction

Science is a systematic means of discovery and exploration that enriches our collective understanding of the world and universe around us. It is a fundamental part of Canadian culture and society, implicated in nearly every aspect of individual and social life. Both science and technology have measurably contributed to the quality of life enjoyed by the average Canadian and citizens of other industrialized countries. As such, most of science's impacts on society are welcomed.

However, science and technology are not universally embraced. Some individuals harbour concerns about science and its role in society. The application of science and technology is frequently the focus of public debate and controversy, and scientific research features prominently in a range of divisive issues faced by governments today such as climate change, nuclear power, genetically modified foods, and the safety of nanotechnology. The complexity of these issues can make them seem inaccessible to the public and the uncertainty associated with the science may be challenging to communicate. The ethical implications of new research and emerging technologies, such as the use of therapeutic stem cells, are also widely debated. The result is that individuals may sometimes feel alienated from science, uncertain about its place in society, and apprehensive about the ability of governments and others to effectively manage any risks associated with scientific research and its application.

These concerns have led to frequent introspection into the nature of society's relationship with science and technology over the past half-century. They have also prompted the development of a large body of research examining how society understands, relates to, and engages with science, and how science is situated within the broader context of the cultures in which it is embedded. Researchers have investigated how science is taught in classrooms, how individuals engage with and learn about science in informal, non-school settings, how science is communicated to the public, how people seek out information about science and technology, and what the general drivers are of public attitudes and understandings towards science. Governments in many countries have sponsored studies exploring their citizens' perceptions of science and technology to assist policy-makers in understanding these relationships and their implications. However, there has been relatively little systematic study of how Canadians engage with and relate to science, and the extent to which science is recognized and supported as an element of Canadian culture.

1.1 THE CHARGE TO THE PANEL

In 2012 the Canada Science and Technology Museums Corporation, Industry Canada, and Natural Resources Canada asked the Council of Canadian Academies (the Council) to form a panel of experts to investigate and report on the state of Canada's science culture. This request was driven by both the recognition of the role that science culture plays in maintaining Canada's demonstrated strengths in science and technology, and by concerns that Canada potentially lags behind other countries in terms of how deeply science is embedded as an element of Canadian culture. The resulting assessment would explore the state and strength of science culture in Canada relative to that of other countries; clarify the avenues of impact by which science culture affects Canadian society; and analyze the system of organizations, programs, and initiatives involved in supporting Canada's science culture. The full charge is presented in Box 1.1.

Box 1.1
The Charge to the Panel

Main Question:
What is the state of Canada's science culture?

Sub-Questions:

i. What is the state of knowledge regarding the impacts of having a strong science culture?
ii. What are the indicators of a strong science culture? How does Canada compare with other countries against these indicators? What is the relationship between *output* measures and major *outcome* measures?
iii. What factors (e.g., cultural, economic, age, gender) influence interest in science, particularly among youth?
iv. What are the critical components of the informal system that supports science culture (roles of players, activities, tools and programs run by science museums, science centres, academic and not-for-profit organizations and the private sector)? What strengths and weaknesses exist in Canada's system?
v. What are the effective practices that support science culture in Canada and in key competitor countries?

In response to this request, the Council convened a 14-member panel of experts (the Panel) with a diverse range of backgrounds and expertise. The Panel included members with expertise in media and communications, science centres and museums, science policy and governance, the study and measurement of science literacy, public engagement with science, and science education in both formal and informal contexts.

The Panel met with the sponsoring departments early in the assessment process to discuss the scope of the study, resulting in a number of clarifications. First, the study is not intended to serve as an evaluation of federal (or provincial/territorial) policies and programs for supporting science culture in Canada. It is also not meant to evaluate federal support for science in general. The primary focus is a review of the available evidence on the general state of science culture in Canada rather than an evaluation of specific initiatives or programs.

Second, while the charge reflects a focus on informal science learning and engagement (e.g., science media, science centres and museums, youth science programs and camps, science fairs and festivals), science culture is a result of experiences in both formal and informal science education environments. The Panel therefore resolved to consider both types of learning environments, while acknowledging the Sponsor's focus on informal organizations and interventions.

Third, the Panel determined that its study would be guided by a broad understanding of "science." The U.K. Science Council's definition of science as "the pursuit of knowledge and understanding of the natural and social world following a systematic methodology based on evidence" was adopted as a useful model (UK Science Council, 2013). This definition captures the essential characteristics of science while preserving the necessary breadth as to what can be counted among scientific methods and disciplines. In line with this definition, the Panel did not eliminate the social sciences from consideration; however, in recognition of the Sponsor's priorities, the main focus throughout most of the study is the natural sciences, mathematics, engineering, and technology (i.e., STEM fields).

The Panel also recognizes that science is not homogenous. Science is a multifaceted combination of approaches to research and discovery, many of which have their own distinct sub-cultures and norms. There are multiple scientific methods and research practices, and many ways in which these practices affect the societies and cultures surrounding them. Nor does the Panel presuppose that the relationship between science and society is undifferentiated across domains of scientific work. Attitudes towards science may vary depending on the type of science in question and society's relationship with science and technology is not necessarily one-dimensional. The Panel made efforts to differentiate between domains of science where possible; however, in line with past studies, it also relied on methodologies that document public views about science and technology in general.

Fourth and finally, the Panel considered the extent to which the assessment would consider technology as a distinct entity from science. The Panel's charge requests an assessment of Canada's "science" culture rather than its "science and technology" culture. Science and technology are conceptually distinct; however, in the context of an assessment of national science culture, distinguishing between the two is impractical as the public often does not differentiate between them. Technological developments, for example, are often identified in public surveys as the greatest "scientific" achievements (Miller, 1990), while theoretical breakthroughs unaffiliated with specific technological advances are comparatively less well known. Public perceptions about the benefits or risks of scientific research are often influenced by views about specific areas of technological development (e.g., cloning, biotechnology), or by individual experiences with technologies (e.g., computers, smartphones). Technological development also represents a part of Canada's scientific heritage and culture, and Canada's national framework for Kindergarten to Grade 12 science education is a "science and technology" curriculum, rather than a "science" curriculum (CMEC, 1997). As a result, both terms are used in this report. *Science* is used preferentially in most cases; however, *science and technology* is also employed where technology is relevant or where it is merited due to the wording of items included in the surveys under discussion, which often ask respondents questions about science and technology.

1.2 THE PANEL'S APPROACH

The Panel met four times over the course of 12 months to review evidence and deliberate on its charge. Evidence for the study was drawn from three principal lines of research:

- a review of existing literature on science culture in Canada and abroad;
- a new public survey of science culture in Canada commissioned by the Panel; and
- an inventory and analysis of the organizations and programs dedicated to supporting and promoting science culture in Canada.

The Panel's literature review prioritized articles published in peer-reviewed journals, but also included reports and studies from other governments, international organizations, and think-tanks. A formal literature search was undertaken of journal databases such as ScienceDirect, Wiley, Journal Storage, and the Education Resources Information Center, focusing on studies relevant to Canada and using search terms such as *science culture, science literacy, science communication, public understanding of science, public engagement with science, informal* *science education*, etc. Targeted searches were undertaken in academic journals such as *Public Understanding of Science*, *Science Communication*, and *Science and Public Policy*. The result was an initial collection of 2,534 articles, books, and reports, which was subsequently narrowed to 120 studies most directly relevant to the Panel's charge.

The Panel also relied on reviews by other organizations such as the 2009 U.S. National Academies of Science study on informal science education (NRC, 2009) and earlier studies of science culture in Canada, such as a 2002 Quebec study, *La culture scientifique et technique au Québec* (CST, 2002a). In addition, two background papers were commissioned by the Panel: an overview of the history of federal policy support for science culture in Canada, and a review of policy initiatives undertaken by other national governments to support the development of science culture.

The Panel also commissioned a public survey of science culture in Canada. Many countries periodically undertake surveys to assess aspects of science culture such as public science knowledge, attitudes, and engagement (EC-DGR, 2010; NSB, 2012). Faced with a lack of comparable data in Canada, the Panel developed and fielded a new survey of Canadians. After a competitive process, EKOS Research Associates Inc. was selected to administer the survey on behalf of the Council and the Panel. The survey was designed to generate internationally comparable data to assist the Panel in assessing different aspects of science culture in Canada. Conducted in April 2013, it was administered by collecting a combination of landline, mobile phone, and internet responses. A total of 2,004 responses to the survey were received. The full text of the Panel's survey questionnaire is available in Appendix A.

Finally, the Panel reviewed the organizations, programs, and initiatives involved in promoting and supporting science culture in Canada, relying in part on a 2011 inventory of public science communication initiatives in Canada completed by Bernard Schiele, Anik Landry, and Alexandre Schiele for the Korean Foundation for the Advancement of Science and Creativity (Schiele *et al.*, 2011). The Panel contacted various organizations in Canada to request assistance in gathering evidence for the assessment, including science centres and museums, science media professionals, representatives from not-for-profits and youth programs involved in providing science learning opportunities, and individuals working in similar contexts in other countries. In some cases the Panel was able to use information from international organizations, such as the Association of Science-Technology Centers, to situate Canadian institutions relative to their international counterparts (ASTC, 2012). Documentation from these organizations provided additional insights into Canada's science culture support system.

1.3 WHAT IS "SCIENCE CULTURE"?

One of the first challenges faced by the Panel was to define science culture. While often used in Canadian discussions of science and technology policy, the term is rarely defined with precision. It is most frequently used to convey the degree to which society and the public are broadly engaged in, and supportive of, science. For example, at the launch of Canada's National Science and Technology Week in 1990, the then Minister for Science, William Winegard, stated that "a science culture means a society that embraces science, involves itself in the development, application and use of new technologies, and celebrates national achievements [in science] with pride and enthusiasm" (National Science and Technology Week, 1990).

The use of this term in Canada partly reflects Canada's bilingual heritage. In other English-speaking countries, terms such as *science literacy*, *public understanding of science*, *public engagement in science*, and *public communication of science* are more common (Durant, 1993). These terms are not synonymous with each other, or with science culture. However, they are related concepts, representing a range of perspectives that have been applied to the study of how the public relates to, interacts with, and develops views about science and technology. Patterns in the use of these terms in the literature over time also reflect an evolution in the way in which scholars, scientists, and policy-makers discuss science and society issues (Bauer, 2009). In French, the preferred term is generally *la culture scientifique* or *la culture scientifique et technique,* and the use of these terms in Quebec may have contributed to the use of the English *science culture* throughout Canada.

Compared with *science literacy* or *public understanding of science*, science culture is a more expansive concept, encompassing different aspects of the relationship between society and science. For example, Godin and Gingras (2000) define scientific and technological culture as "the expression of *all the modes* [emphasis added] through which individuals and society appropriate science and technology." A 2002 study of Quebec's scientific and technological culture defines it as corresponding to a set of "knowledge and competencies in science and technology that citizens and society acquire and use," and that also reflect "the capacity to take a global view regarding the reality of science and technology, with respect to its methods, impacts, and ultimate effects" (CST, 2002a).[1] Such definitions emphasize that there are both individual and social dimensions to science culture, and that science culture transcends any single mode of engagement with science. Traditional definitions of *science literacy*, in comparison, typically consider only factual knowledge of science, though in some cases they include knowledge of scientific processes, methods, and institutions (see Chapter 4 for additional discussion on defining science literacy).

1 Panel's translation from the original French.

Science culture is also distinct from language used to identify specific types of learning environments. Academic literature on science education often differentiates between science learning in formal educational settings (e.g., schools) and in informal contexts (e.g., science museums and science centres, youth science programs, exposure to science media) (e.g., NRC, 2009). Informal science learning contexts are also sometimes referred to as "free-choice" learning environments because they can be characterized as "free-choice, non-sequential, self-paced, and voluntary" (Falk, 2001). Science culture is sometimes more strongly associated with these informal environments, perhaps because they are designed with a broader cross-section of the population in mind (i.e., the entire public rather than school-age children and youth). However, this association is misleading. Science culture encapsulates many dimensions of the public's relationship with science, and is a product of experiences in formal and informal learning settings, as well as of a multitude of other social touch points with science. It would consequently be a mistake to view science culture as a reflection of only those experiences associated with informal science learning environments.

Finally, the term *science culture* is potentially confusing in so far as it conveys the impression that it is something apart from the rest of culture. Science is an inextricable part of Canadian culture and has played a major role in shaping the development of Canadian history and society.

Ultimately, the Panel adopted a multidimensional understanding of science culture. In its view, a society has a strong science culture when that society embraces discovery and supports the use of scientific knowledge and methodology. Such a culture encourages the education and training of a scientifically skilled workforce and the development of an innovative knowledge-based economy. It also recognizes and reflects the values or norms of science such as universalism, objectivity, skepticism, empiricism, and the recognition that science is a communal enterprise (see Box 1.2 in relation to the values of skepticism and empiricism).[2] Four key dimensions of a national science culture include (i) public *attitudes* towards science and technology, (ii) public science *engagement*, (iii) public science *knowledge*, and (iv) the development of science and technology *skills* in the population.

2 In 1942 the sociologist of science, Robert Merton, identified the four defining norms of science as follows: (i) science aims at *universalism* rather than particularism in the creation of knowledge, (ii) science is a *communal* enterprise where knowledge is accessible to all in principle, (iii) science promotes *disinterested* knowledge, and (iv) science is based on *organized skepticism* and the empirical validation of knowledge (as opposed to arguments from accepted beliefs or authority) (Merton, 1942).

Box 1.2
Nullius in verba

The official motto of the United Kingdom's Royal Society, one of the world's oldest and most influential scientific organizations, is a Latin phrase, *Nullius in verba*. Adapted from Horace's *Epistles*, the phrase roughly translates as "take nobody's word for it." The Royal Society explains the choice as "an expression of the determination of Fellows to withstand the domination of authority and to verify all statements by an appeal to facts determined by experiment" (RS, 2013a). The motto illustrates another important element of science culture. Definitions of science literacy often stress an understanding of scientific methods and institutions along with factual knowledge about science. However, a hallmark of science is the willingness to assertively subject knowledge claims to the test of experimental verification. In the Panel's view, the prevalence of this kind of skepticism and critical attitude towards knowledge claims is also a significant marker of the strength of science culture in any society.

This understanding reflects the breadth of the concept while providing guidance on how the relative strength of a society's science culture can be assessed. As shown in Table 1.1, the Panel focused on the four dimensions as the basis for a methodology to assess the state of Canada's science culture. These dimensions capture key elements of the public's relationship with science and can be empirically analyzed using existing methodologies and studies. While not exhaustive, in the Panel's view these dimensions provide a robust basis for assessing the state of Canada's science culture at the national level.[3]

3 In some studies (Godin & Gingras, 2000; Shukla & Bauer, 2012) "objective" indicators such as research and development expenditures are also used as indicators of science culture. While these types of measures provide complementary insights, they are not included in this assessment because Canadian performance on these measures has been comprehensively reviewed in other reports. For example, see STIC (2011) and CCA (2012b).

Table 1.1

Four Key Dimensions of Science Culture

Attitudes	Engagement
• What are Canadian attitudes towards science and technology? • What are their views about the promise of science or their reservations about science and technology? • To what degree does the Canadian public support public investment in scientific research, or believe in the value of scientific education and careers? • What are Canadian attitudes on specific scientific issues such as biotechnology or climate change?	• How interested are Canadians in scientific issues, ideas, and developments? • How do they seek out information about new developments in science? • How engaged are Canadians in scientific activities or pursuits? • To what degree do they participate in scientifically oriented events or visit or contribute to scientific institutions?
Knowledge	**Skills**
• What is the general level of knowledge about science among Canadians? • How well do Canadians understand core scientific constructs such as what a molecule is or what DNA is? • To what extent do Canadians understand what it means to study something scientifically?	• To what extent are Canadians developing professional science and technology skills? • Are Canadian youth pursuing educational opportunities in the sciences? • To what extent are Canadians seeking out advanced training in the sciences or employed in scientific careers?

This study assesses Canada's science culture along four key dimensions: attitudes, engagement, knowledge, and skills. The questions listed above indicate subjects explored by the Panel in each of these dimensions.

1.4 STRUCTURE OF THE REPORT

The structure of the remainder of this report is as follows:

Chapter 2 provides additional context for the study by situating science culture with respect to global and domestic factors affecting public perceptions, understanding, and engagement with science and technology.

Chapter 3 surveys the state of knowledge on the impacts of a strong science culture, exploring the relevance of different dimensions of science culture to individual decision-making, public policy, the economy, and scientific research.

Chapter 4 reviews survey data and other evidence to assess the four dimensions of science culture identified by the Panel: public attitudes towards science, public engagement in science, public science knowledge, and the level of science and technology skills in the population. Available data are placed in context by examining trends over time and comparisons with other countries.

Chapter 5 documents the nature of Canada's science culture support system, focusing on the organizations, initiatives, and programs that provide opportunities for informal science learning and engagement in Canada. It also identifies the functional roles that different types of organizations play in supporting the development of science culture.

Chapter 6 reviews evidence on effective practices for developing a strong science culture, focusing on five main themes: supporting lifelong science learning, making science inclusive, adapting to new technologies, enhancing science communication and engagement, and providing national or regional leadership.

Chapter 7 summarizes the Panel's key findings, and offers some final reflections on the state of Canada's science culture and avenues for future study.

2

The Global and Canadian Science Culture Context

- The Global Context
- The Canadian Context
- Chapter Summary

2 The Global and Canadian Science Culture Context

Key Findings

- Science culture in Canada is evolving in a dynamic social and technological environment, and is influenced by both global and domestic drivers.
- Politically divisive issues such as climate change, genetically modified foods, nuclear power, and the use of embryonic stem cells in medical research have a global impact on science culture. Events abroad can also affect public perceptions of science and technology, as can representations of science and scientists in popular culture.
- New technological developments are transforming many aspects of interaction and communication, creating new types of opportunities for public engagement with science in the process, while challenging the viability of traditional models of science instruction and outreach.
- Domestically, Canada's science culture reflects the country's social, cultural, linguistic, political, and geographic environment. Canada's multicultural heritage, geography, demographic composition, structure of government, and pattern of historical development all influence how Canadians perceive and engage with science, and how science is situated within Canadian culture.

The 20th century witnessed an unprecedented expansion in science and technology. The invention of electric power, antibiotics, nuclear weapons, automobiles, airplanes, radio, television, transistors, computers, vaccines, and the mapping of the human genome all demonstrated the rapid pace of scientific and technological advances, at the same time transforming many aspects of daily life for citizens of modern, industrialized societies. These scientific and technical breakthroughs influenced public perception and attitudes towards science and technology, and underscored the potential of science to improve human well-being, while also potentially leading to disruptive and sometimes frightening impacts on individual and social life.

At the beginning of the 21st century, the scope and depth of our understanding of life continue to rapidly evolve. Advances in biological science over the past 20–30 years already rival those in the physical sciences in past years. Globally, civilization remains in the early stages of an information technology revolution that, in all probability, will continue to transform how societies manage and relate to information of all types.

As a result of these trends, Canada's science culture, along with those of other countries, is evolving in a complicated and dynamic landscape. New technologies, scientific discoveries and inventions, geopolitical events, and social and cultural trends all can potentially shape how Canadians perceive and engage with science in the future. At the same time, not all drivers influencing the evolution of science culture in Canada are global. Canadian science culture also reflects social and cultural influences unique to the Canadian population and environment.

This chapter situates the Panel's assessment of science culture in Canada by briefly surveying the overall global and Canadian context within which that culture is developing. In doing so, it highlights both global drivers related to science and technology and some of the specific characteristics of the Canadian social and cultural environment that have affected the development of Canada's science culture over time.

2.1 THE GLOBAL CONTEXT

Science and technology are global phenomena, and many aspects of scientific research transcend national borders. Canada's science culture is consequently evolving in parallel with those of other industrialized countries, often responding to similar social influences and scientific and technological developments. Global drivers influencing how individuals perceive and relate to science, both in Canada and in other countries, include science and technology policy issues with international dimensions, the development of new technologies and new platforms for public science outreach and engagement, representations of science and scientists in popular culture, and a growing interest in the relationship between science and other forms of cultural and artistic expression.

2.1.1 Global Science and Technology Issues and Events

Public discussions about the role of science in society are now dominated by a number of critical issues. Debates about nuclear power, climate change, biotechnology, nanotechnology, and stem cells are common across many countries and have been frequently the source of both national and international studies. For example, concern about anthropogenic global warming has generated a significant amount of research on public perception and attitudes related to science and technology. Over 170 studies relating to climate change were published in the journal *Public Understanding of Science* between 1992 and 2013. Debates about the environmental and human health risks associated with genetically modified foods are also widespread and divisive, though more so in Europe than in the United States (Gaskell *et al.*, 1999). Other issues that have attracted extensive media coverage and attention include embryonic stem cells; nuclear power and waste; and public health threats such as spongiform encephalopathy (BSE, or "mad cow" disease), global flu pandemics, the safety of nanomaterials, etc. The global reach of many of these issues requires international policy responses involving coordination and alignment of many governments. Both government actions and media coverage of these issues can have an impact on public perception of science and technology on an international scale.

Specific events abroad can also have a major impact on science culture around the world. The crisis at the Fukushima nuclear plant in Japan in 2011, for example, caused widespread concern over nuclear safety across many countries and significantly affected public perception of the safety of these technologies (Kim *et al.*, 2013). In Canada this event precipitated a review of all major nuclear facilities and the development of a four-year action plan to strengthen the safety of the nuclear industry (Canadian Nuclear Association, 2012; Canadian Nuclear Safety Commission, 2012). Similarly, although the severe acute respiratory syndrome (SARS) outbreak of 2002–2003 initially occurred in southern China, it led to 438 probable and suspected cases and 44 deaths in Canada. This prompted significant public apprehension about the ability of Canada's health care system to cope with such a threat, and resulted in several new public health approaches and the establishment of institutions including the Public Health Agency of Canada (PHAC, 2003).

2.1.2 The Development of New Technologies

Canada's science culture is also affected by global trends relating to the development and adoption of new technologies. New developments in biotechnology in past decades fuelled considerable reflection on the moral, ethical, and social implications of these technologies, and continue to generate public concern and debate. Currently, however, some of the most transformative changes affecting public science outreach and education are being driven by developments in information and communication technologies. New computing and communication technologies are having an impact on many elements of individual and social life, including the basic ways in which people communicate, work, and learn.

One such impact concerns how the public can participate in and contribute to scientific work. Canadian physicist Michael Nielsen argues that new possibilities for large-scale scientific collaboration resulting from web-based platforms can potentially transform the practice of science due to changes in how scientists collaborate, and to the development of online platforms for engaging the public in scientific research (Nielsen, 2012). "Citizen science" initiatives allow the public to contribute to many kinds of scientific activity, often through collaborative, web-based platforms (see Box 2.1).

Box 2.1
Citizen Science

Citizen science refers to activities in which general citizens or non-professional scientists engage in scientific research, often in research-related tasks such as observation, data collection, and analysis (Yang *et al.*, 2012). Rick Bonney, the originator of the term, notes that the public can participate in these projects either as contributors, collaborators, or co-creators (Bonney *et al.*, 2009a). Well-known examples of citizen science initiatives include Galaxy Zoo, polymath, eBird, Earthwatch Institute, Evolution MegaLab (Silvertown, 2009; Rotman *et al.*, 2012), and Citizen Science Central (Wiggins & Crowston, 2012). Canadian examples include IceWatch Canada (Hartwell & Shafer, 2011), WormWatch (Karrow & Fazio, 2010), Ontario Forest Bird Monitoring Program (Schalk *et al.*, 2002), and Snowtweets (Bordogna *et al.*, 2014). The concept of citizen science draws on the tradition of volunteer participation in scientific endeavours (Rotman *et al.*, 2012), though in this manifestation technology has extended the possibility of participation to nearly anyone with access to the internet (Silvertown, 2009; Stodden, 2010; Fausto *et al.*, 2012).

Due to the number of ways it allows for individual participation, citizen science has successfully engaged individuals and supported research in a number of fields including biology (Sullivan *et al.*, 2009), environmental studies (Kim *et al.*, 2011), chemistry, astronomy (Raddick *et al.*, 2009), and math (Cranshaw & Kittur, 2011). These initiatives also allow the public to participate in scientific work in various ways. For example, citizens can evaluate scientific arguments, actively collect or analyze scientific data, and work towards scientific goals by monitoring activities (Clark & Illman, 2001). In theory, anyone with internet access can "reproduce results, tweak them, rerun scripts, modify algorithms, try the algorithm on new data, and potentially contribute new scientific discoveries" (Stodden, 2010). The completion of tasks by non-scientists and experts has the potential to create connections between scientists and the public, and lead to increased scientific understanding, participation, and engagement (Raddick *et al.*, 2009).

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> One example of a citizen science project that has attracted widespread attention is Galaxy Zoo. An online platform for classifying galaxy types, this initiative has engaged hundreds of thousands of volunteers, and led to the discovery and publication of a number of novel and significant findings by individuals without training in astronomy (Raddick *et al.*, 2009). These include the discovery of a new type of galaxy (green pea galaxies) (Cardamone *et al.*, 2009), and a novel astronomical object by Dutch schoolteacher Hanny van Arkel (now referred to as Hanny's Voorwerp or Hanny's object) (Lintott *et al.*, 2009). In total, Galaxy Zoo has led to the classification of more than 900,000 galaxies (Lintott *et al.*, 2009), and 25 scientific publications, which would not have been possible without the combination of web-based platforms for collaboration and large-scale public participation.

New technologies are also transforming the ways in which people learn in nearly all educational settings. With potential applications including the use of interactive whiteboards, one-to-one tablet computers, learning-oriented video and computer games, internet-facilitated lessons or interaction, massive open online courses (MOOCs), and new forms of media and communication, these technologies are dramatically changing learning and educational experiences. Luckin *et al.*, (2012) describe how such technologies contribute to a variety of different modes of learning such as facilitating interaction with experts, facilitating collaborative learning, providing opportunities for learning through "making" and "practice," and providing individualized tools for assessment and feedback. These influences are also being felt in informal science environments, as digital technologies are increasingly used to support and enhance science learning in traditional designed settings (e.g., exhibits at science centres and museums), and to create novel, stand-alone avenues for science learning and engagement (NRC, 2009).

Some of these same technologies, however, are also challenging traditional models of operation for organizations such as science media, science centres, and museums. Miller (2010b) argues that the internet era has prompted a generalized shift in learning strategies. A "warehouse" model of learning is being gradually replaced by a "just-in-time" vision of information acquisition, with individuals increasingly seeking out scientific information in response to specific needs (e.g., a medical diagnosis or a new technology in the workplace). This shift threatens the viability of traditional models of both formal and informal science education, and suggests that in the future "museums and similar informal learning institutions will need to be less dependent on their physical setting and more focused on learning as the end product." In a similar vein, Bradburne (1998) likens the traditional model of the science centre to a "dinosaur," doomed to extinction by the factors of "ecology and economy," and suggests that an entirely new type of institution of informal science learning needs to be developed that will be better adapted to the era of digital media and the internet.

Science media professionals and journalists are also adapting to a new era of media and communication. Traditional print journalism is playing an increasingly minor role and there is a growing reliance on new forms of online communication such as blogging and social media (Bivens, 2008). Survey data from the United States have found that the internet is now the most common source for news about specific science and technology issues for Americans (NSB, 2012). These changes are occurring worldwide, affecting both Canadian science culture supporters and their counterparts across the globe. Such changes also have implications for how individuals relate to the information they receive, requiring them to develop new strategies to assess and validate the accuracy of publicly available information on the internet.

2.1.3 The Influence of Popular Culture

Popular culture is another factor influencing the formation of science culture that can have impacts that transcend national boundaries. Representations of science and scientists in popular culture can influence science culture in several ways.

First, popular culture can influence attitudes towards science and technology and perceptions of scientists and their role in society. The foundation of science is the acquisition of knowledge. Ungar (2000) argues that in some segments of society, attaining highly specialized knowledge is viewed as elitist. As such, it is sometimes popular to denigrate intellectualism in favour of a more egalitarian and conversational ethos, which may devalue the contributions of scientists. In a review of U.S. children's educational science programs, Long and Steinke (1996) report that images of science have emphasized characteristics such as truth, fun, accessibility, and ubiquity. Scientists were portrayed through several stereotypes in these shows, ranging from being omniscient and elite to eccentric and antisocial. The impact of popular culture on science culture may also lead to asymmetrical imagery of men and women working in science, which potentially causes women to be misrepresented. Chimba and Kitzinger (2010) note that this asymmetry has led to a scarcity of women scientists in the media and to an expectation that women participate in certain capacities, such as science communicators. In addition, media profiles may focus on women's appearance rather than their intellect.

Second, popular culture can influence how scientific information is communicated to the public. In the explanation of unfamiliar and complex terms, the use of metaphors and clichés extracted from popular culture is playing a critical role. More than just a technique, metaphors are strategically used to explain scientific concepts through imagery and analogy (Edmond & Mercer, 1999). In addition, the interest and drive to popularize science have given rise to new concepts such as "pop science," which combines public education and popular culture. Some of the common buzzwords associated with this new concept are "edutainment" and "sciencetainment" (Kaeser, 2013).

Third, popular culture can influence the level of engagement and public interest in scientific ideas, issues, and development. In the late 1980s pop icons such as Madonna and the Grateful Dead drew attention to the destruction of the Amazon rainforest, thereby contributing to a surge in environmental discourse on global forest issues (Palmer, 1993). Conversely, the popular perception of segments of society may call into question public understanding of and trust in scientific evidence. For instance, in the presence of frequent attacks on the science of climate change, the public may be challenged in distinguishing the anti-scientific arguments of deniers from the concerns of skeptics who respect the scientific process and findings but nevertheless question interpretations of the existing evidence. This could potentially undermine proper scientific debate by confusing the boundaries between anti-scientific and scientific arguments (Kemp *et al.*, 2010).

Finally, images of science in popular media have also influenced interest in developing science and technology skills in some cases. For instance, fields such as forensics science have received significant media attention with the popularity of forensics crime television shows such as *CSI*, *Cold Case*, *NCIS*, and *Bones* (Ley *et al.*, 2012). Concurrently, educators have observed a rapid growth both in the number of forensics courses being offered and the number of students enrolled in them (Hooper, 2005; Samarji, 2012). Similarly, medical professionals have suggested that the popularity of shows such as "ER" has increased the interest of medical students in emergency medicine training. In the United Kingdom, popular television programs such as *The Big Bang Theory* are being cited as contributing to the increased interest in physics among A-levels and university students (Townsend, 2011).

2.1.4 Science, Design, and the Arts

Another widespread trend affecting science culture is an apparent surge of interest in the intersection between science and other forms of cultural expression. While difficult to document conclusively, there appears to be a broadly growing interest in the intersection of science and the arts in many countries, which manifests in a number of ways. One of these is the growing popularity of new venues for science outreach that incorporate aspects of design or the arts. Organizations such as TED (Technology, Entertainment, and Design; see Figure 2.1) or science magazines such as *Seed* cover science and technology issues while also including content relating to forms of design and artistic expression. Science festivals now provide opportunities to celebrate the relationship between science and the arts, often incorporating elements of music, dance, and design into their programming (Nolin *et al.*, 2006). In addition, art is being used as a means to explore some of the environmental, political, and social dimensions of major scientific issues. As one example, in October 2013 the Royal Ontario Museum in Toronto hosted the *Carbon 14: Climate Is Culture* exhibit, a collaborative art exhibit featuring projects by 12 artists whose work explores aspects of climate change such as "a changing Arctic, the health of oceans, biodiversity and extinction, sustainability and new, clean technologies; and central questions of politics, economics, and ethics" (Cape Farewell, n.d.). An interest in the relationship between science and the arts is also manifested in the "STEM to STEAM" movement, which focuses on enhancing science and mathematics education by incorporating elements from the arts and artistic instruction (Piro, 2010).

Courtesy of James Duncan Davidson

Figure 2.1

Presenter at a TED Conference

TED talks, in part, exemplify the growing popularity of venues exploring relationships between science and other forms of artistic or cultural expression such as design and entertainment.

2.2 THE CANADIAN CONTEXT

The drivers noted in the preceding sections are global in nature, affecting science cultures in all countries to varying degrees, Canada included. However, while broadly influenced by these global trends, Canadian science culture is also a function of unique domestic, social, political, and geographic characteristics. This section highlights some of these characteristics and their ongoing role in the development of Canada's science culture.

2.2.1 Canada's Linguistic and Cultural Traditions

One of the defining characteristics of science culture in Canada is the country's multicultural heritage. Canada's diverse linguistic and cultural traditions have played a significant role in the development of this culture in several ways, most obviously through the development of separate Anglophone and Francophone traditions of public science outreach and engagement.

As the only Canadian province with a predominantly French-speaking population, Quebec has its own organizations dedicated to the promotion of science in the public (e.g., Association francophone pour le savoir); its own set of French-language science media organizations and programs (e.g., Agence Science-Presse, "Découverte," "Le Code Chastenay"); French-language science museums and centres (e.g., Centre des sciences de Montréal); science festivals (e.g., Festival Eurêka!); and many other organizations and programs involved in supporting science culture and communication for the Francophone population. The formal science education and training system also differs in Quebec, given the role of institutions such as the collèges d'enseignement général et professionnel (CEGEP). The historical development of science culture in Quebec is also distinct from that of Anglophone Canada, more firmly rooted in French and European discourses about science, culture, and cultural policies (Chartrand *et al.*, 1987; Schiele *et al.*, 1994). As a result of these differences, past inquiries into science culture in Canada have often treated Quebec as separate from the rest of Canada, and the Quebec government has sponsored its own investigations into science culture in the province (e.g., CST, 2002a).

Canada's Aboriginal cultures also play a role in defining the science culture landscape in Canada, both through their own knowledge traditions and their impacts on science education and outreach. Aboriginal knowledge has also been incorporated into some provincial science curricula, and some science textbooks now teach students about both scientific and Aboriginal knowledge systems, as a result of the collaboration between ministries of education, Aboriginal Elders, and one Canadian publisher (Aikenhead & Elliott, 2010). Aboriginal knowledge and traditions have also had impacts on scientific research in Canada, with biologists, ecologists, climatologists, and geologists incorporating Aboriginal knowledge in their research in a number of ways (see Box 2.2). Scientists have turned to "traditional ecological knowledge" (McGregor, 2000; Snively & Corsiglia, 2001) and "traditional ecological knowledge and wisdom" (Turner *et al.*, 2000) to support scientific research and the development of resource management strategies.

Box 2.2
Aboriginal Contributions to Scientific Research in Canada

Aboriginal communities, traditions, and knowledge have now been incorporated into scientific research in Canada, particularly in the areas of ecological conservation and ecosystem management (Turner *et al.*, 2000). The Inuvialuit of Sachs Harbour, Banks Island (Northwest Territories) have, for example, aided scientists in observing changes in northern environments including changes in biodiversity, landscape, and weather patterns. The Hunters and Trappers Committee of Sachs Harbour along with the International Institute for Sustainable Development partnered with specialists from five organizations to develop an innovative process to document and communicate local observations on climate change. This partnership resulted in the publication of seven scientific journal articles that record and share the Inuvialuit knowledge of Arctic climate change and the adaptation strategies currently underway in local communities (Ashford & Castleden, 2001).

Aboriginal knowledge and management systems have also offered insights into biodiversity conservation and resource management in Canada. For instance, the Inuvialuit have partnered with scientific researchers to examine how changes in environmental stressors can affect Arctic char growth, a subsistence resource for the Inuvialuit. The combination of community-based monitoring, ecological knowledge, and local Indigenous knowledge has resulted in a more comprehensive understanding of the impacts of climate change on local fish habitats (Knopp *et al.*, 2012). Aboriginal knowledge has also contributed to the building of cooperatives for the collection and commercialization of non-timber forest products in northwestern Ontario based on scientific research and the knowledge of the Pikangikum (Anishinaabe) First Nations (Davidson-Hunt *et al.*, 2013). Traditional ecological knowledge of the Cree First Nations has been useful in understanding the cumulative effects of resource development in the Lesser Slave Lake region of Alberta (Parlee *et al.*, 2012).

2.2.2 Geography

Certain features of Canadian geography are also relevant to Canada's science culture. With the second largest landmass of any country, Canada has a low population density at approximately 3.5 people per square kilometre (km^2). For comparison, population density is nine times greater in the United States (31 people/km^2), 31 times greater in France (109 people/km^2), and 70 times greater in the United Kingdom (246 people/km^2) (Statistics Canada, 2007). As a result, Canadian cities and communities are often separated by large distances, which may limit access to science culture resources and contribute to the regionalization of different patterns in science engagement and outreach. In addition, Canadians living in remote communities have limited access to cultural resources such as science museums and centres, which may be present in larger urban areas.

Canada's status as an Arctic nation also has a bearing on science and science culture. Canada's large and ecologically diverse Arctic landscape spans a substantial part of the circumpolar Arctic, and comprises almost 40% of the country's landmass (Statistics Canada, 2009). This has influenced the development of Canadian culture more broadly, and also created opportunities in the advancement of Arctic science. Canada's northern inhabitants, the majority of whom are Indigenous peoples, represent a source of knowledge that contributes to scientific research in the North (CCA, 2008). These characteristics have contributed to the exploration of many scientific questions including those related to environmental science, resource development, and the health and well-being of northern populations. Canada also has the longest coastline of any country, and these extensive coastlines and marine areas give rise to unique research opportunities in ocean science (CCA, 2013a).

Finally, despite Canada's vast size, approximately two-thirds of Canadians live in a long strip of the country less than 100 km from the U.S. border (Statistics Canada, 2007). In addition to this physical proximity, Canadians have frequent access to U.S. media sources, and rely on these sources for new information about developments in science and technology. Einsiedel *et al.*, (1994) note:

> It is difficult to talk about this country's media in isolation from US media because of the reception of American programming via cable and satellite. American books and magazines are also ubiquitous products in [Canadian] media outlets. In essence, the average Canadian is exposed to a cornucopia of science information from a very diverse range of sources, many of which are American.

Access to U.S. and other international science media programming through the internet has made isolating the role and importance of Canadian-based science programming even more challenging in recent years. The internet is also potentially reducing the impact of geographical distance and could allow Canadian informal science institutions to reach previously underserved Canadians, such as those living in rural or remote communities.

2.2.3 Demographic Trends

The demographic composition of the Canadian population and shifts in that composition over time also stand to influence elements of Canada's science culture. Canada's comparatively high rate of immigration is continuing to transform the makeup of Canadian society and communities, potentially altering the ways in which those communities engage in, and relate to, science. According to data from Statistics Canada's 2011 National Household Survey, foreign-born individuals represent roughly one-fifth (20.6%) of the Canadian population, with over one million foreign-born people arriving in Canada between 2006 and 2011 (Statistics Canada, 2013b). Perhaps more importantly, more than one-half (50.9%) of all individuals in Canada with STEM degrees are immigrants (Statistics Canada, 2013c). The Canadian population and scientific community consequently reflect not only the influences of educational experience garnered in other countries, but also a diversity of cultural values, attitudes, and preconceptions about science and technology.

Like most developed countries, Canada's population is also aging. In 2011 the median age in Canada was 39.9 years, up from 26.2 years in 1971 (Statistics Canada, n.d.). This ongoing demographic transition will have an impact on science culture in Canada in years to come. An aging population will be increasingly interested in health and medical issues. The ability to make use of this kind of information will depend in large part on the combination of access to the internet, skill in navigating it, and a conceptual toolbox that includes an understanding of genes, probability, and related constructs (Miller, 2010b).

Canada's Aboriginal population is another segment of the population that is growing. Aboriginal people, who account for 4.3% of Canada's population, grew at a rate of 20.1% between 2006 and 2011, compared with 5.2% for the non-Aboriginal population (Statistics Canada, 2014a). As the composition of Canadian communities continues to change over time, organizations involved in public science engagement and outreach will need to continue to reassess their programming to ensure it remains responsive to the needs and interests of the surrounding populations.

2.2.4 Government Structure

Federal, provincial, and municipal governments all play a role in promoting science culture and public understanding of science in Canada, both through funding for cultural institutions such as science centres and museums, and through other dedicated programs or policies relating to science outreach or engagement. Formal science education falls under provincial jurisdiction. Provincial governments are therefore responsible for administering their respective primary, secondary, and post-secondary systems, as well as for developing their own science curricula. The federal government provides support for the education system through various mechanisms such as the Canada Social Transfer (a block transfer in support of post-secondary education, among other things); the national research councils (Natural Sciences and Engineering Research Council of Canada, NSERC; Social Sciences and Humanities Research Council, SSHRC; and Canadian Institutes of Health Research, CIHR); the Canada Foundation for Innovation; and many other organizations and programs. Chapter 5 of this report discusses the role that federal and provincial governments play in supporting the development of science culture in Canada in more detail, highlighting relevant programs and activities.

2.2.5 The Evolution of Support for Science Culture in Canada

Canada's science culture has developed in response to many specific events, organizations, and milestones over the course of Canada's history. A full account of this history is beyond the scope of this assessment. However, Box 2.3 provides selected examples of events that characterize the development of organized support for science culture in Canada, beginning with the formation of the Royal Society of Canada in 1882.[4]

Institutional support for science culture in Canada has evolved through stages of increasing government involvement, roughly in parallel with growing recognition of the role that science and technology play in contributing to economic and industrial development, and the potential risks associated with a lack of public awareness or engagement in science (Einsiedel *et al.*, 1994; Schiele *et al.*, 1994). Paquette (2011) describes five general periods in the evolution of science culture support in Canada, with notable turning points including the creation of the Massey–Lévesque Commission in the early 1950s, which explored Canadian cultural identity and sovereignty, and called for the creation of a national science and technology museum; Canada's centennial in 1967, after which there was rapid growth in the development of new science centres and museum initiatives; and creation of the federal Science Culture Canada program at Industry Canada in 1987.

4 Note that the purpose of this box is illustrative rather than exhaustive. It is impossible to include all relevant events, initiatives, and organizations that have had an impact on science culture in Canada. The selection presented here is intended to suggest the range of these milestones, and to help paint a general picture of the overall historical progression.

Though related to formal rather than informal science education, other important milestones include the publication of the Science Council of Canada's *Science for Every Student* report (SCC, 1984), which then contributed to the development by the Council of Ministers of Education, Canada of national guidelines for the science curriculum: *Common Framework of Science Learning Outcomes K to 12* (CMEC, 1997).

Box 2.3
Selected Milestones in the Development of Canada's Science Culture

- 1882 – Royal Society of Canada is established.
- 1916 – National Research Council is established.
- 1923 – Association canadienne-française pour l'avancement des sciences (ACFAS) is established.
- 1930 – *Canadian Geographic* is first published by the Royal Canadian Geographical Society.
- 1951 – Massey–Lévesque Commission calls for the creation of a national science and technology museum.
- 1959 – Canada sees its first science fairs in Winnipeg, Edmonton, Hamilton, Toronto, Montréal, and Vancouver; volunteer coordination eventually grows into Youth Science Canada.
- 1960 – CBC's *Nature of Things* debuts on television; Fernand Séguin hosts "Aux frontières de la science."
- 1962 – ACFAS creates *Le Jeune scientifique*, which becomes *Québec Science* in 1970.
- 1966 – Science Council of Canada is created to advise Parliament on science and technology issues.
- 1967 – Canada Museum of Science and Technology is created.
- 1969 – Ontario Science Centre opens its doors (the Exploratorium in San Francisco opens the same year).
- 1971 – Canadian Science Writers' Association is formed.
- 1975 – Symons Royal Commission on Canadian Studies speaks to how understanding the role of science in society is important to understanding Canadian culture and identity.
- 1975 – *Quirks and Quarks* debuts on CBC Radio.
- 1976 – *OWL* children's magazine begins publication.
- 1977 – Association des communicateurs scientifiques du Québec is established.
- 1978 – L'Agence Science-Presse is created.
- 1981 – Association des communicateurs scientifiques creates the Fernand-Séguin scholarship to identify promising young science journalists.
- 1982 – *Les Débrouillards* is launched in Quebec.

continued on next page

- 1984 – Science Council of Canada releases comprehensive report on formal science education in Canada.
- 1984 – Marc Garneau becomes the first Canadian to fly on a NASA mission to space.
- 1987 – National science and technology strategy (InnovAction) is released, which includes the objective of "ensuring that science and technology become an integral part of [Canadian] culture."
- 1988 – Science Culture Canada launched.
- 1990 – National Science and Technology Week launched.
- 1992 – Roberta Bondar becomes Canada's first female astronaut in space aboard NASA's Space Shuttle Discovery.
- 1994 – "When Science Becomes Culture" conference is held in Montréal, the first international Public Communication of Science and Technology conference to be held in the Americas.
- 1995 – "Daily Planet" airs on Discovery Channel Canada, originally launched as @discovery.ca.
- 1996 – NSERC's Chairs for Women in Science and Engineering Program is launched with the goal of increasing participation of women in science and engineering.
- 1997 – Council of Ministers of Education, Canada publishes the *Common Framework of Science Learning Outcomes K to 12*.
- 1999 – Perimeter Institute for Theoretical Physics is founded in Waterloo with the mandate to share the wonder and excitement of science across Canada.
- 2000 – Montréal Science Centre is established (originally known as iSci Centre).
- 2002 – New federal innovation strategy is put in place, with the goal of making Canada one of the top three countries in math, science, and reading achievement.
- 2002 – *La culture scientifique et technique au Québec* is published by the Quebec Conseil de la science et de la technologie.
- 2005 – Laurentian University and Science North create a joint graduate program in Science Communication.
- 2007 – Current federal science and technology strategy is announced, with goals of "fostering a culture that values and rewards ingenuity and entrepreneurship" and "getting Canadians excited about science."
- 2008 – Science Rendezvous festival begins in the Greater Toronto Area; by 2013 festivities are held in 23 Canadian cities.
- 2010 – Mount Saint Vincent University launches the first undergraduate degree in Science Communication; the Science Media Centre of Canada officially opens.
- 2013 – Canadian astronaut Chris Hadfield uses social media such as Twitter and YouTube to document life on board the International Space Station.
- 2014 – TED (Technology, Entertainment, Design) talks relocate from Long Beach, CA to the Vancouver Convention Centre.

2.3 CHAPTER SUMMARY

Canada's science culture is developing in a dynamic social, scientific, and technological environment, and reflects the influences of both global and domestic drivers. Globally, the development of new technologies is rapidly changing how people communicate, work, and learn, in the process often redefining the public's relationship with science and technology in significant ways. These developments are also causing science learning providers across all contexts to re-examine traditional modes of instruction and operation. At the same time, public debates about politically divisive issues such as climate change, genetically modified foods, nuclear power, embryonic stems cells, and biotechnology and nanotechnology receive widespread media attention. These issues often transcend national borders and influence perceptions about science and technology both in Canada and abroad. Other factors, such as the representations of science in popular culture and an increasing interest in the intersection between science and art, are also influencing the ways in which scientists engage, communicate, and interact with the public. In the future, Canada's science culture may increasingly reflect the influence of forces originating outside of Canada's borders.

Canada's science culture also continues to be a function of the country's unique social, political, and geographic environment. Canada's multicultural heritage has led to separate Anglophone and Francophone traditions in science outreach and education, and Indigenous cultures have also contributed to scientific research and shaped Canada's national science culture. Demographic trends such as immigration, an aging population, and the rapidly growing Aboriginal population are gradually changing the composition of many Canadian communities, and potentially affecting how these communities engage in and relate to science. Canada's geographic area, including its vast Arctic landmass, contributes to regional patterns of variation in science culture, and its proximity to the United States has facilitated easy access to non-Canadian science media programming and content. Finally, science culture in any country reflects the historical contingencies associated with the development of its institutional and social supporters. Canada's science culture is no exception, having been influenced by key developments and milestones over the course of the country's history, and exhibiting a pattern of progressively increasing institutional support in conjunction with growing government recognition of the importance of science and technology in promoting industrial and economic development.

3

The Impacts of a Strong Science Culture

- Impacts on Individuals
- Impacts on Public Policy and Democratic Engagement
- Impacts on the Economy
- Impacts on Scientific Research
- Chapter Summary

3 The Impacts of a Strong Science Culture

Key Findings

- Definitively establishing relationships between dimensions of science culture and higher-order impacts on society, such as economic outcomes or democratic participation, is methodologically challenging, and the empirical evidence is often limited.
- Available evidence suggests that while a strong science culture can contribute or even be a prerequisite to a range of personal or social benefits, it is not always in itself sufficient to ensure the realization of those benefits.
- Increasing knowledge and understanding of science can benefit individual decision-making and well-being, but the extent of any benefit will vary depending on the type of science knowledge in question. Cultural values and common cognitive biases and frames can also influence decision-making processes.
- Increasing public knowledge of science can also support informed democratic engagement with science and technology issues. However, any impacts on actual policy outcomes will vary depending on the opportunities for public engagement and the institutional mechanisms for incorporating science into policy-making.
- A strong science culture can reasonably be expected to bolster an economy's capacity for innovation through the supply of science and technology skills. However, the relationships between the supply of these skills and economic outcomes are complex.
- Increasing public engagement in science can benefit scientific research, through greater participation in and support of research efforts such as clinical trials or provision of medical samples.

A large proportion of science instructors and science education researchers have confidence in the intrinsic value of science education regardless of whether or not students continue with scientific careers (Feinstein, 2011). Similarly, many take it for granted that higher levels of public understanding, appreciation, and engagement in science are valuable objectives, deserving of public support. However, it is worth considering the extent to which the higher-order impacts of science culture on society have been clearly established with empirical evidence.

Wooden (2006) points out that an understanding of how the public interacts with science and forms opinions is needed before addressing the question of what needs to be done to ensure that sound science informs public policy that serves society's needs and interests. It is also essential to recognize that the scientific community functions within, and not apart, from society, and society is composed of individuals who filter new information through their pre-existing beliefs, ideas, and value systems. In practice, science cannot be separated from society and, to some extent, public opinion because research must be accountable to concerns related to social values and ethics (Wooden, 2006).

With this in mind, many reports and studies have commented on the rationale for supporting public understanding of science and engagement with science (RS & Bodmer, 1985; AAAS, 1989; CST, 2002b; Siune *et al.*, 2009). Examples of benefits cited range from helping individuals make more informed personal choices to improved public health outcomes and increased economic competitiveness and prosperity. Although far-reaching at times, most of these claims are intuitively plausible. Because science and technology are thoroughly integrated into many aspects of modern life, strengthening a society's science culture can reasonably be expected to increase its capacity to harness these forces to advance a wide range of personal and social goals.

However, the evidence available to support such claims is often limited. The Panel found little definitive empirical evidence of causal relationships between the dimensions of science culture and higher-level social objectives like stronger economic performance or more effective public policies. As is the case with much social science research, isolating the impacts of a single variable on complex social phenomena is methodologically challenging, and few studies have attempted to establish such relationships in any detail. As noted in 1985 by the Bodmer report (a still-influential report on public understanding of science in the United Kingdom), although there is good reason *prima facie* to believe that improving public understanding of science has national economic benefits, empirical proof for such a link is often elusive (RS & Bodmer, 1985). This remains the case today. Nevertheless, many pieces of evidence suggest why a modern, industrialized society should cultivate a strong science culture. Literature from the domains of cognitive science, sociology, cultural studies, economics, innovation, political science, and public policy provides relevant insights.

This chapter surveys some of this evidence and the standard arguments advanced in relation to the value of supporting science culture, and comments on the overall state of knowledge on the impacts of science culture. Specifically, the Panel explores four main domains that feature commonly in discussions of the value of science culture and public understanding of science: (i) impacts on individuals, (ii) impacts on democracy and public policy, (iii) impacts on the economy, and (iv) impacts on scientific research. Much of the discussion focuses on claims made about public knowledge (or understanding) of science because it is the subject of most of the pertinent research and commentary. However, when relevant, the Panel identifies where other dimensions of science culture (i.e., attitudes, engagement, skills; see Section 1.3) are implicated in these impacts.

3.1 IMPACTS ON INDIVIDUALS

In a modern, technologically advanced society, individuals make choices involving science and technology in many domains. As consumers, they make choices about the food they buy based, in part, on their understanding of the nutritional implications of the products under consideration. As patients, they make choices about their health care and that of their families based on their understanding of the relevant medical facts. As parents, they evaluate potential threats to their children in their environment. As readers of newspapers and viewers of television, they continually interpret the relevance of stories covered in the news to their own lives, in the process often evaluating probabilities and risks associated with potential threats to their health and safety. And, as employees, they may need to adapt to the presence of new technologies in their workplaces. In all these cases, the choices individuals make, and the outcomes of those choices, partially depend on their understanding of the relevant science.

As a result, one of the most common claims advanced in the literature on public understanding of science is that increasing public knowledge of science can lead to more informed personal decisions across many contexts (RS & Bodmer, 1985; CST, 2002b; Siune *et al.*, 2009). However, there are several forms of this claim and the evidence supporting them is variable, often pointing to significant complexity in how individuals incorporate and use science knowledge in their daily lives.

Many discussions of this kind of impact focus on the value of science knowledge in inculcating generalizable critical thinking skills. Although the development of individuals' language, logic, and learning skills is influenced by a number of factors, such as socio-economic status, cultural context, and health status, the U.S. National Research Council (NRC) points out that science also plays a key role in this regard (NRC, 2009). Siune *et al.* (2009) extend this role to encompass the entire intellectual dimension and the ability to think about a "good society," the future of human nature, and sustainable development, which ultimately contribute to quality of life. The Quebec Conseil de la science et de la technologie (CST)[5] links a strong science culture to individuals' abilities to

5 The CST's mandate was to advise Quebec's Minister of Economic Development, Innovation, and Trade on matters relating to scientific and technological capacity and development in Quebec. The CST was abolished in 2011, as per Bill 130 (Government of Quebec, 2014).

navigate complexity in the world, use technology, and maintain an adaptive capacity and critical judgment (CST, 2002a). Among other groups, the NRC and the U.K. Royal Society argue that private citizens with higher science knowledge benefit in terms of decision-making, which can influence the quality of their daily lives (RS & Bodmer, 1985; NRC, 2009; Randel, 2010). Thus individual critical reasoning skills are often seen as a form of science literacy, and research shows that individuals can make better decisions when they are better able to recognize the difference between personal opinion and evidence-based conclusions (Sadler & Zeidler, 2009). For example, an individual is called upon to assess the reliability of information in many everyday situations such as interpreting advertisements, comparing products for purchase, and evaluating statements made by public figures.

The relevance of scientific knowledge and understanding to choices about personal health is especially evident. Both "health numeracy" and "health literacy" (concepts closely related to science literacy) have been implicated in many different health outcomes. Health numeracy is a basic understanding of numbers and mathematical skills that allows accurate interpretation of health information, such as data presented in charts and tables. Reyna *et al.* (2009) found that low numeracy negatively affects perceptions about the risks and benefits of screening, complicates medication management, inhibits treatment access, impairs risk communication, and may even hinder medical outcomes. National and international data indicate that many people lack the basic health numeracy skills needed to make educated decisions (Reyna *et al.*, 2009).

Health literacy is the ability to synthesize health information for informed decision-making (Reyna *et al.*, 2009). Lower levels of health literacy have been linked to many health-related behaviours and outcomes. Individuals with lower levels of health literacy are less likely to engage in health-promoting behaviours, to take part in screening programs or access appropriate care, to accurately follow preoperative instructions, and to be compliant with treatment protocols (Rudd *et al.*, 2007). A review of health literacy in Canada found that Canadians with the lowest levels of health literacy are 2.5 times as likely to report themselves as being in fair or poor health than those with high levels of health literacy, even when controlling for other variables such as age, gender, education, and immigration status (CCL, 2008). Lower levels of health literacy are also associated with improper use of antibiotics (Dunn-Navarra *et al.*, 2012), which is contributing to the growing threat from antibiotic resistance.

Additional indirect evidence for the role of science knowledge in contributing to health outcomes can be drawn from the relationship between health outcomes and education. Educational attainment is highly correlated with both self-reported health and with longevity in OECD countries. Among 15 OECD countries, a 30-year-old man with a post-secondary education can expect to live eight years longer than a 30-year-old man who did not complete secondary school (OECD, 2013b). While there are multiple channels through which education can exert an influence on health (and health can exert an influence on education), part of this effect may be the result of differences in behaviour. More highly educated people are more likely to exercise, smoke less, regularly wear seatbelts, and participate in screening programs for breast cancer and cervix cancer (Grossman & Kaestner, 1997). In addition, the prevalence of obesity is lower among more highly educated people (Groot & Maassen van den Brink, 2006). These behaviour differences have social and cultural drivers, but also may reflect increased scientific knowledge and understanding of health impacts among more educated individuals. Educational attainment is also strongly associated with measures of adult science literacy (Miller, 2012; NSB, 2012) suggesting a possible link between public understanding of science and health outcomes.

Individuals are often faced with complicated scientific issues presented in the media, where evaluating potential health risks requires a relatively sophisticated grasp of the underlying science. One example relates to vaccinations and autism (see Box 3.1), where individual choices about whether to vaccinate children have serious public health consequences. The ability to make informed choices requires not only a basic grasp of scientific concepts such as viruses and inoculation, but also the ability to ascertain the relative reliability of different sources of evidence. In this case, the issue is particularly complex as the original source of concern was a scientific article in a respected, peer-reviewed medical journal. However, continued low levels of vaccination in many areas demonstrate that public confusion over the implications of a scientific or medical issue, such as the relative risks and benefits of vaccination, can be difficult to resolve once competing sources of information are being disseminated in the public sphere.[6]

6 The ongoing relevance of this threat was recently demonstrated in Canada with the outbreak of measles in the Fraser Valley in British Columbia.

Box 3.1
Autism and the MMR Vaccine

When well-respected scientific journal *The Lancet* published a paper in 1998 that described the onset of autism spectrum disorders and inflammatory bowel disease in children shortly after receiving the MMR (measles, mumps, and rubella) vaccine (Wakefield *et al.*, 1998), other media widely publicized the associative link drawn in the paper as having a causative relation. Although a number of wide-scale studies were launched that did not identify a link between the vaccine and autism spectrum disorders, their results were not available until years later. In 2004 a majority of the paper's co-authors withdrew support for their original claims, and *The Lancet* retracted the article in 2010. Since the publication of the original study in 1998, however, vaccination rates have dropped in the United Kingdom and North America, and the rate of vaccine-preventable diseases like measles has increased (McIntyre & Leask, 2008). Health officials are currently attributing recent outbreaks of measles to the "lost generation" of youth, now aged 10–18, who did not receive MMR vaccination as infants (McLaren, 2013). Public confusion about the science surrounding the benefits and risks of vaccination continues.

However, evidence also suggests that there are limits to the benefits that might be expected to accrue from improving science knowledge at the individual level, and to the degree that individuals might be able to effectively translate scientific knowledge or understanding into more effective decision-making. First, individuals will still need to rely on credible sources of scientific authority for guidance given the impossibility of individually mastering all relevant domains of scientific knowledge. It is unreasonable to expect that all members of a scientifically knowledgeable society will function as "microscientists" (Toumey *et al.*, 2010), seeking out and understanding the complete body of evidence on every issue. Second, as scientific issues on the public policy agenda become increasingly interdisciplinary and reflective of new dynamics in science and technology, individuals will inevitably have to rely on both scientists and the media for information. In such cases, both general critical thinking skills and an ability to rigorously evaluate the reliability of different sources of evidence are critically important.

Sadler and Zeidler (2009) describe two overarching visions for science literacy. One vision reflects the idea that scientific concepts and processes should be taught to help learners understand scientific findings, skills, and methods. The other, broader vision focuses on understanding and using science in practical situations "involving personal decision-making about contextually embedded issues" —

issues relating to science, but influenced by social, political, economic, and ethical perspectives. Through this lens, the boundaries of science become blurred, such that "it becomes difficult to ascertain where scientific considerations end and where social considerations begin" (Sadler & Zeidler, 2009).

With this latter vision in mind, the Panel noted that while a certain level of science knowledge may be necessary to make informed personal decisions in some contexts, it is not always in itself sufficient to ensure effective decisions and outcomes. Research in experimental psychology and behavioural economics has demonstrated that innate biases often characterize human decision-making processes. Individuals often rely on simplified heuristics (learned or innate rules that facilitate decision-making) when faced with complex choices, and their decisions may be influenced by the environmental context as well as values, morals, and judgments (for reviews see Kahneman & Tversky, 2000; Gilovich *et al.*, 2002). Kahan *et al.* (2011) discuss the "cultural cognition of risk," which is the tendency of individuals to form risk perceptions that reflect their personal values. Even in the face of new evidence that refutes a certain viewpoint, informed individuals may hold strong to a belief because of personal values, and they may overestimate the amount of scientific evidence for views they are culturally predisposed to hold (Bell & Lederman, 2003; Kahan *et al.*, 2011; Liu *et al.*, 2011).

The impact of scientific knowledge on individual choices is also complicated by the existence of different types of scientific knowledge. A workshop held by the National Science Foundation in the United States in 2010 articulated three types of science knowledge: factual science knowledge, knowledge of scientific processes and standards for evaluating scientific evidence, and knowledge of scientific institutions and how they operate (Toumey *et al.*, 2010). These types of science knowledge have different implications for individuals in their daily lives. Bell and Lederman (2003) suggest that citizens may be better situated to make decisions on scientific issues if they are empowered to apply current understandings of the nature of science to their decision-making. In other words, knowledge *about* science, rather than scientific knowledge itself, may be more beneficial for enhancing individual decision-making (Collins & Pinch, 1993).

In a similar vein, Feinstein (2011) argues that there is little supporting evidence for traditional arguments on how science literacy benefits individuals. Instead, he proposes a new model of science literacy that focuses on helping individuals to become "competent outsiders" with respect to science. Critical skills include individuals' ability to recognize "moments when science has some bearing on their needs and interests" and to effectively "interact with sources of scientific expertise in ways that help them achieve their own goals" (Feinstein, 2011).

This section has focused on the impacts associated with improving individuals' science knowledge or understanding, as these claims have been the primary focus of much of the literature. Strengthening a society's science culture can also lead to other benefits for individuals through expanded opportunities for public engagement and entertainment in scientific activities. Cultural institutions such as science centres and museums provide opportunities for leisure, recreation, and learning for individuals and families. Science coverage in the media provides both information and entertainment on new developments in science and technology. See Chapter 5 for a discussion of these patterns of engagement in Canada.

3.2 IMPACTS ON PUBLIC POLICY AND DEMOCRATIC ENGAGEMENT

Science is a central component of the public policy agenda in most countries, playing a role in debates on emerging issues such as use of genetically modified organisms in agriculture; the safety and economic impact of renewable and non-renewable energy sources (e.g., nuclear, wind, oil, gas, hydro); climate change; biodiversity preservation; and support for investigational health research including stem cells, genetics, and nanotechnologies. Citizens of democratic countries frequently encounter debates about these issues in the public sphere. As a result, another argument often advanced in support of cultivating science culture and public understanding of science is that doing so will enable more informed public participation in debates and thereby enhance democratic engagement and potentially improve policy outcomes (RS & Bodmer, 1985; Miller *et al.*, 1997; Miller, 2002, 2010c; Toumey *et al.*, 2010).

The logic of this argument is straightforward. Democratic governments are predicated on the notion that citizens can effectively express their preferences on issues of public importance. Citizens who do not have an adequate foundation of scientific knowledge lack the ability to participate in these debates in an informed manner, thereby compromising the effectiveness of the democratic process. Some level of scientific knowledge or understanding is therefore a *prerequisite* for *informed* citizen involvement and engagement on these issues (Miller *et al.*, 1997). As a result, improving public knowledge and understanding of science can lead to enhanced public participation and engagement in these debates, and potentially better policy outcomes for issues involving science and technology.

These arguments have been advanced many times. Building on Shen's (1975) multidimensional conception of science literacy, Miller (1998, 2002, 2004, 2012) has discussed the relevance of a basic threshold of science literacy to the capacity for effective citizenship and democratic participation in modern societies.

Similar arguments have been advanced by the NRC (2009) and National Science Foundation (NSB, 2012) in the United States, and the Royal Society in the United Kingdom (RS & Bodmer, 1985), all of which postulate that improving public understanding of science helps foster citizen engagement in science and technology issues.

Empirical work linking public scientific literacy to observed patterns of democratic engagement is more limited. Earlier studies of public political participation in the United States have provided some evidence of the importance of information and interest in terms of supporting ongoing political engagement. For example, Roseneau (1974, as cited in Miller *et al.*, 1997) found that citizens are significantly more likely to act on a political issue by voting, contacting a legislator or government official, or engaging in political meetings or activities when they have a high level of interest in the issue, feel well-informed, and follow the issue in the news. A more scientifically knowledgeable or well-informed public may therefore be also more likely (as well as more able) to actively engage in public debates and discussions on scientific issues.

It is also not clear what level of scientific knowledge is required of the public to ensure an "adequate" level of informed engagement. This level may vary depending on the nature of political institutions and the structure of government. Miller *et al.*, (1997), for example, speculate that parliamentary systems may possibly require a lower threshold of informed public participation than a U.S.-style congressional system. Studies by Miller *et al.*, (1997) and Miller (2012) have regularly assessed science literacy levels in the United States and other countries, often using a threshold based on the share of the population achieving the level of science literacy necessary to understand science journalism such as that found in *The New York Times* (see discussion in Chapter 4). These studies have typically found that less than one-third of the population in assessed countries meets that threshold. Although these levels are often argued to be sufficiently low to endanger the quality of democratic engagement with science and technology issues (Miller, 2002), no objective standard exists for determining an appropriate target level.

These arguments are sometimes made without consideration of the extent to which citizens are afforded opportunities to engage in public discussions about science and technology and policy-making processes. The mechanisms employed to facilitate public engagement in science also play a role in determining impacts on policy. The idea that science policy-making can be improved through public dialogue seems straightforward. By opening up science governance, a more diverse range of perspectives may influence the course of science policy in ways that are more socially beneficial (Sturgis, 2014). Mutual benefits can come from communication and cooperation between policy-makers, citizens, and the scientific community, but, in many cases, meaningful engagement is lacking (Wooden, 2006). Citizens are also not afforded the same opportunities for such engagement across countries. In Europe, for example, citizens report being comparatively less happy with their own levels of participation in science and technology in countries that have (i) a weak culture of science communication, (ii) undeveloped public engagement processes and institutions, and (iii) a relatively small role for science in policy-making (Mejlgaard *et al.*, 2012a).

Burgess (2014) notes that, during the past two decades, there has been a shift away from the view that "publics need to be educated so that they trust science and its governance to the recognition that publics possess important local knowledge and the capacity to understand technical information sufficiently to participate in policy decisions." The legitimacy of public engagement with science and technology policy depends, in no small part, on its impacts (Stilgoe *et al.*, 2014). Critics observe that, rather than using public engagement to rethink policies and practices, such exercises can be initiated by institutions to gain support for predetermined approaches (Wynne, 2006), and are thereby reduced to tokenism (Feinstein, 2011). Further, relatively little is known about whether citizens share the same level of enthusiasm for participatory dialogue as is held by institutional actors (Sturgis, 2014). Consideration of such factors has led some researchers to the conclusion that "public engagement would seem to be a necessary but insufficient part of opening up science and its governance" (Stilgoe *et al.*, 2014). In other words, public engagement can be a part of supporting democratic science policy, but it is not the sole means by which science is linked to politics, or politics to policy.

The impacts of public understanding of and engagement in science on governments and policy are also affected by the institutional mechanisms that support the translation of scientific evidence into public policies. Societies incorporate scientific evidence into policy-making to different extents. The Monitoring Policy and Research Activities on Science in Society in Europe has evaluated the level at which science-based knowledge is formally and informally integrated into the policy-making process, along with the level of collaboration among science experts, civil servants, and policy-makers (Mejlgaard *et al.*, 2012b). Of 37 European countries, science has a stronger impact on policy-making and is incorporated more formally in France, Germany, the Netherlands, the United Kingdom, and Nordic countries (no similar analysis is available for Canada).

As explained in Section 3.1, in addition to an understanding of the science, opinions on divisive socio-scientific issues are shaped by personal and cultural values (Kahan *et al.*, 2011). As a result, increasing public understanding of science may not be linked to specific policy preferences on science and technology issues, or public attitudes and preferences that are more "pro-science." However, findings that individuals are limited in their capacity to form scientific opinions unaffected by personal or cultural values do not necessarily translate into a lack of impact of science knowledge on public policy. Although interpretations of science are mediated by societal values and contextual factors (Brace & Geoghegan, 2011), citizens and governments still benefit from a society that values and promotes science knowledge and evidence-based policies. There are limits, however, on the degree to which policy preferences can be informed by scientific evidence versus other sources of cultural and social values. In addition, the extent of any impact on democratic engagement and public policy is a function of the types of engagement opportunities afforded to the public, and the mechanisms through which scientific knowledge and advice are incorporated into policy-making processes.

3.3 IMPACTS ON THE ECONOMY

The role of science and technology in promoting long-term economic growth is well established. A large body of economic theory and research has explored the importance of innovation and technological development in promoting economic development. Traditional neoclassical macroeconomic models (Solow, 1956; Swan, 1956) have suggested that an "economy's long-run growth rate is determined exclusively by the rate of technological progress" (Howitt, 2007).

More recently, alternative economic models based on endogenous growth theory or Schumpeterian principles have also focused on the role of technology in driving economic growth, but factored in the determinants of the pace of technological change (Romer, 1986; Lucas, 1988; Aghion & Howitt, 1992). While the nature of these relationships and the ways in which technical change and innovation interact with other economic drivers have been extensively researched and debated, these theories and models are in agreement that technological change is a key driver of productivity growth and long-term economic outcomes. In Canada recognition of this fact has created ongoing concern about the nation's comparatively low levels of business investment in research and development (R&D) and record of poor productivity growth. Some researchers and policy-makers have concluded that these are symptomatic of an innovation deficit in the economy (see CCA, 2013b for a recent discussion).

Technological innovation depends on the presence of science and technology skills in the workforce. While at one point it may have been possible for relatively low-skilled individuals to substantively contribute to technological development, in the 21st century this is no longer the case. Advanced science and technology skills are now a prerequisite for most types of technological innovation. In

Canada 60% of industrial R&D expenditures go to compensating researchers and technicians undertaking that R&D (Statistics Canada, 2013d). In the absence of these personnel, that R&D would not be possible. By definition for the Panel, a society with a strong science culture is one that supports the development of science and technology skills in the population. As a result, a strong science culture can also reasonably be expected to enhance the economy's aggregate capacity for innovation by supporting the development of these skills in the labour force.

However, many uncertainties relate to this impact such as the relative importance of different types and sources of skills, what constitutes an adequate supply of skills in the economy, and how the demand for highly skilled labour is evolving in response to other economic and technological trends. While economic studies have established the importance of general measures of "human capital" (i.e., the quality or skill level of the labour force) as a determinant of economic growth (e.g., Schultz, 1961; Becker, 1964; Mincer, 1970; Barro, 2001), very few empirical studies have explored how specific science and technology skills contribute to innovation and subsequent macroeconomic outcomes (see OECD (2011a) for a discussion).

There is some indirect evidence pointing to the potential benefits of these skills. For example, a recent analysis of 11 million U.S. workers in 320 metropolitan areas found that each high technology job in an urban centre eventually leads to five additional local jobs outside of high technology, due to the multiplier effect (Moretti, 2012). The creation of these jobs is spurred by the generous salaries, benefits, and disposable income related to the high technology occupations. Moretti also found that two of these five jobs are likely to be professional (e.g., doctors, lawyers), and three non-professional (e.g., servers, retail clerks). In contrast, 1 traditional manufacturing job creates 1.6 local service jobs. This analysis demonstrates the important role of highly skilled innovators in building an economy.

Science and technology skills are also relevant to an increasingly wide range of occupations. U.S. data indicate that an increasing number of jobs at all levels require some degree of STEM knowledge (Ginsburg, 2011). Science and technology awareness and skills are a benefit not only in STEM-specific careers, but in many other careers today, which are increasingly reliant on technologies and the incorporation of new technologies. Individuals with a strong science knowledge base may also be more receptive to emerging technologies along with ideas that can stimulate businesses and the economy (NAS *et al.*, 2007).

While the development of science and technology skills in the population is viewed by the Panel as an indicator of a strong science culture, other dimensions of science culture, such as engagement in scientific activities and pursuits and attitudes towards science, can further contribute to skills development. Individual decisions to pursue education and training opportunities in the sciences are based on the combined influence of many factors (e.g., gender, education, aptitude, attitudes and preferences, environment, culture) (Dorsen *et al.*, 2006; Subotnik *et al.*, 2009; CCA, 2012a). However, student attitudes towards science are a significant predictor of eventual career decisions. A longitudinal study by Tai *et al* (2006) found that U.S. students who expressed an interest in scientific careers in Grade 8 were 3.4 times more likely to earn a degree in the physical sciences or engineering than students without that interest.

Participation in informal science learning and engagement opportunities can also have impacts on youth attitudes towards science and science careers. Canadian studies investigating attitudes of participants both before and after participation in science programs have found evidence of impacts on attitudes to science and scientific careers (Crombie *et al.*, 2003). A recent Canadian study of youth in the Maritime provinces concluded that participation in STEM activities such as science fairs, robotics, or science camps is a significant predictor of whether girls express an interest in scientific careers (Franz-Odendaal *et al.*, 2014).

However, despite the broad relevance of science culture to the national economy, the relationship between science and technology and economic outcomes is complex. Many other factors (e.g., macroeconomic and regulatory environment, trade patterns and barriers, industry structure, availability of financing, relationships with universities and research institutes) also affect rates of innovation and therefore economic outcomes. Changes in the availability of science and technology skills do not necessarily affect all economies equally. McEneaney (2003) cautions that variations in economic conditions around the world mean that science and technology skills can have varying levels of impact on the economy; small gains in science knowledge can have more profound impacts on economies at earlier stages of development.

In an analysis of Canada's situation, the Expert Panel on the State of Industrial Research and Development (CCA, 2013b) found limited alignment between areas of science and technology, industrial R&D, and economic strength; and identified Canada-specific barriers to the translation of science and technology knowledge (and skills) into innovation and wealth creation. As a result, while a stronger science culture can contribute to economic growth by supporting the development of science and technology skills in the population, the realization of those benefits is dependent on many other factors affecting national economic outcomes. Thus increasing the availability of such skills does not necessarily yield economic benefits in all contexts.

3.4 IMPACTS ON SCIENTIFIC RESEARCH

According to the Panel's understanding of science culture (Section 1.3), a strong science culture encourages discovery and supports the use of scientific knowledge and methodology. By definition, such a culture is supportive of scientific research. However, increasing public involvement and engagement in science can benefit scientific research in ways that may not be readily apparent. As discussed in Section 2.1.2, citizen science initiatives are expanding the ways in which the public can engage in scientific research. In addition, public participation in research activities such as clinical trials or provision of medical samples can enhance research outcomes of medical and biological research. Clinical research often depends on volunteers who provide permission for themselves, their health data, or their tissues to be used in research. However, recruiting these participants can be a major challenge, with barriers including safety and privacy concerns, potential out-of-pocket expenses, and inconveniences associated with multiple clinic visits for follow-up (Sung *et al.*, 2003). Ensuring continued participation in this type of scientific research is critical to sustaining future clinical research. Durant *et al.* (1992) reported evidence that medical science might be "paradigmatic" in the public's understanding of science and scientific processes in the United Kingdom, strongly influencing how people conceive of science and scientific research. Given this finding, increased public understanding of and engagement in science in general may translate to a greater willingness on the part of many individuals to participate in medical research.

New approaches to incentivizing this participation often use gathered data from individuals to further long-term scientific research goals for a particular issue. This may be done via online data-sharing platforms (e.g., Patientslikeme) or with kits to conduct at-home genotypes of DNA samples (PLM, 2013). There are reciprocal benefits. Participants can get access to results, and receive information about their ancestry, disease risk, and drug response. Results can potentially lead to better and earlier diagnoses, a greater understanding of disease progression, and the development of more effective treatments. Although these services are expanding the possibilities for consumers to analyze their own genetic makeup, the availability of "direct-to-consumer" genetic testing has also created consumer concerns about the quality of these products, their therapeutic appropriateness in different circumstances, and the adequacy of consumer protection (Hudson *et al.*, 2007).

3.5 CHAPTER SUMMARY

This chapter has reviewed the state of evidence on common claims about the impacts of science culture, and public understanding of science, focusing on four main domains: impacts on individuals, impacts on public policy and democratic engagement, impacts on the economy, and impacts on scientific research. These claims are common in the literature on public understanding of science, and in reports and studies from scientific organizations such as the Royal Society in the United Kingdom, and the American Association for the Advancement of the Sciences in the United States, among others.

Many of these claims are plausible given the extent to which science and technology feature in most aspects of individual and social life. However, the state of knowledge about many of these impacts is limited. Very few studies have tried to empirically establish direct links between dimensions of science culture, such as public attitudes towards or understanding of science, and higher-order social impacts such as economic outcomes or democratic participation. Given the number of potential confounding factors, conclusively establishing causal relationships is methodologically challenging. Some evidence also suggests that these impacts are more complex than often acknowledged. While increasing individuals' understanding of science can improve their capacity to make personal decisions in contexts involving science and technology, decision-making processes are affected by many factors, including underlying cultural values and common cognitive biases and heuristics. Different forms of science knowledge (i.e., knowledge of scientific processes versus scientific facts) are also not of equal value or relevance in informing individual decisions in daily life.

Some level of knowledge of science is critical to enabling informed public participation in policy issues involving science and technology in democratic countries. However, knowledge in itself does not ensure higher levels of participation or more effective engagement or policy-making. The types of engagement opportunities available to citizens and the nature of institutional mechanisms for incorporating scientific advice into public policy-making are equally important. A strong science culture can also bolster an economy's capacity for innovation through the supply of science and technology skills. However, the relationships between the supply of these skills and economic outcomes are complex and many other factors also affect innovation and economic outcomes. Science culture can also benefit scientific research, through more public support and engagement in different kinds of research activity.

In summary, a strong science culture, one that manifests relatively high levels of science knowledge and engagement, is often a prerequisite to the realization of a range of personal and social benefits. However, such a culture is not always sufficient, in itself, to ensure the realization of those benefits.

4

Measuring Canada's Science Culture

- Survey Methods and Limitations
- Public Attitudes Towards Science and Technology
- Public Science Engagement
- Public Science Knowledge
- Science and Technology Skills
- The Determinants of Science Knowledge and Attitudes
- Data Gaps
- Chapter Summary

4 Measuring Canada's Science Culture

Key Findings

- Canada's science culture can be quantitatively assessed by using existing methodologies and studies to measure four key dimensions of the public's relationship with science: attitudes, engagement, knowledge, and skills. International comparisons and trends over time can put Canadian findings in context.
- Canadians have positive attitudes towards science and technology and low levels of reservations about science compared with citizens of other countries.
- Canadians exhibit comparatively high levels of engagement with science and technology, with 93% of Canadians reporting being interested in science and technology. Canadians are more likely to visit a science and technology museum than citizens of most countries, and exhibit high levels of engagement with science in other ways.
- Most Canadians have a high level of science knowledge relative to citizens of other countries, though many still lack an understanding of basic scientific concepts. Factual knowledge about science in the adult population has also improved since 1989.
- Canada's performance on indicators of science and technology skills development is variable. The proportion of Canadian students pursuing degrees in the sciences and engineering is modest relative to students in other industrialized countries, as is the relative size of the science and technology workforce. Women continue to be underrepresented in some fields, particularly engineering and computer sciences.

This chapter reviews evidence on the four key dimensions of science culture assessed by the Panel: public attitudes towards science, public engagement in science, public science knowledge, and level of science and technology skills in the population. Efforts to quantitatively assess dimensions of science culture such as public science knowledge, attitudes, and engagement have been conducted since the 1950s in the United States and Europe, and many countries periodically field surveys gauging public understanding and perceptions of science and technology, and public attitudes towards them. However, this type of survey data is lacking for Canada, with the last nationwide survey undertaken in 1989 (Einsiedel, 1990). In the absence of more up-to-date data for Canada, the Panel commissioned a new survey of Canadians based on a suite of internationally comparable survey questions. Drawing heavily on results from this survey, this chapter explores Canada's performance on a range of indicators that measure these dimensions of the public's relationship with science and technology. Findings are placed in context by identifying trends over time and comparing Canadian results with those from other countries where possible.

4.1 SURVEY METHODS AND LIMITATIONS

The Panel's survey of Canadian science culture, designed to be comparable to surveys undertaken in other countries as well as to the 1989 Canadian survey, assessed public attitudes towards science and technology, levels and modes of public engagement in science, and public science knowledge or understanding. (The evidence reported in this chapter on the fourth dimension, science and technology skills, is drawn from other sources such as Statistics Canada and the OECD).

Conducted in April 2013, the survey relied on a combination of landline and mobile phone respondents (60%) and internet respondents (40%), randomly recruited from the general population. In analyzing the results, responses to the survey were weighted based on Statistics Canada data according to region, age, education, and gender to ensure that the sample was representative of the Canadian public.[7] A total of 2,004 survey responses were received, with regional breakdowns presented in Table 4.1. At a national level, survey results are accurate within a range of plus or minus 2.2% 19 times out of 20 (i.e., at the 95% confidence interval), and margins of error for regional results range from 3.8% to 7.1%). Three open-ended questions were also included in the survey, which were coded using protocols previously applied to these questions in other international surveys.[8] All open-ended questions were coded independently by at least three bilingual coders, and any discrepancies in coding were settled through a review by a fourth coder.

Appendix A contains the full text of the survey questionnaire and Appendix B contains the coding protocol used to evaluate the open-ended questions. Appendix C identifies the international surveys referred to in the chapter. The full dataset from the survey is available upon request by contacting the Council of Canadian Academies.

7 These weights were used for the sample to represent the true population at a national level, but are less reliable when applied to population sub-groups. A separate set of weights was calculated for each of the following six regions: British Columbia and the Territories, Alberta, Saskatchewan and Manitoba, Ontario, Quebec, and the Atlantic Provinces. Region-specific weights align respondents in each region to Statistics Canada data on age, education, and gender. These region-specific weights are used when presenting regional analyses throughout the chapter.

8 The Panel is grateful for assistance from researchers at the University of Michigan, University of Calgary, and l'Université du Québec à Montréal in completing this coding, as well as from coders at EKOS Research Associates Inc.

Table 4.1

Panel Survey Sample Size and Margin of Error by Region

Region	Sample Size	Margin of Error %
British Columbia & Territories	278	5.9
Alberta	175	7.4
Manitoba & Saskatchewan	200	6.9
Ontario	646	3.8
Quebec	514	4.3
Atlantic Provinces	191	7.1
Canada	**2,004**	**2.2**

The survey included 2,004 Canadians and is sufficient to allow for a discussion of regionally disaggregated performance. At the national level, survey results are accurate plus or minus 2.2% at the 95% confidence interval (i.e., 19 times out of 20).

Canadian results are presented here alongside results for other countries for which comparable data are available. These typically include European Union members and the United States, and in some instances China, Russia, South Korea, Australia, India, and Japan. To facilitate comparisons, figures in this chapter often feature a smaller subset of the countries for which there are data.

While the evidence collected in this survey, and in similar surveys undertaken in other jurisdictions, provides valuable baseline information on the state of Canada's science culture, several methodological limitations may affect the interpretation of these results. Questions asked in different countries are sometimes phrased differently (Bauer *et al.*, 2012a), complicating international comparisons. Where question wording varies in the surveys referred to here, differences are noted in the relevant figures and tables. Language and cultural differences can affect the interpretation of these questions, and international comparisons therefore should be undertaken cautiously. The frequency of data collection also varies by country, with some comparisons involving data collected at different points in time, again complicating international comparisons. The mode through which surveys such as these are administered may also have effects on the results. Survey results for Canada presented here are based on a combination of landline, mobile phone, and internet responses; however, many international surveys used for comparison relied on face-to-face survey protocols.[9] Finally, changes in survey results over time may reflect underlying shifts in Canadian culture and demographics, including age structure and education levels. As a result, changes in Canadian survey results over time should also be considered carefully, with attention to how other demographic and social shifts in the population may have affected these trends.

4.2 PUBLIC ATTITUDES TOWARDS SCIENCE AND TECHNOLOGY

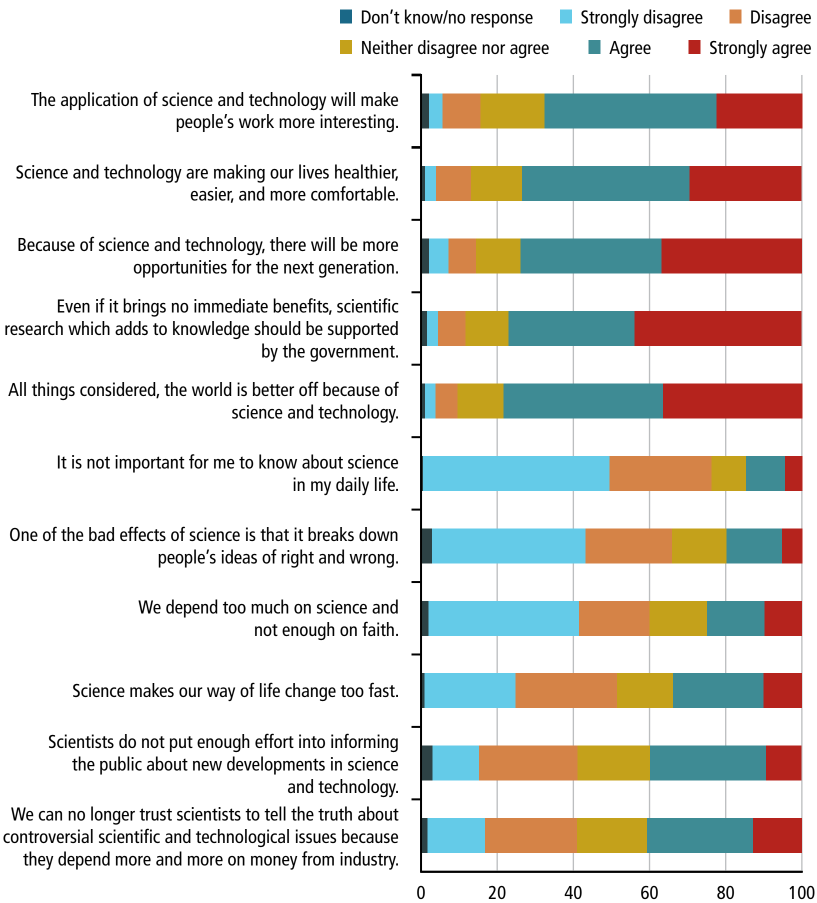
The majority of citizens of modern industrialized societies tend to have positive views of science and technology, and Canada is no exception. Figure 4.1 shows survey results from a set of attitudinal questions frequently used to explore public views on science and technology (EC-DGR, 2010; NSB, 2012). Most Canadians hold broadly positive views about science and technology and its effects on society. For example, 77% of Canadians agree that, all things considered, the world is better off because of science and technology, and 72% express agreement with the statement that science and technology are making our lives healthier, easier, and more comfortable. Most Canadians also generally believe that science will continue to create more opportunities for the next generation. However, while broadly positive attitudes towards science and technology predominate in the Canadian population, they are not universal. Between 10% and 15% of Canadians typically disagree with these statements.

9 Most international surveys referred to in this chapter were conducted through face-to-face interviews rather than via phone or internet. There is evidence that phone respondents are more likely to provide what they perceive as socially desirable responses than face-to-face participants, and mixed evidence of higher acquiescence bias by phone (Jäckle *et al.*, 2006). Using a mode test for the European Social Survey, researchers found that mode differences between phone and face-to-face interviews were significant for about one-third of the questions, but the differences were small and did not alter the relationships between questions (Jäckle *et al.*, 2006). Web-based respondents appear to be more knowledgeable overall and less likely to provide socially desirable responses than face-to-face survey respondents (Duffy *et al.*, 2005). For the Panel's survey, slight mode differences between phone and internet participants are observable for some questions despite weighting of responses to match the demographics of the overall Canadian population.

Canadians also express other reservations about science and technology. For example, 25% of Canadians hold the view that we depend too much on science and not enough on faith, and 21% are concerned that one of the effects of science is that it breaks down people's ideas of right and wrong. In addition, 35% of Canadians believe that science is making our way of life change too fast, and 41% express a concern that scientists may not be trustworthy, due to their dependence on funding from industry.

These questions can also be used to assess how Canadian attitudes towards science and technology have evolved over time. Past survey data for Canada are limited, but several science attitude questions included in a 1989 Canadian survey were also repeated in the Panel's survey. Changes over the 24-year period are mixed. In 2013 slightly fewer Canadians than in 1989 agreed that science and technology are making life healthier, easier, and more comfortable, but fewer Canadians also expressed concerns or apathy about science (see Figure 4.2). The share of the population holding the view that we rely too much on science and not enough on faith declined by nearly 20% in the same period,[10] and the share expressing the view that science makes our way of life change too fast declined by 11%. Canadians' views on science and technology appear to have moderated since 1989. In general, Canadians are somewhat less optimistic about the potential benefits of science and technology than they were in 1989. Concerns about potential negative effects of science, however, have declined substantially and Canadians' perception of the relevance of science to their lives has increased.

10 This pattern may be driven by declining religiosity in the Canadian population in general. According to Statistics Canada, the share of the population attending weekly religious services declined from 30% in 1985 to 21% in 2005, and the share reporting no religious affiliation doubled over the same period (Statistics Canada, 2008).

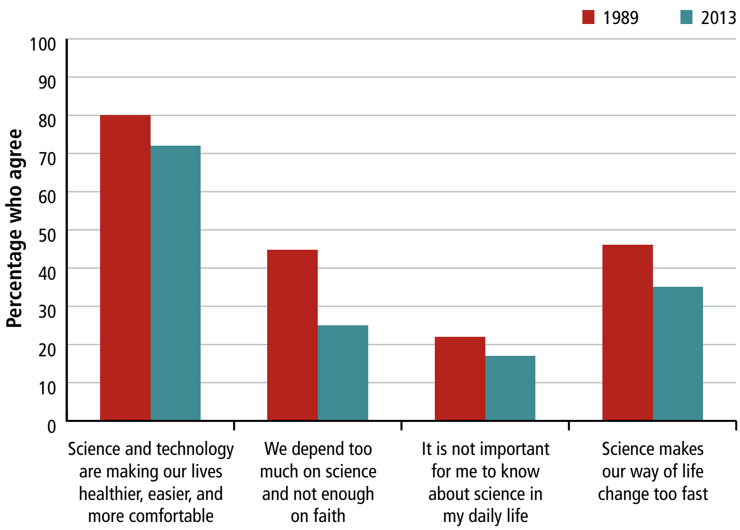


Data Source: Panel survey data

Figure 4.1

Canadian Attitudes Towards Science and Technology

The figure shows responses to standard attitudinal questions used to assess public views on science and technology. Canadian responses here are aggregated based on a scale of 0 to 10 (0 to 1=strongly disagree, 2 to 4=disagree, 5=neither agree nor disagree, 6 to 8=agree, and 9 to 10=strongly agree). Results are accurate to ± 2.2% 19 times out of 20.



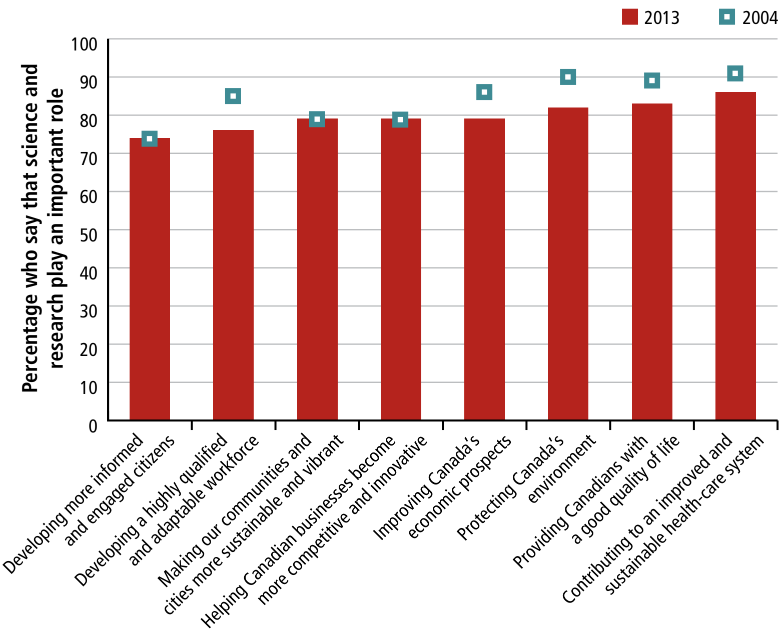
Data Source: Panel survey data and Einsiedel (1990)

Figure 4.2

Canadian Attitudes Towards Science over Time, 1989 and 2013

As a percentage of the population, fewer Canadians today agree that science and technology are making life healthier, easier, and more comfortable than in 1989. At the same time, Canadians today hold fewer reservations about science than they did in 1989, and are more likely to believe that science is important in daily life. The percentage that agrees captures both "agree" and "strongly agree" responses from the 1989 survey, and all responses between 6 and 10 of the Panel's 2013 survey, which asked respondents to signal agreement using a 0 to 10 scale. Results are accurate to ± 2.2% 19 times out of 20.

Canadian beliefs about the social benefits of science show a similar pattern, having moderated slightly in recent years. As shown in Figure 4.3, between 70 and 80% of Canadians affirm the importance of science and research in fulfilling a range of social, economic, and environmental objectives. However, the strength of these views appears to have diminished between 2004 and 2013. For instance, in 2004, 85% of respondents said that science and research play an important role in developing a highly qualified and adaptable workforce, but this fell to 76% by 2013 (not all declines shown in this figure are statistically significant given the margins of error associated with the survey results).



Data Source: Panel survey data and EKOS Research Associates Inc. (2004)

Figure 4.3

Views of Canadians on the Role of Science and Research in Achieving Socio-Economic Objectives, 2004 and 2013

Although Canadians think that science and research play important roles in achieving a range of socio-economic objectives, on average their perception of the importance of science in these areas has declined since 2004. In both surveys, respondents were asked to indicate the importance of science and research to each issue on a scale of 1 to 7 where 1 means not at all important, 7 means extremely important, and the mid-point 4 means somewhat important; responses of 5 and above are tabulated in the figure. Results for both surveys are accurate to ± 2.2% 19 times out of 20. Differences of less than 4.4% between the two years may not be significant.

4.2.1 International Comparisons

Citizens of most countries are optimistic about science and technology, and Canadians are broadly similar in this regard. However, as shown in Table 4.2, Canadians are less prone to positive views of science and technology than citizens of the United States. For example, 90% of Americans believe that science and technology are making their lives healthier, easier, and more comfortable, compared with only 72% of Canadians. Canadian responses to these questions are more comparable to those seen in most EU countries.

Canadians, however, have fewer reservations about science than citizens of many other countries. More than twice as many Americans express the view that we depend too much on science and not enough on faith. The share of Canadians who believe that science is not important for their daily lives is less than half the average for EU countries.

Table 4.2

Public Attitudes Towards Science and Technology by Country/Region

	U.S. (2004 or 2010)	EU (2010)	Japan (2001)	South Korea (2008)	Russia (2003)	China (2001 or 2007)	India (2004)	Canada (2013)
	Total Agree (%)							
Science and technology are making our lives healthier, easier, and more comfortable.	90	66	73	93	NA	86	77	**72**
With the application of science and new technology, work will become more interesting.	76	61	54	85	NA	70	61	**67**
Because of science and technology, there will be more opportunities for the next generation.	91	75	66	84	NA	82	54	**74**
We depend too much on science and not enough on faith.	55	38	NA	54	NA	16	NA	**25**
It is not important for me to know about science in my daily life.	14	33	25	30	31	17	NA	**17**
Science makes our way of life change too fast.	51	58	62	73	30	73	75	**35**

Data Source: Panel survey data and NSB (2012)

The table presents data on attitudes towards science and technology in selected countries or regions for the most recent year available. U.S. responses to a 2004 survey include "Science and technology are making our lives healthier..."; "With the application of science and new technology..."; "We depend too much on science..."; and "It is not important for me to know about science..." Responses to other items are from a 2010 survey. China's responses to a 2007 survey include "Promise of science" questions and "We depend too much on science…" China's responses to a 2001 survey include "It is not important for me to know about science…" and "Science makes our way of life change…". See Appendix C and NSB (2012) for details such as sample sizes and confidence levels for the surveys used in each country.

Past research has found that public attitudes towards science and technology are typically two-dimensional, with respect to views about the promise of science and concerns or reservations about science and technology. Using data from this survey as well as international data from the World Values Survey, the Panel analyzed public attitudes towards science and technology across countries based on two indices: one measuring views on the promise of science and technology, and one measuring reservations about science (see Box 4.1). The results of this analysis are shown in Figure 4.4 and Figure 4.5. In Canada moderate levels of belief in the promise of science and technology are coupled with comparatively low levels of reservations about science. Australia, Sweden, and Qatar all show a similar pattern, which could be interpreted to indicate a public climate that encourages and supports science and technology. In contrast, countries like Chile, India, and Spain all exhibit more reservations about science and technology. Generally, there is less variation among countries about the promise of science than with respect to reservations. Canada stands as having the lowest level of reservations about science among the countries for which data are available.

Box 4.1
Indices for Promise of Science and Reservations About Science

After analyzing international survey results with attitudinal questions on science and technology, Miller and colleagues concluded that attitudes towards science are typically two-dimensional (Miller *et al.*, 1997). The first dimension relates to views about the promise of science and technology, and the second to common reservations about science. These two dimensions do not necessarily move together. Individuals can, at the same time, hold positive attitudes about the promise of science and harbour reservations about the impacts of science on society. The Panel's analysis of data from its survey and from the World Values Survey confirmed that this two-dimensional attitudinal structure is present in recent data from 17 modern industrial nations.

To assess these two dimensions of attitudes, the Panel developed two indices. A "promise of science" index incorporates level of agreement with the following three statements:

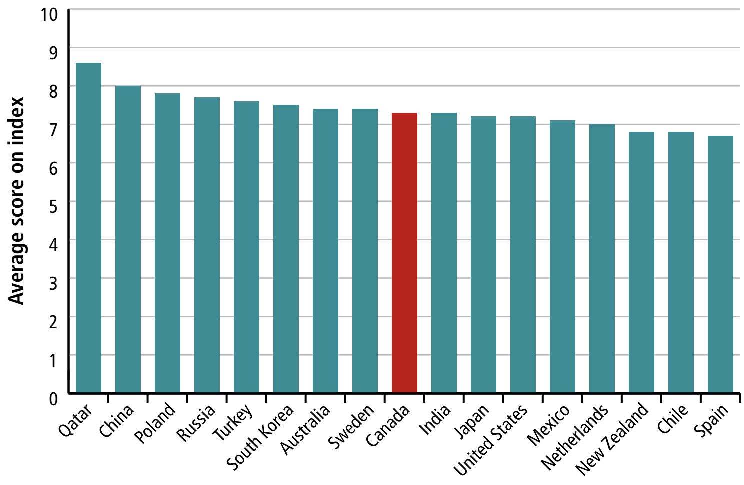
- Science and technology are making our lives healthier, easier, and more comfortable.
- Because of science and technology, there will be more opportunities for the next generation.
- All things considered, the world is better off because of science and technology.

continued on next page

A "reservations about science" index incorporates level of agreement with three other statements:

- We depend too much on science and not enough on faith.
- One of the bad effects of science is that it breaks down people's ideas of right and wrong.
- It is not important for me to know about science in my daily life.

The Panel undertook a confirmatory factor analysis to assess these indices and found that the selected items are significantly related to the two underlying dimensions in all countries. The relationship is stronger in the case of the promise of science index, but also evident in the reservations index. The correlation between these indices was also examined for Canada and other countries. The predominant pattern is a negative correlation around -0.50. In non-statistical terms, the implication is that many adults generally have a positive attitude towards science and technology and hold some reservations about potential consequences, but that the promise of current and future benefits from science and technology tends to dominate concerns and reservations (Miller *et al.*, 1997; Miller, 2004).

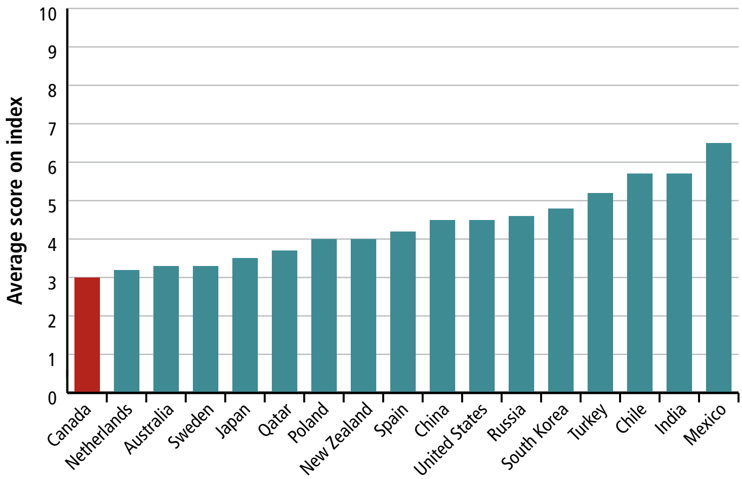


Data Source: Panel survey data and WVSA (2013)

Figure 4.4

Public Attitudes Towards the Promise of Science by Country, 2011–2013

Attitudes towards the promise of science can be appraised using an index that combines responses on the level of agreement with three statements (see Box 4.1). The analysis excludes respondents who show no variation in responses across the attitudes questions and respondents who offer neutral and non-responses. Standard errors for all countries are between 0.03 and 0.07.



Data Source: Panel survey data and WVSA (2013)

Figure 4.5

Public Reservations Towards Science by Country, 2011–2013

Reservations about science can be appraised using an index that combines responses on the level of agreement with three statements (see Box 4.1). The analysis excludes respondents who show no variation in responses across the attitudes questions and respondents who offer neutral and non-responses. Standard errors for all countries are between 0.04 and 0.08.

In comparisons of public support for investing in scientific research, Canadian attitudes are moderate, though generally in line with attitudes in other countries. For example, 76% of Canadians agree that research should be supported by the government even if it brings no immediate benefits. This is lower than the proportion agreeing in countries such as Sweden, the United States, and France, but higher than in many other countries, including the United Kingdom, Germany, and Finland (see Figure 4.6).

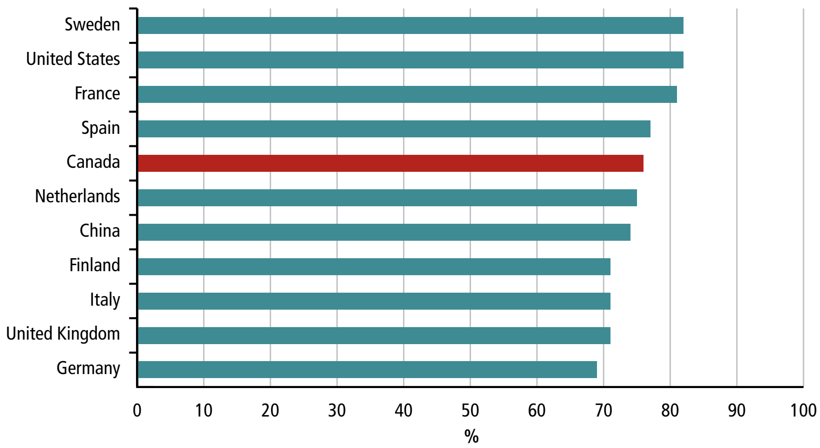


Figure 4.6

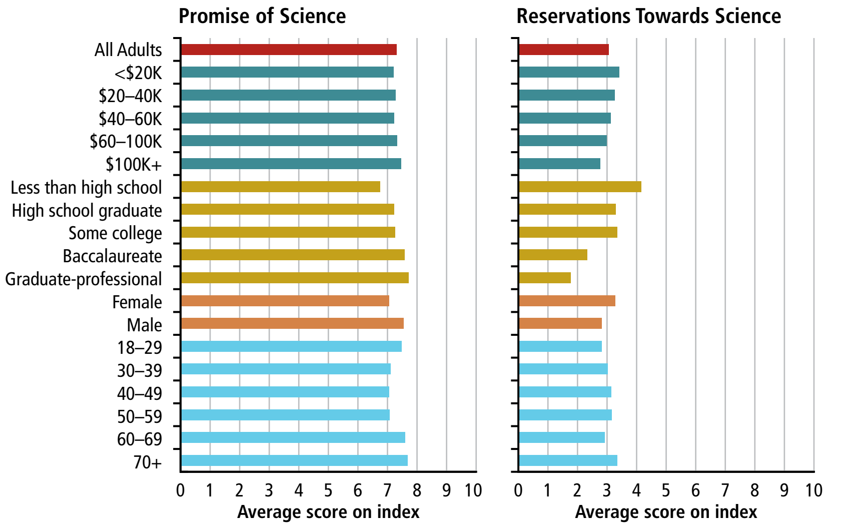
Public Support for Government Funding of Scientific Research by Country

Levels of support for government funding of scientific research are quite consistent across countries, with roughly 70–80% of the population agreeing that governments should support such research. Survey respondents were asked to signal their agreement with the statement: "Even if it brings no immediate benefits, scientific research which adds to knowledge should be supported by Government." U.S. respondents were asked to signal their agreement with the following statement: "Even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the federal government." European results include both "totally agree" and "tend to agree" responses, U.S. results include both "strongly agree" and "agree" responses, and Canadian results include all responses between 6 and 10 when asked to signal agreement using a 0 to 10 scale. U.S. respondents were not given the option of a neutral response while respondents in other countries were. All data shown in the figure were collected in 2010 with the exception of the Canadian data (2013) and the Chinese data (2007). Canadian results are accurate to ± 2.2% 19 times out of 20. Accuracy of international results varies across countries. Additional details are available in Appendix C.

4.2.2 Variation in Attitudes Across Regions and Demographic Groups

Figure 4.7 shows the average score on the indices for belief in the promise of science and reservations towards science by demographic group. More educated respondents and those with higher incomes are more likely to express beliefs in the promise of science and less prone to express reservations about science. The same is true for men when compared with women. Earlier analysis conducted using the 1989 survey data shows these same trends for education and gender (Miller *et al.*, 1997).[11]

11 One possible explanation for these trends relates to the ability of respondents to evaluate and respond to questions about science and technology. Pardo and Calvo (2006) note that respondents with lower levels of income, education, and science knowledge are more likely to provide neutral and non-responses to questions about science attitudes, and conclude that these respondents "have the most difficulties evaluating science." However, an analysis of the Panel's survey responses reveals that fewer Canadians provide non-differentiated responses relative to respondents in other countries.



Data Source: Panel survey data

Figure 4.7

Canadian Attitudes Towards Science and Technology by Demographic Group

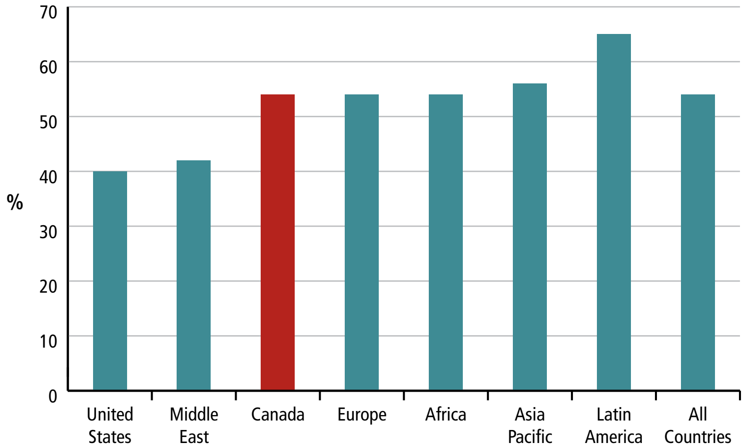
In general, Canadians hold positive attitudes towards the promise of science. These attitudes are quite consistent across demographic groups, with more educated respondents and male respondents holding somewhat more positive attitudes about the promise of science. Canadians tend to hold few reservations about science, but these attitudes vary more across demographic groups. Women and Canadians with lower income levels and lower levels of education are more likely to express these reservations.

Some regional variation in these views exists across Canada, but it is less pronounced than by demographic group. Attitudes towards the promise of science appear fairly uniform across Canada. The degree of reservations about science is more variable and generally rises moving from west to east.

4.2.3 Attitudes Towards Specific Science and Technology Issues

Surveys have also tracked attitudes to specific science policy issues. Attitudes towards science are not uniform, and instead vary across topics (Allum *et al.*, 2008). A significant amount of public opinion research has focused on the issue of climate change. Canadians are in the middle of the pack internationally in their views on climate change. Recent polling data collected by the Pew Global Attitudes Project suggest that Canadians and Europeans have comparable levels of concern about the degree to which climate change is a serious threat, while concern is significantly lower in the United States (Pew Research Center, 2013) (see Figure 4.8).

Public attitudes towards biotechnology are also regularly examined in many jurisdictions (EC, 2006; NSB, 2012). Canadian attitudes towards biotechnology have become increasingly positive since 2000. In 2000 only about one-half of the population was supportive of the use of biotechnology. By 2011, support had risen to 70% (Harris/Decima, n.d.) (see Figure 4.9). Data gathered between 1996 and 2005 show that Canadian optimism about the contribution of biotechnology is consistent with the U.S. level and greater than the European level (Gaskell *et al.*, 2005).



Data Source: Pew Research Center (2013)

Figure 4.8

Percentage Identifying Climate Change as a Major Threat to Their Country

The figure indicates the percentage of the population (or the median percentage of the population by region) that believes climate change is a major threat to their country. At 54%, the share of the Canadian population that agrees with this statement equals the world average. Canadian results are accurate +/- 5.2% 19 times out of 20.

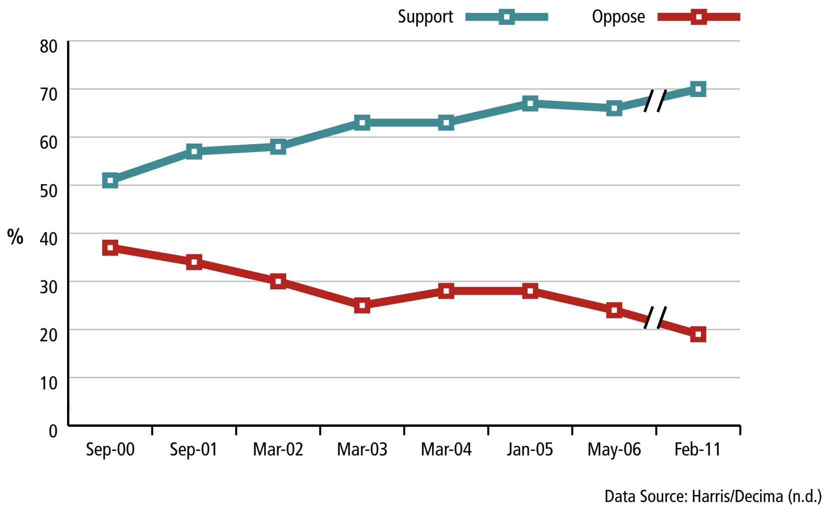
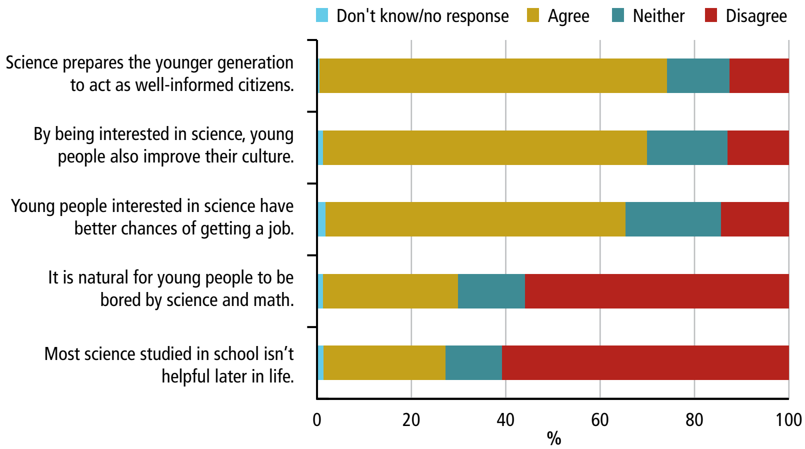


Figure 4.9

Canadian Support for Biotechnology, 2000–2011

Canadian support for the use of biotechnology has gradually increased over the past decade, rising from roughly 50% in 2000 to 70% in 2011. The figure shows the percentage of respondents who support or oppose "the use of products and processes that involve biotechnology."

The Panel's survey also explored the attitudes of Canadian adults about the importance of science interest and learning among youth, with 71% saying they would recommend a career in science to their child or a young relative. The majority of respondents see multiple benefits of science learning and engagement, and reject the idea that science studied in school is boring and unhelpful later in life (see Figure 4.10). Canadians' attitudes about the extent to which science helps to improve employment prospects, prepare well-informed citizens, and improve culture are broadly comparable to those in European countries (EC-DGR, 2010). For example, 70% of Europeans and 68% of Canadians agree that young people improve their culture by being interested in science. Canadians, however, are somewhat more likely to indicate that young people interested in science have a better chance of getting a job, with 63% of Canadians agreeing with this statement compared with 51% of Europeans.



Data Source: Panel survey data

Figure 4.10

Canadian Attitudes Towards Youth Science Engagement and Learning, 2013

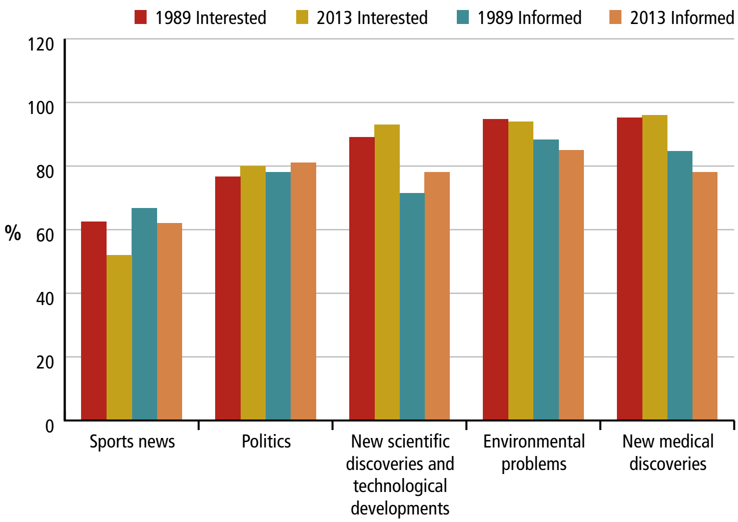
Canadians generally agree that science improves the ability of youth to participate as citizens, contributes to improving culture, and improves employment prospects. Canadians disagree that youth are naturally bored by math and science and that science learned in school will not be helpful in life. The agree responses reported in the figure are an aggregation of "totally agree" and "tend to agree" responses and the disagree responses are an aggregation of "tend to disagree" and "totally disagree." Results are accurate to ± 2.2% 19 times out of 20.

4.3 PUBLIC SCIENCE ENGAGEMENT

Canadians engage in scientific activities and seek out information about science and technology in a variety of ways. While all Canadian youth engage with science through schooling, many also engage in non-mandatory science activities throughout their lives. This section explores science interest and engagement of Canadian youth and adults, based on data from the Panel's survey and other youth-focused surveys conducted in recent years.

4.3.1 Public Interest in Science and Technology

A high proportion of Canadians report an interest in science and technology compared with interest in other topics such as sports news and politics. Interest tends to exceed self-assessed "informedness" about science issues, suggesting an appetite for more information about science (see Figure 4.11). These patterns have remained fairly stable from 1989 to 2013.



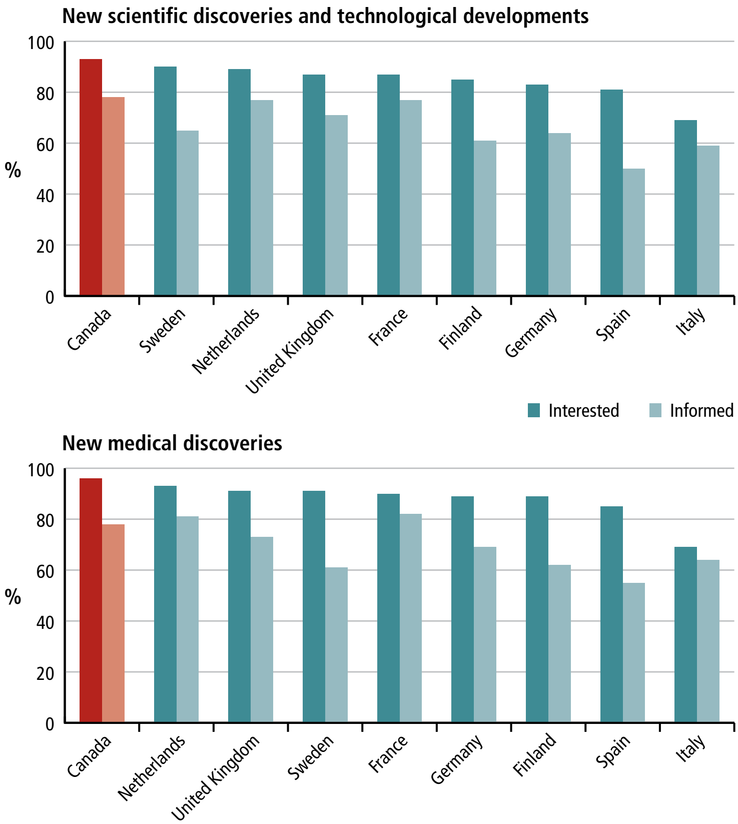
Data Source: Panel survey data and Einsiedel (1990)

Figure 4.11

Canadian Science Interest Over Time, 1989 and 2013

Canadians report high levels of interest in new scientific discoveries, and these patterns are stable over time. The 1989 survey used slightly different language for some topics, asking about "sports," "politics," "stories about new scientific discoveries," "stories on the environment," and "stories on medicine and health." Results include both "very interested" and "moderately interested" responses, and "well informed" and "moderately well informed" responses. Results are accurate to ± 2.2% 19 times out of 20.

Similar patterns are found in other countries. Public interest in scientific discoveries and technological developments, and medical discoveries, often exceeds interest in sports, culture and arts, and politics. However, individuals are less apt to describe themselves as well informed when it comes to developments in science and technology (Miller *et al.*, 1997; EC-DGR, 2010). Figure 4.12 compares Canadian levels of interest and informedness with those of several European countries. In this group, Canadians report the highest levels of interest in new scientific discoveries and technological developments, and new medical discoveries. Canadian levels of self-reported informedness are also relatively high by international standards.



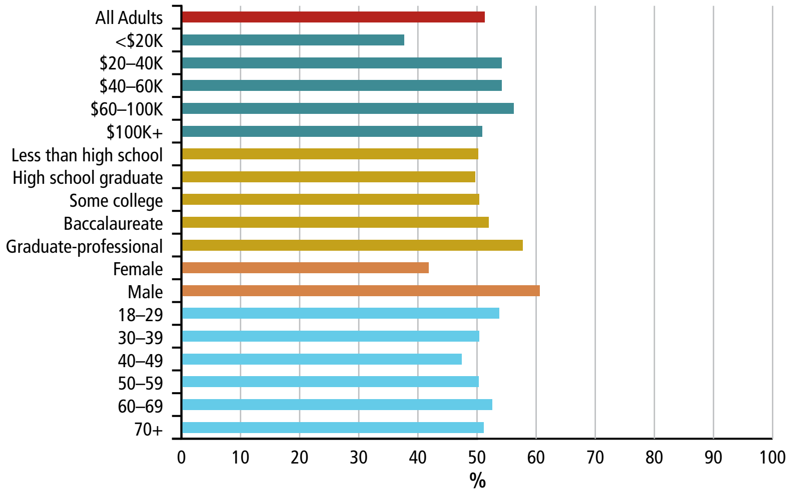
Data Source: Panel survey data and EC–DGR (2010)

Figure 4.12

Public Interest in Science by Country

Canadians tend to express higher levels of interest and self-assessed informedness in science than citizens of selected European countries. Results include both "very interested" and "moderately interested" responses, and "well informed" (or "very well informed" in the case of the European data) and "moderately well informed" responses. Canadian data were collected in 2013 while European data were collected in 2010. Canadian results are accurate to ± 2.2% 19 times out of 20. Accuracy of results varies across countries but in all instances surveys included a minimum of 1,000 respondents. Additional details are available in Appendix C.

Within Canada, interest in science varies by demographic group (see Figure 4.13). The greatest difference is between men and women: approximately 60% of men, but only 40% of women, say they are very interested in new scientific discoveries and technological developments. Interest levels are generally higher among younger respondents, more educated respondents, and higher income respondents, although not all of the differences are statistically significant. The same demographic patterns do not hold for interest in new medical discoveries or environmental issues.



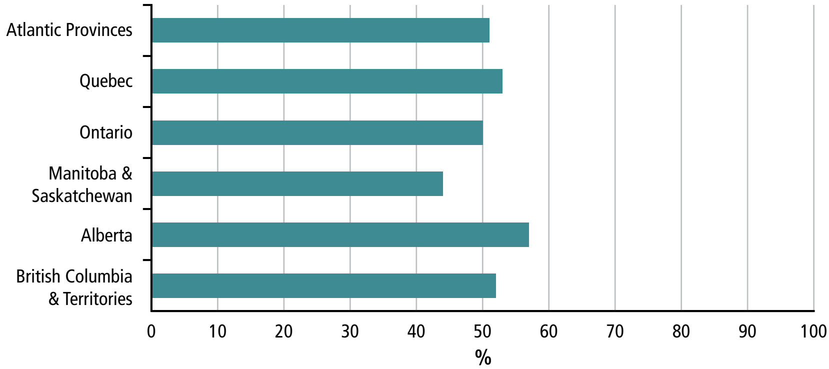
Data Source: Panel survey data

Figure 4.13

Canadian Interest in Science by Demographic Group

The figure shows the percentage of respondents by demographic group who report being "very interested" in new scientific discoveries and technological developments. Men are more likely than women to say that they are very interested in new scientific discoveries and technological developments. More educated respondents and higher income respondents are also more likely to report that they are very interested in scientific discoveries and technological developments.

Interest in science also varies regionally across Canada. Respondents in Alberta are most likely to say they are very interested in new scientific discoveries and technological developments, while respondents in Manitoba and Saskatchewan are the least likely (see Figure 4.14).



Data Source: Panel survey data

Figure 4.14

Canadian Interest in Science by Region

The figure shows the percentage of respondents by region who report being "very interested" in new scientific discoveries and technological developments. Interest in new scientific discoveries and technological developments varies slightly across regions in Canada. People in Alberta are the most likely to say they are very interested in new scientific discoveries and technological developments while people in Manitoba and Saskatchewan are the least likely to report this interest. The accuracy of results varies between ± 3.8% and ±7.4% 19 times out of 20 (see Table 4.1 for details).

Interest in science is particularly important among youth as this is when choices about education shape career trajectories and a greater science interest can maintain or strengthen the volume and quality of students training for science careers. While the Panel's survey assessed the adult population, Box 4.2 uses other sources to explore the attitudes of Canadian youth towards science learning and interest in science careers, including demographic factors that contribute to science interest.

4.3.2 Information Sources

Canadians have an expanding range of choices for where to get science information. At least 4 in 10 Canadians access news on the internet and television every day, while fewer than 2 in 10 do so through a newspaper. About 8 in 10 survey respondents report having spoken to friends, family, or colleagues about a science and technology issue in the news, or watched science programming on TV in the last three months. A further 7 in 10 have read a science-related newspaper article, while 6 in 10 have read an article in a science magazine or watched an online video. Eight in ten respondents have used the internet to get weather and health and medical information in the past three months. This growing use of the internet to respond to informational needs marks a stark generational change in science-related behaviours. Leading factors that drive adults to seek science information online include health issues, occupational requirements, having young children at home, and emerging public policy issues (Miller, 2012).

4.3.3 Other Forms of Science Engagement

More and more Canadians are visiting a range of cultural institutions, including science and technology museums and natural history museums. As demonstrated in Figure 4.15, over 30% of Canadians report having visited these two types of museums at least once in the past year.[12] Unsurprisingly, people in close proximity to various types of institutions and those with children under age 18 are most likely to make use of these institutions: 41% of respondents with children under age 18 living at home have visited a science or technology museum at least once in the last year compared with only 28% of respondents without children at home. In urban areas 34% of respondents have visited a science or technology museum at least once in the last year compared with only 21% of respondents in rural areas.

12 The Panel noted that these survey results suggest higher attendance levels for science centres than the annual numbers reported by the Canadian Association of Science Centres (CASC, 2011). Several factors could explain this discrepancy. In a public survey, respondents may include institutions not formally recognized as a science centre or museum. In addition, respondents may be reporting visits that took place outside of Canada. Figures generated by museums may also in some cases exclude unpaid admissions or visits to special events.

Box 4.2
Exploring Science Interest Among Canadian Youth

Two recent Canadian surveys provide insights on science interest among youth. First, a 2012 report on science learning by Amgen Inc. and Let's Talk Science includes results from a survey of 500 students between the ages of 16 and 18. The survey assesses views on science education; on the extent to which students see science learning as important for life, for career choices, and for future incomes; and on plans to pursue science education and/or reasons for not pursuing science learning (Amgen Canada Inc. & Let's Talk Science, 2012). Second, in 2010 Ipsos Reid issued the Canadian Youth Science Monitor based on an online survey of 2,605 youth between the ages of 12 and 18 (Ipsos Reid, 2010b). Respondents were surveyed on their understanding of the term *science*, science knowledge, level of interest in science, plans to pursue science-related careers, and engagement in science activities outside of the classroom (Ipsos Reid, 2010b).

Overall, 68% of Canadian youth report being somewhat or very interested in science (Ipsos Reid, 2010a). An analysis of the Ipsos Reid survey results reveals that perceptions of science as "fun, cool, inspiring, interesting, boring or important" determine science interest, but perceptions of science as difficult or complicated do not necessarily deter interest. Among youth, learning about how things work and enjoying experiments, building things, and undertaking hands-on activities are identified as explanations of why students find science interesting (Ipsos Reid, 2010b). Students do not identify parents and teachers as playing a leading role in shaping interest (Ipsos Reid, 2010a), but a U.S. analysis suggests that parental encouragement to attend university and study science and mathematics is correlated with a higher likelihood of being employed in a STEM field (Miller & Kimmel, 2012). A recent study of over 600 youth mostly in Grade 7 conducted in the Maritime provinces shows that the people who influence youth the most are their families. Interestingly, girls are more likely than boys to report the media as an influencer of their future career choice (Franz-Odendaal *et al.*, 2014).

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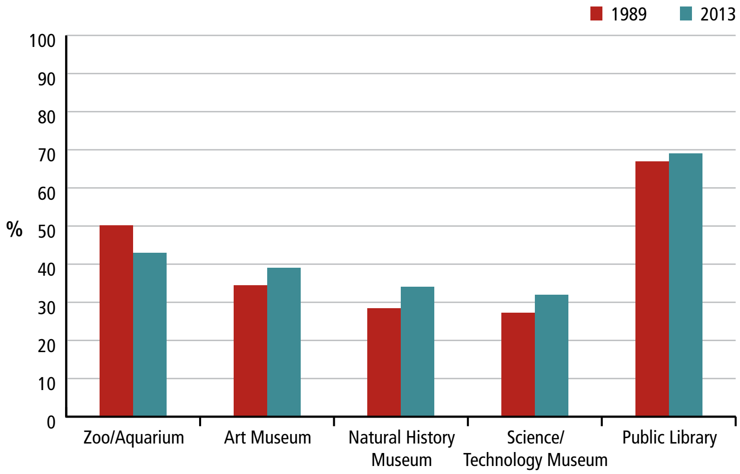
While 82% of Canadian youth aged 16–18 recognize that science studies can open up career options, only 25% have a lot of interest, and 38% have some interest, in taking post-secondary science courses (Amgen Canada Inc. & Let's Talk Science, 2012). Among Canadian students who choose to take none or one science course in high school, 47% explain this is because additional courses are not a requirement for graduation, 27% are not interested, and 14% already feel sufficiently informed (Amgen Canada Inc. & Let's Talk Science, 2012).

Survey data demonstrate that interest is shaped by many demographic factors including age, gender, and family background. Younger Canadian respondents are more likely to think grades are important and have positive attitudes about school (Ipsos Reid, 2010b). Survey data from Canada have found that interest in science declines with age. Of youth aged 12–13, 78% report being very or somewhat interested in science. This declines to 67% of 14- to 16-year-olds, and 58% of 17- to 18-year-olds. When prompted, 52% of youth say science is difficult while 22% say science is boring. These perceptions both rise with age among youth.

Gender is also an important factor. Girls are more likely to think grades are important and have positive attitudes about school, but their interest in science tends to fall faster than that of boys. Socio-economic circumstances also shape science interest among youth. Youth interest in science is lower in households where "parents have lower levels of education and income." Cultural background also matters. Youth born outside of Canada are more likely to enjoy "learning new things," and report "that they try their best to succeed and their friends would say they are smart." Science interest is higher for non-Caucasians (Ipsos Reid, 2010b).

Benchmarking Canadian youth against youth in other countries is problematic due to a lack of comparable survey data. One exception is a 2009 Wellcome Trust survey of youth in the United Kingdom, which inspired the Canadian Youth Science Monitor. Compared with U.K. youth, the interest of Canadian youth in science classes and in pursuing a scientific career is lower, and fewer Canadian youth think that science would be a good career option. Other results from these surveys are consistent across both countries: girls display lower levels of interest than boys, and interest levels taper off as students grow older (Ipsos Reid, 2010b).

Relative to respondents in other countries, Canadians are among the most likely to visit science and technology museums and natural history museums. Figure 4.16 shows the proportion of respondents by country who have visited a science or technology museum at least once in the last year.

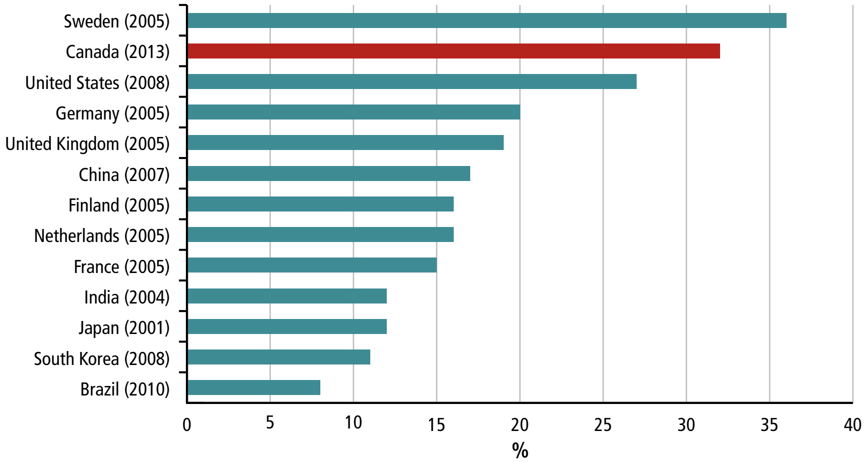


Data Source: Panel survey data and Einsiedel (1990)

Figure 4.15

Canadian Attendance at Selected Cultural Institutions, 1989 and 2013

The figure shows the percentage of Canadians who report having visited various cultural institutions in the previous year. While zoo visitation has declined somewhat, the share of Canadians visiting natural history and science and technology museums has increased since 1989. Results are accurate to ± 2.2% 19 times out of 20.



Data Source: Panel survey data, EC (2005), and NSB (2012)

Figure 4.16

Public Attendance at Science and Technology Museums by Country

The figure shows the percentage of respondents that report having visited a science and technology museum at least once in the previous year. Canadians are more likely to visit these museums than citizens of most other countries. In South Korea respondents were only asked about "science museums"; in India they were asked about "science parks"; and in the EU they were asked about "science museums or technology museums or science centres." Canadian results are accurate to ± 2.2% 19 times out of 20. Accuracy of results varies across countries but in all instances surveys included a minimum of 1,000 respondents. Additional details are available in Appendix C.

When asked about involvement in other science-related activities, 34% of Canadians report regularly or occasionally participating in a science and technology related hobby or interest. Relative to citizens of comparator countries in Europe, Canadians are more likely to sign petitions or join street demonstrations, attend public meetings or debates, or participate in the activities of a non-governmental organization (NGO) on issues related to science and technology. They are among the most likely to regularly or occasionally donate to medical research campaigns (see Figure 4.17).

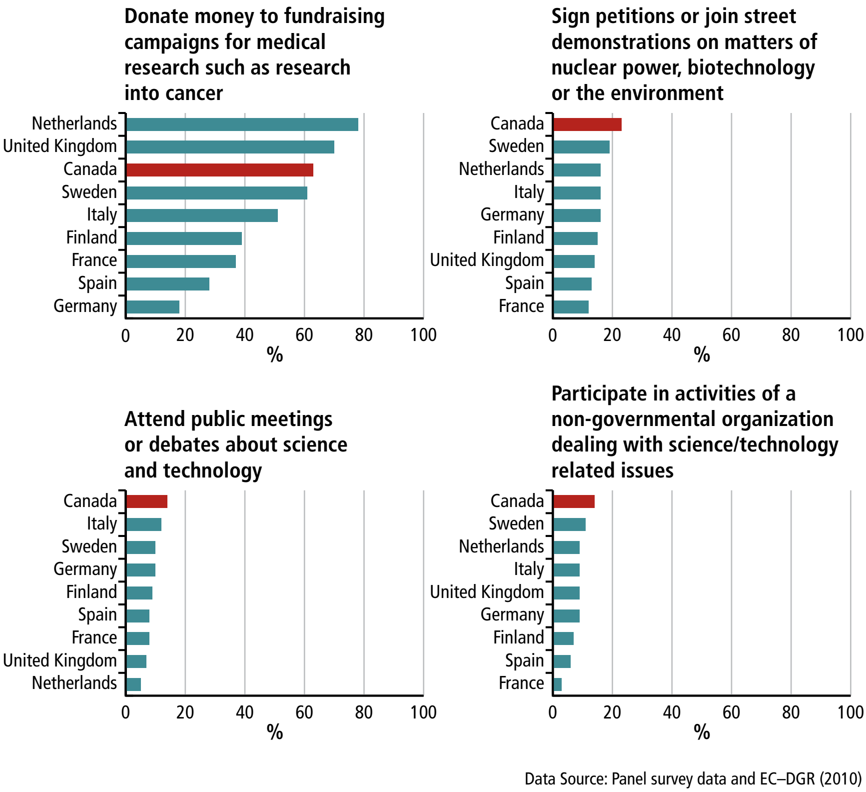


Figure 4.17

Public Engagement with Science and Technology by Country

Canadians are more likely to sign petitions, join demonstrations, attend public meetings and debates, and participate in activities of an NGO related to science and technology issues than those in many countries. Results include those who engage in each activity "regularly" and "occasionally." Canadian data were collected in 2013 while European data were collected in 2010. Canadian results are accurate to ± 2.2% 19 times out of 20. Accuracy of results varies across countries but in all instances surveys included a minimum of 1,000 respondents. Additional details are available in Appendix C.

4.4 PUBLIC SCIENCE KNOWLEDGE

Public knowledge or understanding of science can be defined and assessed in many ways. Box 4.3 presents a selection of definitions of science literacy, all of which may lead to different strategies for assessment. Attempts to gauge public knowledge or understanding of science typically recognize the relevance of both knowledge of scientific facts or concepts and knowledge of scientific processes and methods (Durant, 1994; OECD, 2003; Miller, 2010c). Student assessments can be used to evaluate levels of scientific knowledge and understanding among youth; however, a set of standardized survey-based measures have been used in many countries to assess patterns of public science knowledge and understanding in the adult population.

Box 4.3
Defining Science Literacy

A review of literature on science literacy notes that a wide range of "different interpretations result in scientific literacy appearing to be an ill-defined and diffuse — and thus controversial — concept" (Laugksch, 2000). The U.S. National Research Council views scientific literacy as the knowledge and understanding that is necessary for decision-making, civic and cultural engagement, and economic development:

> Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately (NRC, 1996).

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The OECD (2006) Programme for International Student Assessment (PISA) defines science literacy as:

> an individual's scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues, understanding of the characteristic features of science as a form of human knowledge and enquiry, awareness of how science and technology shape our material, intellectual, and cultural environments, and willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen.

In its *Science for All Americans* report, the American Association for the Advancement of Science defines a scientifically literate person as:

> one who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes (AAAS, 1989).

The Panel's assessment of science knowledge in the Canadian public follows the approach established by Miller (1998) for measuring "civic science literacy." According to this methodology, for a citizen to be scientifically literate, they need to have both (i) "a basic vocabulary of scientific terms and constructs," and (ii) "a general understanding of the nature of scientific inquiry" (Miller, 2004). This approach relies on both quiz-style factual knowledge questions and selected open-ended questions that assess whether respondents understand basic biological and physical scientific constructs and the scientific process. A set of survey questions associated with the methodology was designed to remain relevant over time, and these questions have now been employed in surveys of science knowledge in many countries including the United States, EU countries, Japan, and China (Miller, 1998). The questions are intended to test a minimum proficiency required to make sense of and participate in science in society, or, as Miller suggests, to understand *The New York Times* Science section both today and 20 years into the future (Miller, 2012).

Survey-based measures provide only one method of assessing knowledge of science in the public. While providing valuable insights on science knowledge (or "civic science literacy"), other aspects of science literacy are excluded from this approach. For instance, in the context of an assessment of science culture, it would be helpful to assess the extent to which the population applies a scientific way of thinking to various aspects of life. The Panel, however, did not identify an evidence base that could support such a discussion in relation to the adult population. In addition, the Panel's approach assesses knowledge based on expert-defined criteria of what people should know (Brossard & Shanahan, 2006), and focuses on the type of knowledge taught in the classroom. An alternative approach to measuring understanding of science terms focuses on terms commonly used in the media rather than the key terms that experts perceive as the most important. Scientific understanding, as measured by this approach, was positively correlated with results of the civic science literacy test. The authors argue that their "measure has the crucial advantage of representing a societal view of what is important about science at certain points in time" (Brossard & Shanahan, 2006).

However, for assessing adult science knowledge in the general population, the approach adopted by the Panel has two principal advantages. First, since many of these same survey questions were used in Canada in 1989, trends over time can be documented. Second, the approach has been widely used internationally, and a large body of data is available to benchmark Canadian performance. No alternative approach would allow for extensive international comparisons. In line with previous surveys, the Panel relied on a set of 14 factual true or false questions and 3 open-ended questions to assess the general level of science knowledge in the Canadian public.

4.4.1 Canadian Science Knowledge

Data from the Panel's survey are consistent with patterns in other countries, revealing that a large segment of the Canadian population often incorrectly answers questions about basic scientific facts or concepts. However, the data also indicate that public science knowledge in Canada is relatively high by international standards and has increased since 1989.

Despite some differences in the suite of questions used in the Panel's 2013 survey and the 1989 Canadian survey, seven questions were used in both surveys. Figure 4.18 shows Canadian performance over time, revealing an improvement in science knowledge during this period for each of the questions. This pattern may in part be explained by a rise in educational attainment of Canadians over time.

Internationally, Canadians compare well by these measures, on a par with some of the best-performing European countries (e.g., Finland, Sweden). Table 4.3 shows the share of correct responses to 11 survey questions of this type that have been repeated in many jurisdictions. Note that Canadian data are more recent, and it is possible that scores in other countries may have improved in the years since the survey was fielded.

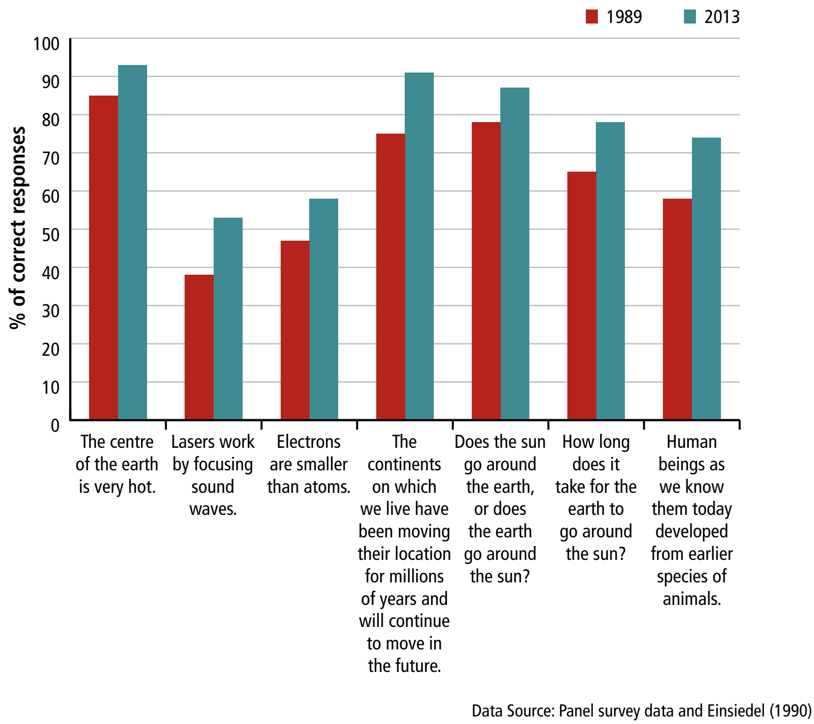

Figure 4.18

Canadian Science Knowledge Over Time, 1989 and 2013

Canadian science knowledge in the adult population has improved since 1989 across a range of factual knowledge questions. Results from the Panel's 2013 survey aggregate "definitely true" and "probably true" responses and aggregate "definitely false" and "probably false" responses. Results are accurate to ± 2.2% 19 times out of 20.

Table 4.3

Comparing Public Science Knowledge Across Countries

Question	United States (2010)	South Korea (2004)	Japan (2001)	India (2004)	China (2007)	Russia (2003)	Germany (2005)	France (2005)	Netherlands (2005)	Finland (2005)	Sweden (2005)	United Kingdom (2005)	Canada (2013)
	% of correct responses												
Physical science													
The centre of the earth is very hot. (True)	84	87	77	57	49	NA	94	88	90	89	94	88	**93**
The continents have been moving their location for millions of years and will continue to move. (True)	80	87	83	32	44	40	93	93	94	92	94	93	**91**
Does the earth go around the sun, or does the sun go around the earth? (earth around sun)	73	86	NA	70	78	NA	69	58	68	73	76	56	**87**
All radioactivity is man-made. (False)	67	48	56	NA	40	35	69	58	70	78	80	67	**72**
Electrons are smaller than atoms. (True)	51	46	30	30	22	44	42	49	43	48	49	43	**58**
Lasers work by focusing sound waves. (False)	47	31	28	NA	20	24	46	50	58	52	67	54	**53**
The universe began with a huge explosion. (True)	38	67	63	34	22	35	NA	NA	NA	NA	NA	NA	**68**

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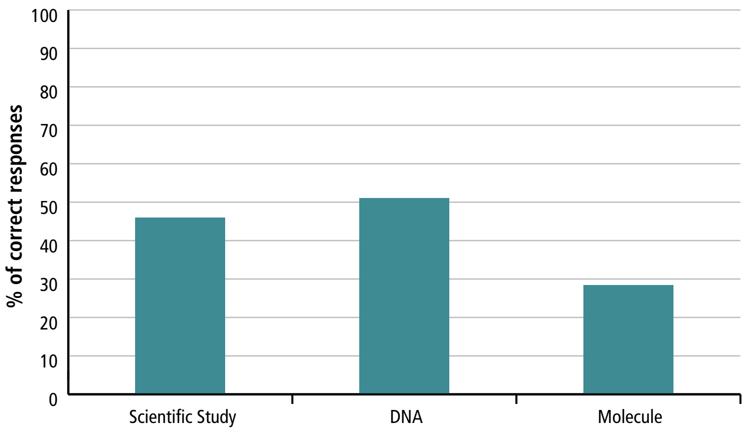
Question	United States (2010)	South Korea (2004)	Japan (2001)	India (2004)	China (2007)	Russia (2003)	Germany (2005)	France (2005)	Netherlands (2005)	Finland (2005)	Sweden (2005)	United Kingdom (2005)	Canada (2013)
	% of correct responses												
Biological science													
The cloning of living things produces genetically identical copies. (True)	80	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**77**
Ordinary tomatoes do not contain genes, while genetically modified tomatoes do.(False)	47	NA	NA	NA	NA	22	NA	NA	NA	NA	NA	NA	**59**
Antibiotics kill viruses as well as bacteria. (False)	50	30	23	39	21	18	45	59	69	77	78	53	**53**
Human beings, as we know them today, developed from earlier species of animals. (True)	47	64	78	56	69	44	69	80	68	66	82	79	**74**

Data Source: Panel survey data, EC (2005), and NSB (2012)

Canadian performance on science knowledge questions relative to international peers is strong overall and on a par with some of the leading European countries. *International comparisons of survey data from different years should be undertaken with caution given that science knowledge levels have gradually improved in most countries over time*. The Russian survey used the statement: "Ordinary plants do not contain genes, while genetically modified plants do." Results from the Panel's 2013 survey aggregate both "definitely true" and "probably true" responses and aggregate "definitely false" and "probably false" responses. The numbers shown in the table indicate the percentage of correct responses.

In addition to these true or false questions, three open-ended questions were included in the Panel's survey, asking respondents to explain in their own words what it means to study something scientifically and to describe their understanding of the terms "DNA" and "molecule" (see Figure 4.19). These questions were coded using a standardized protocol developed for other international surveys (see Appendix B). An analysis of the results reveals that approximately 51% of respondents have a general understanding of the term "DNA" (i.e., their response indicates an understanding of DNA as the basis of inheritance and the constituent material in genes or chromosomes), while 28% understand the term "molecule" (i.e., their response indicates an understanding that molecules are combinations of atoms). Assessing knowledge and understanding of the scientific process is more complicated given the range of study types and methodologies; however, 46% of Canadians are able to articulate one or more of the features of a scientific study such as the formulation and testing of hypotheses, the conducting of experiments, the use of control groups, systematic data collection and analysis.



Data Source: Panel survey data

Figure 4.19

Canadian Understanding of Key Scientific Concepts

As part of the Panel's survey, respondents were asked to explain, in their own words, their understanding of several key scientific terms and concepts. Responses to these questions were coded based on a protocol that has been applied to these questions in other international surveys (see Appendix B). Results are accurate to ± 2.2% 19 times out of 20.

4.4.2 Civic Science Literacy Index

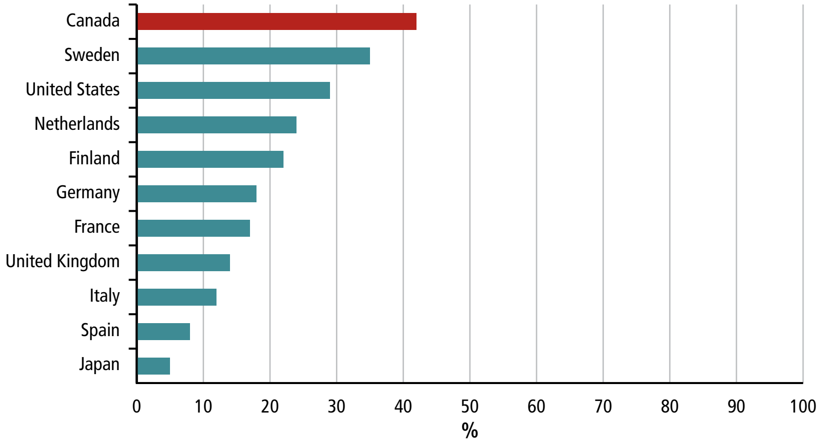
To consider overall levels of science knowledge and explore demographic differences, the Panel used an index based on a combination of 15 survey questions, including the 3 open-ended questions assessing Canadian's knowledge of key scientific constructs.[13] The development of the index relies on a statistical method called "itemized response theory," which pulls together multiple closed and open-ended questions to offer a total score for each respondent on a scale of 0 to 100. By factoring in a guessing component, and distinguishing between difficulty levels of questions and the extent to which the question differentiates respondents with higher and lower levels of scientific knowledge, this methodology provides a more informed picture of overall scientific knowledge than a simple sum of correct responses. In addition, as the methodology does not require each data set to ask all of the exact same questions in order to compare results, new questions can be introduced over time and the method can also accommodate variation across data sets gathered in different countries. The method therefore allows for international comparisons as it has been used to develop such indices for several international data sets. This index has been calculated and reported for other countries based on analogous survey data (Miller, 2012).

The mean score on this index for Canadians was 69/100. While any threshold on the index is arbitrary to an extent, past research using this methodology (e.g., Miller, 2012) has found that the division between respondents with a score of 70 or higher and those with a score of less than 70 is a useful device for highlighting the attainment of a level of science knowledge that generally corresponds to the ability of an adult to read high-quality science journalism such as that published in *The New York Times*. By this definition, approximately 42% of Canadian adults qualify as scientifically literate.[14] Consistent with the comparisons of individual questions reported earlier, this is a relatively high level of performance compared with that of other countries, with the next highest score, of 35%, in Sweden (see Figure 4.20).

13 Two factual science knowledge questions included in the Canadian survey were not used in the construction of this index. One question related to global warming was excluded due to low correlation with other items in the survey, and one question on the cloning of living things was excluded because it had not been used in any other surveys. The index also groups two questions about the earth orbiting around the sun into one question.

14 The Panel's analysis uses the term *science knowledge* preferentially but characterizes the population scoring above 70 on this index as *scientifically literate* for consistency with Miller's approach.

However, once again these data may not provide a complete picture of how two countries compare today because the European data were collected in 2005, eight years prior to those in the Canadian survey. Losh (2012) observed a general increase in science knowledge in the United States between 1979 and 2006, and the National Science Board (2012) noted an improvement in European performance between 1992 and 2005. Other countries therefore would likely see improvements in their scores on this index if survey data were collected again. However, citizens of all countries show considerable room for improvement on this index. Despite Canada's strong performance internationally, this analysis suggests that over half of Canadians likely lack the level of knowledge of scientific concepts and processes necessary to grasp much of the coverage of science and technology issues in the media.



Data Source: Panel survey data and Miller (2012)

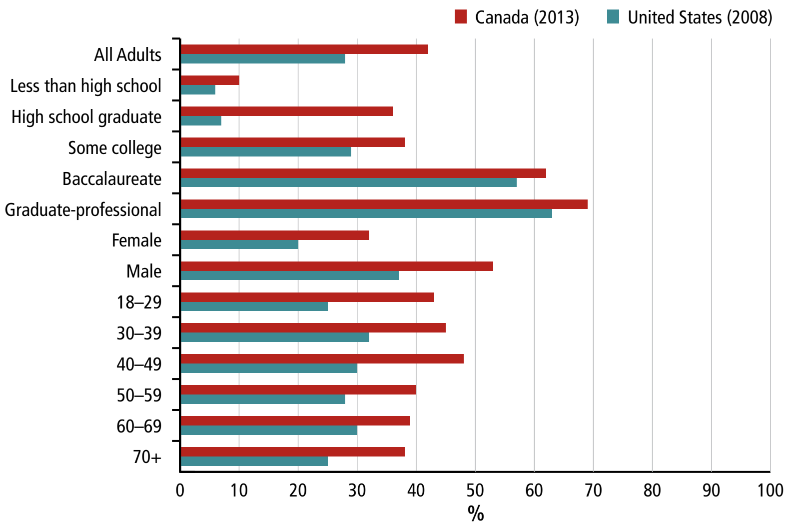
Figure 4.20

Civic Science Literacy by Country

The figure shows the percentage of respondents who qualify as scientifically literate as defined by achieving a score of 70 or above on the civic science literacy index. Forty-two per cent of Canadians are scientifically literate based on this measure. Past studies have found that this level is roughly equivalent to the knowledge needed to understand science articles such as those reported in *The New York Times* (Miller, 2012). Canada's performance is higher than that of any comparator countries for which data exist. *However, data from other countries were collected in earlier years, and performance may have improved in those countries in the meantime*. European data are from 2005, U.S. data are from 2008, and Japanese data are from 2001. Accuracy of results varies across countries but in all instances surveys included a minimum of 1,000 respondents. Additional details on international surveys are available in Appendix C.

4.4.3 Demographic and Regional Variation in Science Knowledge

As shown in Figure 4.21, gender and educational attainment are both important predictors for science knowledge. Only 32% of women in Canada, compared with 53% of men, meet the threshold for science literacy based on the science literacy index. The lower participation of women relative to men in natural science and engineering degrees may account for some of this disparity (see Section 4.5). Similarly, 69% of respondents with graduate degrees are scientifically literate compared with 10% of those with less than a high school education. Science knowledge is highest among Canadians aged 40–49 and somewhat lower among older Canadians (see Figure 4.21). These same patterns exist in the United States, although the performance on this index is consistently higher for each group in Canada.



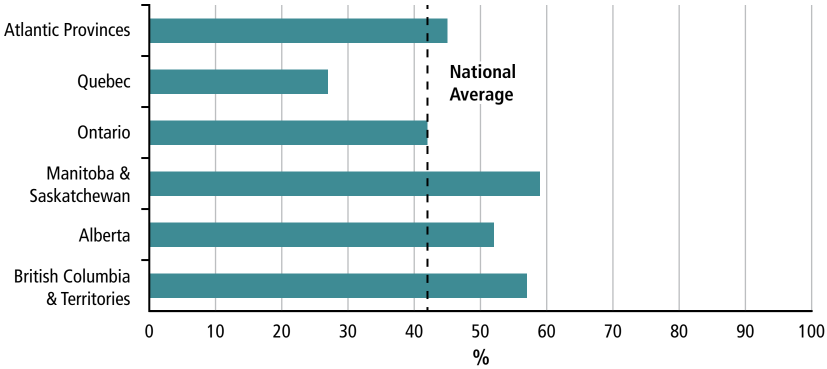
Data Source: Panel survey data

Figure 4.21

Civic Science Literacy by Demographic Group, Canada and United States

The figure shows the percentage of respondents who qualify as scientifically literate by demographic group. Canadians with higher levels of education are more likely to exhibit higher levels of science literacy than those with less education. Men have higher rates of scientific literacy than women. Older adults exhibit lower levels of scientific literacy. U.S. data exhibit the same trends, though the impact of post-secondary education is more pronounced in the United States and science literacy rates are lower across all groups. Since Canadian data were collected in 2013 and U.S. data were collected in 2008, U.S. science knowledge may have improved since the data were collected.

Science knowledge also varies regionally across Canada (see Figure 4.22). Respondents in Quebec score below the national average: only 26% achieve the benchmark level of scientific literacy by this measure. The Western provinces perform above the national average, while Ontario is in the middle. While the explanation for Quebec's comparatively lower science literacy levels is unclear to the Panel, these results are consistent with earlier surveys of public science knowledge in Canada and Quebec. The 1989 national survey of science culture in Canada also found lower levels of knowledge in Quebec relative to other provinces (Einsiedel, 1990). A 2002 survey of the Quebec population included seven of the same questions (CST, 2002a). Based on comparison with these data, science knowledge in the province has improved over the past decade, with the share of respondents offering correct responses increasing in six of the seven questions repeated in both surveys.



Data Source: Panel survey data

Figure 4.22

Canadian Civic Science Literacy by Region

The figure shows the percentage of respondents who qualify as scientifically literate by region. Western provinces exhibit higher levels of science literacy than Ontario and Quebec. Quebec's performance is lower than the national average, with 27% of respondents meeting the threshold for science literacy compared with a national average of 42%. For these comparisons, region-specific weights were employed to ensure that the samples were representative at the regional level.

4.4.4 Student Assessments of Science and Mathematics Knowledge

International student assessments of science and mathematics learning provide another window into the development of science literacy in Canada. The OECD's PISA assesses the science knowledge of 15-year-old students in 65 countries and regions (not only in the OECD). PISA's science testing evaluates scientific literacy based on the following four components:

> scientific contexts (i.e., life situations involving science and technology); the scientific competencies (i.e., identifying scientific issues, explaining phenomena scientifically, and using scientific evidence); the domains of scientific knowledge (i.e., students' understanding of scientific concepts as well as their understanding of the nature of science); and student attitudes toward science (i.e., interest in science, support for scientific inquiry, and responsibility toward resources and environments).
>
> (Bybee *et al.*, 2009)

Canadian students perform well in PISA, with relatively high scores on all three of the major components of the assessment (reading, science, and mathematics) compared with students in other countries (Table 4.4). In 2012 only seven countries or regions had mean scores on the science assessment higher than Canada on a statistically significant basis: Shanghai–China, Hong Kong–China, Singapore, Japan, Finland, Estonia, and Korea (Brochu *et al.*, 2013). A similar pattern holds for mathematics scores, where nine countries had mean scores higher than Canada on a statistically significant basis: Shanghai–China, Singapore, Hong Kong–China, Chinese Taipei, Korea, Macao–China, Japan, Lichtenstein, and Switzerland (Brochu *et al.*, 2013). Regions scoring higher than Canada are concentrated in East Asia, and tend to be densely populated, urban areas. Among G8 countries, Canada ranks second on mean science and mathematics scores, behind Japan.

Table 4.4

PISA Science and Mathematics Scores for Canada, 2003–2012

	2003 PISA Test		2006 PISA Test		2009 PISA Test		2012 PISA Test	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Canada's mean score on OECD PISA math test	532 (500)	7th out of 40 countries and economies	527 (498)	7th out of 57 countries and economies	527 (497)	10th out of 65 countries and economies	518 (494)	13th out of 65 countries and economies
Canada's mean score on OECD PISA science test	519 (499)	11th out of 40 countries and economies	534 (500)	3rd out of 57 countries and economies	529 (501)	8th out of 65 countries and economies	525 (501)	10th out of 65 countries and economies

Data Source: Brochu *et al.* (2013)

Canada performs relatively well in the OECD's PISA tests, which assess scholastic performance in mathematics and science of 15-year-old students in roughly 75 countries (not only in the OECD). Since 2003, Canada has continued to perform above the OECD average in both math and science. In the 2012 survey only 12 of the 65 participating countries/economies did better than Canada in math and only 9 did better in science. However, since 2006, there has been a gradual decline in Canada's mean score and rank in both subjects. OECD mean scores are shown in parentheses.

However, the 2012 PISA results also show statistically significant declines in Canada's scores on both the mathematics and science components. Canada's science score declined by nine points from its peak in 2006 (with a fall in ranking from 3rd to 10th), and the math score declined by 14 points since first assessed in 2003 (a fall from 7th to 13th) (Brochu *et al.*, 2013). Changes in Canada's standing relative to other countries reflect both the addition of new countries or regions over time (i.e., the addition of regions such as Hong Kong–China and Chinese Taipei in 2006, and of Shanghai–China in 2009) and statistically significant declines in mean scores.

PISA scores also vary regionally in Canada. For example, on the science assessment, Alberta and British Columbia students continue to score above the national average, while in mathematics, Quebec students surpass those in the rest of the country on average across all domains of mathematics skill measured (Brochu *et al.*, 2013). All provinces except Quebec and Manitoba had statistically significant declines in math scores. Science scores decreased in Newfoundland and Labrador, Prince Edward Island, Quebec, and Manitoba, but remained stable in the remaining provinces (Brochu *et al.*, 2013).

Another feature of Canada's PISA scores is a relatively high level of equity in their distribution. Both mathematics and science scores in Canada show smaller differences between the average scores of the students at the 90th percentile and those at the 10th percentile than are typical for OECD countries (Brochu *et al.*, 2013). This is notable given that the variation in student performance is often greater in higher performing countries, which does not appear to be the case in Canada. The success of high-performing students in Canada does not appear to be coming at the expense of students at the other end of the spectrum.

Student performance at the high and low ends of the spectrum may also be indicative of different opportunities and challenges. The share of high-performing students is sometimes interpreted as indicative of the body of students most likely (or able) to pursue future education and careers in science and technology, while the lowest performing students may struggle to develop the basic skills required to make use of tomorrow's technologies (Salzman & Lowell, 2008). In this respect, another concerning trend in the Canadian data is that the proportion of students achieving the highest proficiency levels in science (Level 5 or above) declined from 14% in 2006 to 11% in 2012 (OECD, 2014), indicating that a smaller share of Canadian students are achieving the level of proficiency likely required to pursue professional careers in the sciences.

The Trends in International Mathematics and Science Study (TIMSS) also provides insights into youth science knowledge through its assessments of student performance in Grade 4 and Grade 8 across more than 60 countries (Mullis *et al.*, 2009). Not all Canadian provinces participate in this study, but data are available for Alberta, Quebec, and Ontario. These results reinforce the PISA findings, again showing relatively strong performance among Canadian students (Martin *et al.*, 2012; Mullis *et al.*, 2012).

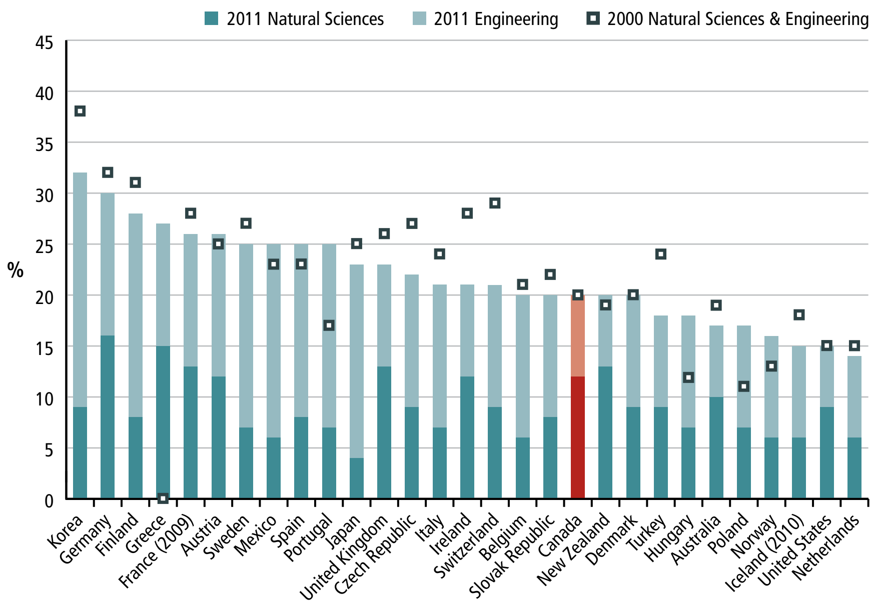
4.5 SCIENCE AND TECHNOLOGY SKILLS

The development of science and technology skills in the population is another dimension of a country's science culture, revealing the extent to which Canadians are engaged in cultivating the ability to work professionally in scientific, information technology, or engineering fields.

On measures of overall post-secondary educational attainment, Canadians consistently perform well compared with citizens of other countries, with Canada ranked first among OECD countries in post-secondary education among 25- to 64-year-olds.[15] However, student participation in degree programs in the sciences and engineering at the university level in Canada is modest relative to other countries. Among graduates from undergraduate programs in Canada in 2011, approximately 20%

15 Post-secondary education includes both college and university education. Canada's high levels of educational attainment are, however, driven primarily by high rates of college graduation. Canada ranks 1st among OECD countries in college education graduates, and 10th in university graduates (OECD, 2012).

of students completed a science or engineering degree (OECD, 2013a) (see Figure 4.23), of which 12% were degrees in the natural sciences and 8% were in engineering. While this rate of student participation in the sciences is consistent with that of many western European countries and the United States, it is substantially lower than that of countries such as Korea and Germany (Figure 4.23) where 30% or more of enrolled university students pursue courses of study in the sciences.[16] The share of degrees granted in engineering in Canada is particularly low by international standards, with only New Zealand, Australia, and the United States showing smaller shares of university students going into engineering. The share of Canadian students pursuing education in these fields has, however, remained stable in Canada over the past decade, while many other advanced economies have experienced declining student graduation rates in these fields of study.



Data Source: OECD (2013a)

Figure 4.23

Natural Science and Engineering Graduates as Percentage of Total Graduates by Country, 2011 and 2000

The figure shows the percentage of university graduates (first degrees) in Canada and other countries granted with degrees in the natural sciences and engineering. In Canada 20% of first degrees were awarded in natural sciences and engineering in 2011, with 8% in engineering.

16 An analysis of STEM graduates on a per capita basis reveals a similar pattern. STEM university graduates represent just over 1% of the 25- to 34-year-old population in Canada, in comparison with an OECD average of nearly 1.5%, leaving Canada ranked 23rd among OECD countries (Finance Canada, 2014).

At the graduate level, Canada's performance is characterized by two divergent patterns. While the share of the Canadian population that graduates from any doctoral program is lower than the OECD average (and substantially lower than in the United Kingdom and the United States) (OECD, 2011b), the share of doctoral students in Canada pursuing degrees in the sciences is high compared with the number in other fields, and significantly exceeds the OECD average. In 2009, 54% of doctoral students in Canada graduated from a science and engineering program,[17] compared with the OECD average of less than 40%. The result is that Canada's overall performance in science and engineering PhD graduates on a per population basis is slightly above the OECD average.[18]

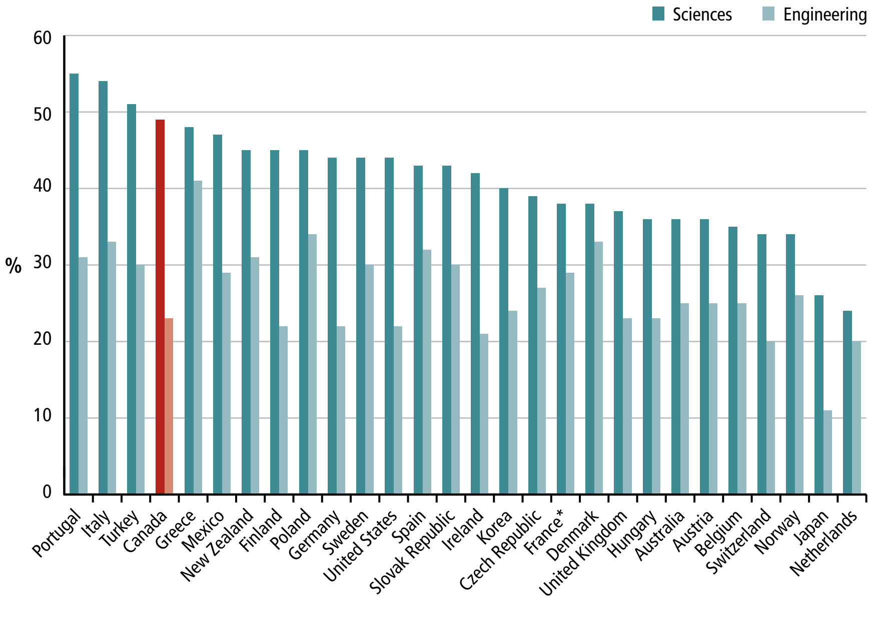
Participation in educational opportunities in the sciences also varies by gender. According to OECD data, 49% of first degrees in the natural sciences in Canada are now granted to women, indicating near gender parity. This level of participation by women is high relative to other countries; only Italy, Portugal, and Turkey report higher shares of female participation in the sciences (see Figure 4.24). However, only 23% of first degrees in engineering in Canada are granted to women.

Similarly, the participation of women in science varies significantly across fields. As shown in Figure 4.25, women now account for the majority of graduating university students in the life sciences. However, the share of women participating in the physical sciences and mathematics is lower, and significantly lower in computer sciences and engineering. Although a high proportion of female students in Canada are pursuing natural science or engineering degrees compared with those in other countries, when Canada's modest overall rate of graduation in natural science and engineering fields is taken into account (Figure 4.23), the result is that the proportion of young women in Canada with natural science and engineering degrees remains low compared with the share in many other countries (NSERC, 2010).

17 This includes life sciences, physical sciences, mathematics, statistics, computing, and engineering.

18 Patterns in student migration complicate the extent to which these figures can be interpreted as an indicator of Canada's domestic base of science skills. For example, 42% of Canadian census respondents with PhDs received their degree outside of Canada; this is the case for 21% of bachelor's degrees (Statistics Canada, 2013e). Similarly, many students enrolled in Canadian post-secondary education institutions are international students: in 2008 international students accounted for 6.6% of bachelor's enrolments and 20.6% of doctoral degrees (McMullen & Elias, 2011). As a result, the location of study (or national origin) is not necessarily a clear indication of where an individual will pursue career opportunities.

At the career level, gender disparity in the sciences becomes even more pronounced. According to the latest data from Statistics Canada, women account for only 22% of total employment in natural and applied sciences and related occupations in Canada (Statistics Canada, 2014b).

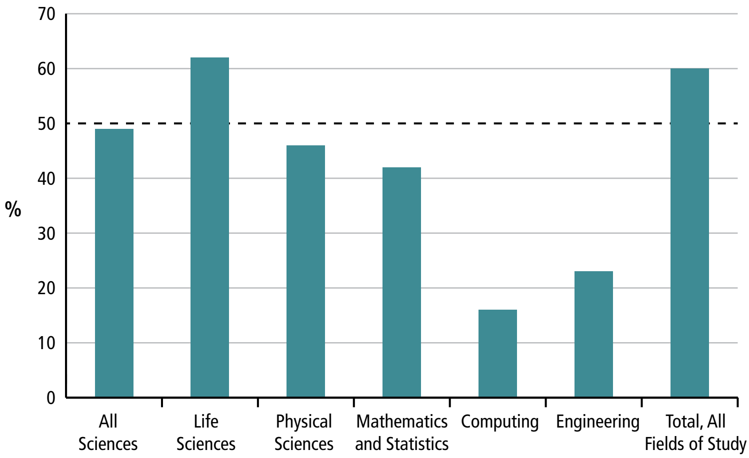


Data Source: OECD (2013a)

Figure 4.24

Percentage of Natural Science and Engineering Degrees Granted to Women by Country, 2011

In Canada women account for 49% of students granted first degrees in the natural sciences and 23% of students granted first degrees in engineering. Canada has a high level of female participation in natural science programs compared with most countries. However, the number of women pursuing engineering degrees is lower and below that of many countries including the United States, United Kingdom, France, and Germany. *Data for France are for 2009.



Data Source: OECD (2013a)

Figure 4.25

Percentage of Science and Engineering Degrees Granted to Women in Canada by Field of Study, 2011

Women receive 60% of all university degrees in Canada and 49% of all degrees in the natural sciences (excluding engineering). In the life sciences, women account for more than half of all degrees granted. However, levels of female participation in fields of study such as computing and engineering are still well below parity. Dashed line indicates gender parity (i.e., 50%).

When interpreting statistics about student participation in the sciences, it is important to note that decisions pertaining to field of study are driven by many factors, including aptitude, personal interest, and perceptions about the nature and extent of career opportunities. As a result, lower or higher levels of student participation may not necessarily be a signal of students' levels of interest in science or scientific pursuits.

Data on employment related to science and technology in Canada, for example, show that approximately 30% of Canadian employees are engaged in work pertaining to science or technology (OECD, 2011a). In comparison, this share is over 35% in countries such as the United States, Finland, Germany, Australia, the Netherlands, and Sweden. Other OECD data show that the proportion of manufacturing workers engaged in science and technology related work is particularly low in Canada (OECD, 2011a; STIC, 2011). While the overall level of student participation in the natural sciences and engineering in Canada is relatively modest compared with many advanced economies, this evidence does not necessarily indicate that the supply of these skills is below that required to meet current demand in Canada.[19]

4.6 THE DETERMINANTS OF SCIENCE KNOWLEDGE AND ATTITUDES

Science culture indicators cannot be neatly aggregated to compare overall performance. Indicators of various dimensions of science culture do not always move together in the direction one would expect. Data gathered for the ROSE (Relevance of Science Education) project indicate that science knowledge often goes hand in hand with low interest levels (Sjoberg & Schreiner, 2010). Knowledge can also be linked closely to science skepticism, with the most knowledgeable individuals likely to be more skeptical (Shukla & Bauer, 2012). Climate change offers one example where the most scientifically knowledgeable are sometimes the most polarized in their views (Kahan *et al.*, 2012). People can be scientifically knowledgeable but also believe that astrology is scientific (Allum & Stoneman, 2012). Boy (2012) has shown that belief in astrology and other "parascientific" phenomena such as telepathy and spiritualism in France are more common in younger, more highly educated generations, and that these beliefs are quite stable over time. Many highly religious people also have positive attitudes about science (Keeter *et al.*, 2012).

At the same time, the dimensions of science culture explored by the Panel do influence one another, often in predictable ways. Structural equation modelling provides one tool to explore how demographic variables and various dimensions of science culture interact (see Appendix D for a more detailed methodological description of this approach). To explore the relationships between these variables, the Panel developed a model that started with demographic variables, and then added the number of university science courses, degree of interest in science and technology issues, science knowledge, informal science resource use, and, finally, science attitudes. The results of the modelling show the extent to which earlier elements of the model influence its later elements.

19 The question of the relative supply and demand of these skills will be taken up in greater detail in an upcoming Council of Canadian Academies study on STEM skills. See www.scienceadvice.ca for more information.

According to this analysis, the number of university science courses does influence public science knowledge in Canada, but the level of interest in science and technology issues does not. The number of university science courses and the level of interest in science and technology issues have both influenced science attitudes: more university courses and more interest led to more belief in the promise of science and fewer reservations about it. Science knowledge has influenced attitudes in the same way: more knowledge led to more belief in the promise of science and fewer reservations. This last effect was one of the most pronounced, suggesting that one of the key effects of increasing public knowledge and understanding of science is a reduction in reservations about science of the kind measured by these survey questions.

In this model, use of informal science resources was not found to influence attitudes towards science and technology in Canada. The sequence of the model did not allow for an assessment of the use of informal science resources on science knowledge. However, earlier structural equation models built with 2005 data showed that use of informal science learning resources in the United States, such as magazines, museum visits, and the internet, was the third greatest predictor of science knowledge after formal education and university science classes. Similar patterns exist across European countries (Miller, 2012). A more disaggregated analysis using U.S. data from 2007 found that internet and print media use contribute to higher levels of science knowledge while television watching contributes to lower levels. Museum use does not have a significant effect on knowledge once education, print media, and internet use are controlled for, which likely reflects the fact that many of the families visiting informal science learning venues are composed of parents with higher levels of education with some interest in science and therefore already relatively high levels of science knowledge and understanding (Miller, 2010b).

4.7 DATA GAPS

While this chapter provides useful insights into the four key dimensions of science culture, there are many other aspects of Canada's science culture for which no comparable indicators are available. Downstream indicators that could capture the extent to which science attitudes, engagement, knowledge, and skills affect individual decision-making and public policy would be valuable in assessing the impacts of science culture. The Panel noted that an appreciation of science does not provide a guarantee that scientific ways of thinking will drive decision-making. Data on science media coverage and individual information acquisition and appraisal skills are also typically unavailable or insufficient to support comparative analysis.

As part of a European initiative to build a stronger knowledge-based society, a group of experts undertook to benchmark public understanding of science and efforts to promote research, technology, and development culture. The expert group analyzed survey responses from the Eurobarometer, issued information requests to member states, and identified areas of interest where information was not currently available. Among others, they identified the need for new indicators to track government investments, assess the contribution of science culture promotion activities, and better understand the contribution of industry to outreach efforts (Miller *et al.*, 2002). In general, while survey-based methods such as those used by this Panel provide useful information on patterns of public knowledge, attitudes, and engagement, there is a lack of robust, standardized, and internationally comparable data on the extent of institutional and social support for science culture (see further discussion in Chapter 5).

4.8 CHAPTER SUMMARY

Overall, Canada performs well relative to its peers abroad on many measures of science culture. Table 4.5 summarizes Canada's performance on a selection of indicators reviewed in this chapter, using both survey data and other data sources where appropriate. In general, Canadians have positive attitudes towards science and technology, are supportive of public investments in scientific research, and see a clear role for science and technology in achieving social goals. They are also more likely than citizens of other countries to visit science and technology museums and participate in a range of science-related social activities. Performance in PISA testing and the results of the Panel's science knowledge survey questions confirm that both Canadian youth and adults exhibit comparatively high levels of scientific knowledge, though Canada's declining PISA scores have raised concerns about the degree to which this will remain true in the future. Canada's performance on indicators pertaining to the development of science and technology skills is more variable. While the Canadian population is highly educated overall, the rate of enrolment in university science and engineering programs is modest by international standards, as are rates of employment in science and technology related professions.

Canada's performance has also improved over time (since the 1989 survey) on many of these measures, with Canadians exhibiting a higher level of science knowledge, increased engagement in science-related activities, and declining reservations towards science. Graduation from university science programs has been stable in Canada over the past decade, despite declines in many other countries. However, Canadians have become slightly less optimistic about the ability of science to contribute to a range of social goals, and fewer Canadians now believe that science is making their lives healthier, easier, and more comfortable than they did in 1989.

While these results point to the relative strength of Canada's science culture by international standards, there remains the potential for improvement on many measures. Despite the high level of science knowledge of Canadians compared with citizens of other countries, the Panel's analysis suggests that more than half of Canadians likely lack the level of understanding of basic scientific concepts needed to make sense of emerging scientific issues or major public debates on scientific issues. Persistent gender disparities with respect to science attitudes, interest, and knowledge also indicate that Canada's science culture is not equally well established across all segments of the population.

Table 4.5

Summary Table of Selected Science Culture Indicators

Indicator	% or Score	Rank
Public Attitudes Towards Science and Technology		
Public views about the "promise" of science (index)[a]	7.3/10	9th out of 17 countries
Public reservations about science (index)[b]	3.0/10	1st out of 17 countries
% of pop. agreeing that even if it brings no immediate benefits, scientific research that adds to knowledge should be supported by government	76%	12th out of 35 countries
Public Science Engagement		
% of pop. that reports being very interested or moderately interested in new scientific discoveries and technological developments	93%	1st out of 33 countries
% of pop. that has visited a science and technology museum at least once in previous year	32%	2nd out of 39 countries
% of pop. that regularly or occasionally signs petitions or joins street demonstrations on matters of nuclear power, biotechnology, or the environment	23%	3rd out of 33 countries
% of pop. that regularly or occasionally attends public meetings or debates about science and technology	14%	5th out of 33 countries
% of pop. that regularly or occasionally participates in activities of a non-governmental organization dealing with science/technology related issues	14%	1st out of 33 countries
% of pop. that regularly or occasionally donates to fundraising campaigns for medical research	63%	7th out of 33 countries

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Indicator	% or Score	Rank
Public Science Knowledge		
Estimated % of pop. that demonstrates a basic level of scientific literacy[c]	42%	1st out of 35 countries
Average score on OECD PISA 2012 science test[d]	525	10th out of 65 countries
Average score on OECD PISA 2012 math test[d]	518	13th out of 65 countries
Science And Technology Skills		
% of pop. aged 25–64 with tertiary education	51%	1st among OECD countries
% of first university degrees in science and engineering fields	20%	19th out of 29 countries
% of first university degrees in science fields awarded to women	49%	4th out of 28 countries
% of first university degrees in engineering awarded to women	23%	19th out of 28 countries
% of all doctoral degrees in science and engineering fields	54%	4th out of 37 countries
% of total employment in science and technology occupations	30%	22nd out of 37 countries

The table presents data for a selection of science culture indicators examined by the Panel. Canada's performance is ranked relative to other countries for which comparative data are accessible for each indicator. In cases of ties, both countries receive the same rank. [a]Index that combines responses to three science attitudes questions whereby a higher score represents more positive attitudes about the promise of science. [b]Index that combines responses to three science attitudes questions, with a lower score representing fewer reservations about science (/10). [c]Percentage of population that is identified as "civically scientifically literate" using Jon Miller's methodology, i.e., having the level of science knowledge necessary to comprehend the Science section of *The New York Times* (Miller, 2012). This rank should be interpreted with caution as the year of data collection varies by country. [d]Organisation for Economic Co-operation and Development (OECD) Programme for International Student Assessment (PISA) test scores are scaled so that the mean score is approximately 500 and the standard deviation is 100.

5

Informal Science Engagement and Learning in Canada

5 Informal Science Engagement and Learning in Canada

Key Findings

- Survey data show that Canadians engage in and learn about science in many informal contexts. These include traditional channels such as public lectures, television programs, science centres, and museums, as well as online sites and forms of engagement like social media and blogs.
- The network of organizations, programs, and initiatives involved in supporting science culture in any country is dynamic. A 2011 inventory of science culture and communication initiatives in Canada identified more than 700 programs and organizations involved in these activities across Canada.
- Due to a lack of internationally comparable data, there is no scientifically rigorous way to evaluate the strengths and weaknesses of Canada's informal science culture providers relative to their counterparts in other countries.
- Canada has a well-developed network of science centres and museums, and several long-standing, successful Canadian science media programs, but science coverage in the general Canadian media is less extensive. Research organizations also play a role in supporting science culture in Canada. All levels of government contribute to supporting science culture. Canada's federal government, however, has been less active than some peers in articulating a national vision for science culture and creating opportunities for public science outreach and engagement. Canada's formal science education system is also a critical driver of Canada's science culture.

The preceding chapter revealed that Canadians compare favourably with citizens of most developed countries on survey-based indicators of public science knowledge, public attitudes towards science and technology, and public science engagement. This raises the question of what is driving Canada's performance on these measures. The state of a country's science culture is the result of a complex combination of drivers. As discussed in Chapter 2, science culture is affected both by global trends and by the unique social, political, and even geographic environment in which a country's scientific establishment is situated. Performance on many measures of science culture is also influenced by demographic characteristics of the population, such as age, gender, ethnicity, and socio-economic status.

However, not all factors affecting science culture are fixed or contextual. The strength of a society's science culture also reflects the deliberate actions of the institutions, organizations, and programs that work to positively develop various dimensions of science culture. This chapter documents key characteristics of social and institutional support for science culture in Canada. In doing so, it reviews evidence on the Canadian institutions and organizations involved in promoting science culture in Canada, and identifies — to the extent possible given the evidence base — their strengths and weaknesses relative to similar institutions in other countries. In keeping with the Panel's charge, the focus is on informal science engagement and learning (i.e., science learning and experiences in non-school settings). However, the Panel also briefly comments on Canada's formal science learning system in recognition of its complementary role.

In contrast to the preceding chapter, there is no robust, well-developed source of internationally comparable data (or methodologies) that can be used to evaluate the relative effectiveness of Canada's informal science culture system. While there are a number of compilations of country-specific studies, (e.g., Durant & Gregory, 1993; Bauer *et al.*, 2012b; Schiele *et al.*, 2012), there is no systematic basis for comparison of these types of institutions or programs. As a result, the evidence reviewed in this chapter to characterize the Canadian science culture landscape is primarily descriptive rather than analytical, relying on the Panel's survey data, a comprehensive inventory of public science communication initiatives (see Box 5.1), and other data sources specific to Canadian institutions and programs.

Box 5.1
An Inventory of Public Science Communication Initiatives in Canada

The system of organizations, programs, and initiatives that supports science culture in any country is dynamic. As a result, any inventory provides only a snapshot at a single point in time, and risks quickly becoming out of date. No sustained effort has been made to track public science outreach and engagement efforts in Canada at the national or regional level. Some of the Panel's analysis relies on data from an unpublished inventory of public science communication initiatives in Canada undertaken in 2011 by Bernard Schiele, Anik Landry, and Alexandre Schiele for the Korean Foundation for the Advancement of Science and Creativity (Schiele *et al.*, 2011). This inventory identified over 700 programs and organizations across all provinces and regions in Canada, including over 400 initiatives related to museums, science centres, zoos, or aquariums; 64 associations or NGOs involved in public science outreach; 49 educational initiatives; 60 government policies and programs; and 27 media programs. (An update of this inventory completed by the Panel brings the total closer to 800 programs.) The inventory is used throughout the chapter to characterize different components of the Canadian system supporting public science outreach, communication, and engagement.

5.1 PATTERNS OF INFORMAL SCIENCE ENGAGEMENT IN CANADA

Canadians engage with science in many informal contexts. Table 5.1 shows the average annual frequency with which Canadians informally engage with science, ranging from attendance at science centres and natural history museums to using the internet to seek out information on scientific topics. It also shows the proportion of Canadians who have engaged in each activity at least once in the past 3 or 12 months. The relative frequency of participation varies considerably by activity. The average Canadian visits a planetarium or attends a science festival only once every five years, and only 10–11% of respondents reported having visited these types of institutions or events in the last 12 months. In comparison, the average Canadian visits a zoo or aquarium almost once a year, and a nature park or nature area around four times a year.

Canadians also acquire information about science and technology through other channels. As shown in Table 5.1, the average Canadian reports watching a science program on television approximately 35 times a year. There is a similarly high level of exposure to newspaper articles about scientific issues, and Canadians also report speaking to friends, family members, or colleagues about science or technology issues frequently over the course of a year. Over one-third of Canadians reported having read a book related to science and technology in the previous three months.[20]

Canadians are increasingly using the internet to seek out information relating to science. This activity can take the form of generalized searches about science-related issues or more targeted forms of information acquisition. For example, Canadians report using the internet to seek out information on health and medical issues an average of 47 times a year, or nearly every week. Other forms of online exposure to scientific content also appear to be common. For example, 46% of Canadians report having read a blog post or listserv related to science and technology at least once in the last three months, and 62% having watched an online video related to science and technology.

20 The data provided here were self-reported by survey respondents and may exaggerate use of these resources. Survey respondents may have interpreted this question to include books related to health as well as general science or technology. When U.S. citizens were asked a similar question, 30% reported having read a science or health book over the course of the last year (Miller, 2010a).

An increasing reliance on the internet as the main source of information about science and technology is consistent with the evolution of the media environment, as well as with survey data from other countries. Based on the Panel's survey, 17% of Canadians, for example, report reading a printed newspaper daily, while 40% report reading about the news or current events online every day. The latest U.S. data suggest that the internet is now the primary source of information when seeking information on specific scientific issues such as nuclear power, climate change, genetically modified foods, and stem cell research (NSB, 2012). As noted in Chapter 2, with Canadians increasingly turning to online sources for information about science, it is difficult to ascertain the relative importance of Canadian versus non-Canadian sources of information about science.

Table 5.1

Patterns of Informal Science Engagement in Canada

Informal Science Engagement Activity	Avg. annual frequency	% of resp. who engaged at least once in the past 3 (or 12) months
Events and Activities		
Attended a science activity at a school/college/university	1.1	28 (12 months)
Attended a public lecture/talk on a science-related subject	1.0	28 (12 months)
Visited a science or technology museum	0.6	32 (12 months)
Visited a natural history museum	0.7	34 (12 months)
Visited a zoo or aquarium	0.9	43 (12 months)
Visited a planetarium	0.2	11 (12 months)
Visited a science festival	0.2	10 (12 months)
Visited a nature park	4.0	70 (12 months)
Media and Information-seeking		
Watched a science program on television	35.2	80
Listened to a science program on the radio	6.4	30
Read a newspaper article about a scientific issue	33.6	70
Read an article in a science magazine (in print or online)	26.8	58
Read a blog post or listserv related to science or technology	23.2	46
Read a book about science or technology	4.8	38
Spoke to a friend, family member, or colleague about a science and technology issue in the news	36.0	79

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Informal Science Engagement Activity	Avg. annual frequency	% of resp. who engaged at least once in the past 3 (or 12) months
Online Activity		
Watched an online video related to science or technology	23.2	62
Heard about a science or technology news story through social media such as Twitter	25.2	42
Used the internet to look for information on health and medical issues	47.2	82
Used the internet to look for information on climate change	18.0	44
Used the internet to look for information on influenza and other infectious diseases	9.2	45
Used the internet to look for information on energy issues	17.6	49

Data Source: Panel survey data

The table reports the annual frequency with which an "average" Canadian reports engaging in activities related to informal science engagement or seeking information about science and technology, and the percentage of respondents who engaged in that activity at least once over the last 3- or 12-month period. For events and activities, averages may underestimate the true mean as all responses were capped at"10 or more." For questions on media exposure and online activity, annual frequencies are inferred from questions asking the respondent the number of times they engaged in that activity over the past three months. In these cases, to limit the influence of outlying values, responses were truncated at the 95th percentile. Data are weighted according to age, gender, region, and educational attainment to be representative at the national level.

5.2 CANADA'S INFORMAL SCIENCE LEARNING AND ENGAGEMENT OPPORTUNITIES

The modes of informal science engagement highlighted in the previous section arise from a diverse set of organizational and learning environments. These range from traditional venues for public science outreach such as lectures, natural history museums, and science centres, to more contemporary forms of engagement such as science festivals or online science learning resources. They also include settings where Canadians learn about or engage with science while pursuing other recreational activities, such as nature areas and parks. The following sections document some of the features of Canada's informal science learning landscape, and address, where possible given the limitations of the available evidence, how Canadian informal science engagement opportunities and resources compare with those in other countries.

5.2.1 Science Centres, Museums, and Other Designed Environments

Science centres, museums, and related institutions such as zoos, aquariums, planetariums, and botanical gardens are a central component in the system of organizations that support science culture, and Canadians benefit from access to many such institutions. A 2011 inventory of public science communication organizations and initiatives identified over 400 individual science centres, museums, and organizations and related initiatives distributed across Canada (Schiele *et al.*, 2011).

Science Centres

Science centres are found in all provinces and regions of Canada, and in communities of many sizes, ranging from Watson Lake, Yukon (Northern Lights Centre) with a population of 1,458, to Toronto, Ontario (Ontario Science Centre) with a population of 5.5 million (CASC, 2011). The Canadian Association of Science Centres (CASC) currently has 45 members. CASC estimates that more than eight million people visited its member organizations in 2011 (CASC, 2011). Box 5.2 provides additional facts about Canada's science centres based on a recent survey of its members, including statistics on visitor numbers and demographics and funding models.

Canada's 10 largest science centres are also members of the international Association of Science-Technology Centers (ASTC). These centres are located in Canada's larger urban areas, and together accounted for nearly four million on-site visits in 2011 (or almost 50% of the total science centre visits in Canada estimated by CASC) (ASTC, 2012). The institutions range in size from the 140,000 ft^2 of the Ontario Science Centre in Toronto to the 3,000 ft^2 of Science East in Fredericton. The Ontario Science Centre accounts for the largest number of visits, with approximately 1.1 million annual visitors (ASTC, 2012).

While the largest science centres are well known and located primarily in Canada's major urban centres, many small-scale, local, or community centres focus on content specific to their region (geographic, environmental, cultural, etc.). For example, the Yukon Beringia Interpretive Centre in Whitehorse (pictured in Figure 5.1) provides visitors with information on the climatic/geographic region of Beringia. Similarly, the Musée du Fjord in Saguenay, Quebec focuses on the natural and historical heritage of the Saguenay Fjord, and the Oil Sands Discovery Centre in Fort McMurray, Alberta explores the science, history, and technology associated with the Athabasca Oil Sands. These smaller science or interpretive centres often play a unique role in connecting science and technology to local cultural or historical events and traditions.

Box 5.2
Data from the CASC 2011 Survey of Member Organizations

In 2011, CASC undertook a survey of its member organizations, investigating visitor patterns and institutional characteristics. Key findings include the following:

- **Number of Visits:** Members responding to the survey reported 5.8 million total visits in 2011. Extrapolating to include non-responding members, CASC estimates the total number of visits to Canada's science centres at approximately 8 million. Roughly two-thirds of members reported their visitor numbers to be stable or increasing.
- **Visitor Age:** On average, 45% of visits were by adults, 14% by youth (variously defined, though generally 13+), 33% by children, and 8% by seniors.
- **School Groups:** On average, 27% of on-site visits to Canada's science centres were by students in school groups, with the general public accounting for the remainder.
- **Budgets and Funding Models:** The average operating budget for a CASC member is $1.5 million, with two-thirds of members having annual operating budgets of less than $2 million. Approximately 80% of members are registered charities; however, five are federal agencies, two are run by municipalities, and one is a provincial crown agency. On average, members generate 39% of their revenue from admissions, education fees, memberships, and other fees and services. All members receive public funding support, often from multiple levels of government, and the majority (60%) also receive support through corporate sponsorships.
- **Volunteers:** The median number of volunteers for members is 70, with a median number of volunteer hours contributed annually of 2,872. This adds to a total of 12,707 volunteers together providing nearly 300,000 hours of volunteer service annually.

CASC (2011)

Courtesy of the Government of Yukon

Figure 5.1

The Yukon Beringia Interpretive Centre

Science centres and museums often focus on subjects with a regional relevance. For example, the Yukon Beringia Interpretive Centre in Whitehorse provides visitors with information on the region of Beringia, which remained ice-free throughout the last ice age.

Natural History Museums

Natural history museums also provide opportunities for Canadians to learn about and engage with science. These museums are institutions with dual roles of collecting and conserving biological, archaeological, or geological specimens, and educating the public about Canada's natural environment. While these institutions share many characteristics with science centres, some of their roles are distinct.[21] Museums have historically been "object-based" institutions, and include collections of natural or scientific specimens. Some museums also have scientists on staff and actively support research. Science centres, on the other hand, typically do not maintain collections or support scientific research. Canada's natural history museums include the Canadian Museum of Nature, Royal Ontario Museum, Royal

21 Of the 13 members of the Alliance of Natural History Museums of Canada (ANHMC), 3 are also members of CASC. A full list of ANHMC members is available on its website: www.naturalhistorymuseums.ca.

Saskatchewan Museum, Royal British Columbia Museum, Manitoba Museum, New Brunswick Museum, etc. Like some science centres, the museums also often have a regional, as well as a national, focus, prioritizing collections and exhibits relating to the natural environment in the surrounding area. Canada's only museum dedicated to paleontology is the Royal Tyrrell Museum in Drumheller, Alberta. Internationally renowned as a leading paleontology museum, it attracts more than 400,000 visitors annually (Royal Tyrrell Museum, 2012).

Zoos, Aquariums, and Botanical Gardens

Zoos, aquariums, and botanical gardens also help promote public awareness of and engagement with science. Public aquariums in Canada include the Vancouver Aquarium, the Shaw Ocean Discovery Centre, and the Aquarium du Québec. The Vancouver Aquarium, one of the five largest aquariums in North America, reports that, since opening in 1956, it has received over 35 million visitors (Vancouver Aquarium, 2013a). Canada's Accredited Zoos and Aquariums lists 21 zoological parks in Canada, with larger zoos located in Toronto, Granby, Calgary, Moncton, Edmonton, Vancouver, and Winnipeg. There are also many botanical gardens in Canada, with some of the more prominent being the Royal Botanical Gardens in Burlington, the Montréal Botanical Garden, the Devonian Botanical Garden in Edmonton, the University of British Columbia Botanical Garden, and the Memorial University of Newfoundland Botanical Garden.

While zoos, aquariums, and botanical gardens generally focus on providing both an educational and entertaining experience for visitors, in some cases these organizations also take on conservation work and significant public outreach and engagement efforts. The five botanical gardens mentioned above, for example, have formed a consortium to promote the conservation of biodiversity. The Vancouver Aquarium is active in conservation of marine life, and in public education and outreach, and now operates a travelling exhibit (the Aquarium's AquaVan), which has carried out educational visits to schools and communities in British Columbia, Alberta, and the Northwest Territories (Vancouver Aquarium, 2013b).

Planetariums

Planetariums offer visitors a unique educational experience in astronomy and space science, subjects that typically generate high levels of public interest. There are a number of planetariums in Canada, including facilities that operate as part of larger science centres (e.g., planetariums at Science North, TELUS World of Science in Edmonton, Manitoba Museum), as well as stand-alone institutions (e.g., H.R. MacMillan Space Centre in Vancouver, Rio Tinto Alcan Planetarium in Montréal (pictured in Figure 5.2), Doran Planetarium in Sudbury, and Northern Lights Centre in Watson Lake). Canada's telescopes and observatories also afford opportunities for public engagement; for example, the Plaskett Telescope at the Dominion Astrophysical Observatory in Victoria offers public viewing periods during the summer months.

Courtesy of David Giral

Figure 5.2

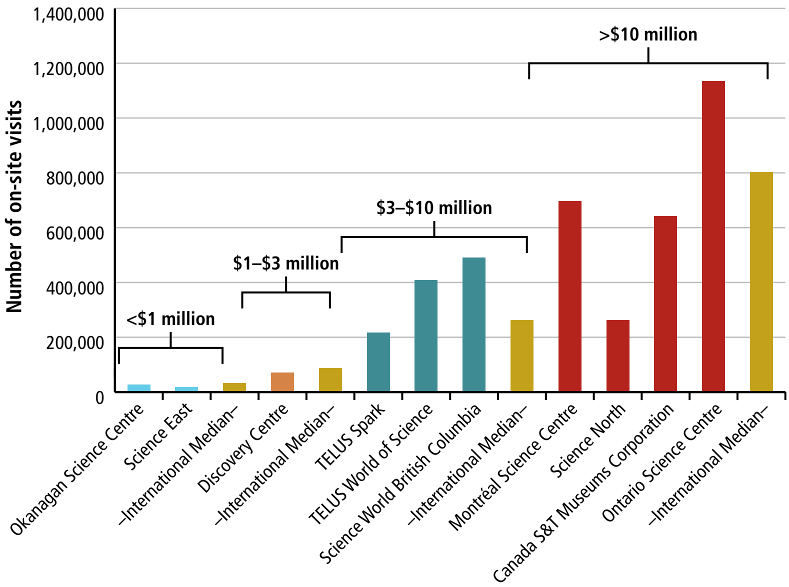
Interior of the Rio Tinto Alcan Planetarium, Montréal

Canada's planetariums, such as the Rio Tinto Alcan Planetarium pictured above, provide opportunities for Canadian students and the public to learn about astronomy and space science in an engaging setting.

International Comparisons

While it is impossible to rigorously compare the quality or aggregated impacts of such institutions across countries based on the available data, Canadians appear to benefit from a relatively well-established network of these kinds of informal science learning environments, on a par with that found in other countries. The United States is often recognized as having a well-developed system of science centres and museums (Falk & Dierking, 2010), and, based on available metrics, Canada's institutions appear broadly on a par with those in the United States. Judging from ASTC data, as a share of the population, attendance at major science centres in Canada is roughly equivalent to attendance in the United States (ASTC, 2012). The data also suggest that the ratio of visits to exhibit square footage in Canada is slightly higher than the U.S. ratio.

An examination of visitor numbers relative to operating budgets shows Canada's science centres are in line with international medians in most cases (see Figure 5.3). Several of Canada's science centres are also recognized leaders in the field. The Ontario Science Centre, along with the Exploratorium in San Francisco, was one of the first examples of this type of institution, and has served as a model for the creation of other science centres since its formation (Beetlestone *et al.*, 1998).



Data Source: ASTC (2012)

Figure 5.3

Science Centre Attendance in Canada by Operating Budget Class, 2011

The figure shows the annual on-site attendance at a selection of Canada's major science centres, grouped according to the size of their overall operating budget. As seen here, in most cases, Canadian visitor numbers are comparable to the medians defined by other science centres internationally. The comparatively lower number of visitors at Science North is a function of the smaller population size of the community, and its operating budget reflects a large outreach program and export business.

5.2.2 Youth Programs, Science Camps, and Science Fairs

Youth programs, camps, and science fairs provide stand-alone science learning and engagement experiences for youth and augment science instruction in the classroom. The 2011 inventory of public science communication initiatives identified over 60 associations or NGOs in Canada involved in providing science outreach or education support for youth. Although many of these initiatives are small-scale programs limited to a single community or area, a number of them have a national reach, such as Let's Talk Science, Actua, and Shad Valley (see Box 5.3).

Box 5.3
Nationally Active Canadian Youth Science Organizations

- **Shad Valley** offers a four-week summer enrichment program for academically excelling secondary students (students completing Grade 10, 11, or 12 or Québec secondaire IV, V, or CEGEP I), which consists of workshops and lectures that focus on science, engineering, mathematics, technology, and entrepreneurship. Founded in 1980 in Waterloo, Ontario, the organization now delivers these camps at 12 host universities across Canada, and camp alumni number over 12,000 (Shad Valley, 2013).
- **Actua** was founded in 1988, and is based around a network of outreach organizations hosted by science and engineering departments in universities and colleges across Canada. The member organizations provide workshops and camps to interested youth, often relying on undergraduate students and high school volunteers in the delivery of programs. Actua now reports annually engaging around 225,000 youth across Canada, and programs are often focused on youth who are typically underrepresented in STEM fields and careers (Actua, 2012).
- **Let's Talk Science** was founded in 1993 and focuses on providing a variety of science education and outreach programs, such as school visits from volunteer scientists and science students, structured science activities for early learning (ages six months to six years), and online resources, including an interactive website for teens (Let's Talk Science, 2013). According to its 2012 annual report, Let's Talk Science's outreach activities reached more than 160,000 Canadian youth and 26,000 parents and members of the general public in over 300 communities in 2011–2012 (Let's Talk Science, 2012).

Science fairs are another well-known type of science programming for youth. The Canadian system of science fairs is coordinated by Youth Science Canada. The first Canadian science fairs were held in Winnipeg, Edmonton, Hamilton, Toronto, Montréal, and Vancouver in 1959. Growing out of the volunteer efforts involved in organizing these events, Youth Science Canada[22] was formed in 1966, to host science fairs and engage in other activities to support science learning, teachers, and the coordination of extracurricular activities relating to science. The organization is best known, however, for running the Canada-Wide Science Fair, which hosts the top 500 young scientists from across the country every year. According to Youth Science Canada, 500,000 young Canadians annually participate in extracurricular project-based science activities such as science fairs — approximately as many as participate in minor league hockey in Canada (Youth Science Canada, 2012).

22 Originally named the Youth Science Foundation in 1966, the organization changed its name to the Youth Science Foundation Canada in 1995 and to Youth Science Canada in 2008.

Courtesy of FIRST Robotics Canada

Figure 5.4

FIRST Lego League Competition

In the FIRST Lego League (FLL) competition, students aged 9–14 compete to build and program an autonomous robot (using the LEGO® MINDSTORMS® robot set) to score points on a thematic playing surface. Over 20,000 teams in 70 countries now participate in FLL competitions (FLL, 2013).

Other organizations in Canada offer analogous opportunities. For example, FIRST Lego League competitions, pictured in Figure 5.4, provide students with a forum to compete in building small robots capable of solving defined challenges.

Canadian youth also have opportunities to participate in science-related programs and competitions hosted outside of Canada. For example, at the 2013 Google Science Fair, 15-year-old Canadian Ann Makosinski was one of the top prize winners for her invention of a flashlight powered by the heat from a user's hand (CBC, 2013a). Another example is the International Genetically Engineered Machine (iGEM) Competition, a synthetic biology competition spun out of the Massachusetts Institute of Technology, where teams are challenged to build biological systems and operate them in living cells (iGEM, 2013). Canadian teams have been well represented in years past and in several cases have advanced to the finals (ASTech Foundation, 2013; University of Calgary, 2013).

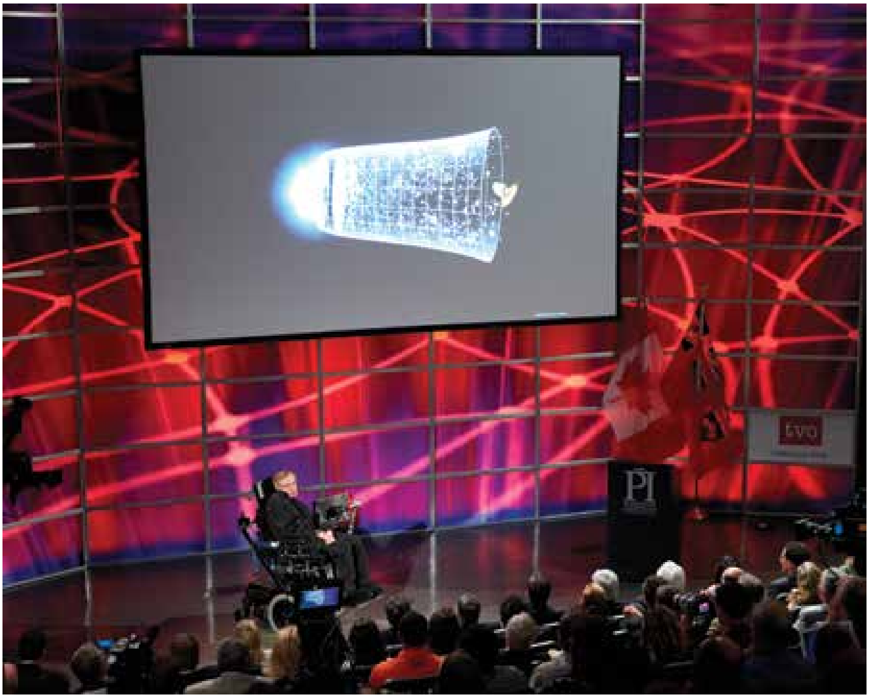
These programs provide many opportunities for science learning and engagement often not available in the formal education system. Participating students may have the opportunities to hear first-hand from working scientists, participate directly in the development of scientific experiments or new technologies, or experience instruction better tailored to their background or current level of knowledge. While sometimes challenging to evaluate due to less structured or formalized learning goals, these programs can have measureable impacts on participants. Many evaluation studies of specific programs have demonstrated positive impacts on outcomes such as student attitudes, grades, test, scores, graduation rates, etc. (NRC, 2009). Similarly, although there has been little systematic analysis of Canadian youth programs, individual evaluation studies have found evidence of positive impacts on participants. An unpublished 2012 evaluation of the Let's Talk Science outreach program, for example, found positive impacts on youth attitudes towards science and scientific careers based on surveys administered before and after their participation in the programs. A study of Actua's week-long science summer camps revealed positive attitudinal impacts on participants, including improved confidence in their abilities, improved enjoyment of science and technology, and increased intentions of pursuing future educational opportunities in science and engineering (Crombie *et al.*, 2003).

5.2.3 Public Science Lectures and Related Outreach Events

Canadians also have access to a range of public science lectures or science outreach events, depending on their proximity to urban areas. Many events are sponsored or hosted by Canadian research institutions that support public science outreach activities and provide science learning opportunities for youth. One active host of these types of opportunities, for example, is Perimeter Institute for Theoretical Physics in Waterloo. Since its inception in 1999, Perimeter Institute has included as part of its mandate both the training of new researchers, and public engagement and outreach. The Institute hosts a popular public lecture series, free of charge, where scientists and researchers from around the world are invited to share insights from their work with a general audience (see Figure 5.5). The Institute has also hosted special events and festivals such as Einsteinfest in 2005. This three-week festival in celebration of Einstein's *annus mirabilis* featured 38 lectures and 21 concerts and performances, and was attended by over 28,000 people.[23] Other events have included From Quantum to Cosmos, a public celebration of the institution's 10th anniversary, and the Waterloo Global Science Initiative (WGSI) in 2011, a joint effort with the University of Waterloo to "reboot" the global conservation of energy. A similar WGSI Equinox Summit in 2013 explored the future of education

23 Many other science and research institutes across Canada also convened events celebrating the 100th anniversary of Einstein's "miracle year." The United Nations declared 2005 the World Year of Physics, and events and programs across Canada celebrated Einstein's achievements and sought to raise public awareness about physics.

and learning in 2030. Perimeter Institute also provides a variety of online and digital learning resources, for both students and teachers, and runs a two-week physics summer school program for Canadian and international youth who have shown high levels of achievement and interest in physics. Finally, the Institute fosters connections between science and other forms of cultural expression by hosting events such as musical concerts and a gastronomy series.[24]



Courtesy of Perimeter Institute for Theoretical Physics

Figure 5.5

Stephen Hawking Speaking at Perimeter Institute

Perimeter Institute hosts a popular public lecture series as well as a range of other public science outreach and engagement opportunities. The photograph shows Professor Stephen Hawking, a Distinguished Visiting Research Chair at Perimeter Institute, during a June 2010 outreach event titled "Hawking at the Perimeter" in which Professor Hawking recounted his research and life and times in a public address recorded in front of a live audience and televised across Canada by TVO.

24 See the Perimeter Institute website for descriptions of its public outreach and engagement programs (Perimeter Institute, 2012), https://www.perimeterinstitute.ca/outreach.

Many other scientific research institutions engage in similar educational and outreach programming. TRIUMF, a national laboratory for particle and nuclear physics at the University of British Columbia, hosts similar programs, providing both educational resources for students and teachers and opportunities for the general public to learn more about current research topics in physics (TRIUMF, 2013). The Canadian Light Source, Canada's national synchrotron in Saskatoon, offers high school students the opportunity to directly participate in scientific research through its Students on the Beamlines program.[25] SNOLAB, a research facility built around the Sudbury Neutrino Observatory (SNO) located two kilometres underground in a specially excavated section of the Creighton Mine, is also committed to public outreach and engagement. The lab has worked in collaboration with Science North to develop exhibits about the facility and its research and create educational videos for the SNOLAB YouTube Channel, and has sponsored activities such as family workshops, classroom presentations, public talks, etc. (SNOLAB, 2012). These kinds of outreach efforts are replicated on a smaller scale across Canada. The 2011 public science communication inventory identified over 50 initiatives undertaken by various organizations in the scientific community, many of which are hosted or organized by science and engineering faculties at Canadian universities (Schiele *et al.*, 2011).

Scientific societies also play a role in increasing public understanding and appreciation of science and scholarship. Generally, these societies are composed of scientists from academia, industry, government, and the not-for-profit sector in a given field of science. In addition to organizing conferences and conducting advocacy, these organizations encourage education in and knowledge about their respective areas of scientific expertise. For example, the Chemical Institute of Canada hosts YouTube contests for the best chemistry video, a national crystal growing contest, and the Canadian Chemistry Olympiad, an event to encourage interest in chemistry among high school students (CIC, 2013). The Canadian Association of Physicists hosts an Art of Physics Competition where individuals and organizations are invited to photograph unusual physics phenomena alongside a description that must be concise and understandable by the general public (CAP, 2013). The Canadian Meteorological and Oceanographic Society promotes meteorology and oceanography in Canada by organizing public lectures, supporting science fairs, and funding prizes and workshops (CMOS, 2013).

25 See the Canadian Light Source website for examples of student projects: http://www.lightsource.ca/education/students.php.

L'Association francophone pour le savoir (ACFAS) has been contributing to the advancement of science in Quebec and in the wider Canadian francophone society since its creation in 1923. In addition to supporting young scientists, ACFAS has a mission to support the exchange of knowledge between science and society. It fulfils this mandate through various activities including hosting an annual congress, a platform for knowledge dissemination, debate, and discussion; publishing scholastic research in the French language; holding scientific picture contests to stimulate interest in and discussion of scientific knowledge; and hosting discussion forums for students, teachers, and researchers that address topical science issues such as climate change, green agriculture, and urban development. ACFAS makes a critical contribution to public engagement in and appreciation of science and scholarship in Canada's francophone society (ACFAS, 2014).

The Canadian Science and Technology Awareness Network (STAN) is another non-profit organization involved in many different forms of public science outreach and engagement in Canada. STAN is an umbrella organization, whose members encompass over 380 public- and private-sector institutions, including government ministries, school boards, corporations, museums, science centres, and individuals (STAN, 2014). One of STAN's activities is hosting an annual conference that provides a venue for member organizations to discuss current issues or challenges, share resources and strategies, and better coordinate or align their programming.

5.2.4 Science Festivals

Science festivals offer another form of support for science culture, and are attracting an increasing amount of interest worldwide (see Box 5.4). The general aim of science festivals is to integrate science with different aspects of local culture, and thus attract the attention of the broad cross-section of the public (SFA, 2012a). The founder of the Cambridge Science Festival, John Durant, describes them as "public celebrations of science and technology" (Durant, 2013). Science festivals often draw inspiration from other festivals with a central theme such as food, music, or dance, and appeal to people based on their entertainment value (Nolin *et al.*, 2006). Additional objectives include inspiring public engagement in science and inciting interest in STEM careers. Science festivals also provide an opportunity for public contact with scientists and engineers, and incentive for scientists and engineers to interact with their communities (SFA, 2012a).

In Canada there are two established, large-scale science festivals. Science Rendezvous takes place in about 20 cities across the country and combines a variety of programming to comprise a day-long free event (Science Rendezvous, 2013).

The annual Eureka! Festival in Montréal (see Figure 5.6) has over 100 activities over three days; it attracted over 68,000 attendees in 2012 (Eureka! Festival, 2013). More science festivals have recently been created. The University of Toronto launched the Toronto Science Festival in fall 2013 (UofT, 2013), and Beakerhead, a new festival described as a "collision of art and culture, technology, and engineering," was launched in 2013 in Calgary (Beakerhead, 2013). Two Canadian cities have also recently won bids to host STEMfest (Saskatoon in 2015 and Halifax in 2018), an international festival of science, technology, engineering, and mathematics (Global STEM States, 2014).

Courtesy of Roland Lorente

Figure 5.6

Eureka! Festival

Science festivals are an increasingly popular form of public engagement in science worldwide. Canada has a number of established science festivals such as the Eureka! Festival in Montréal, pictured above, which attracted over 68,000 attendees in 2012.

Box 5.4
Science Festivals: A Worldwide Movement

In the last five years science festivals have grown increasingly popular, with more than 100 science festivals occurring globally in 2012, reaching an estimated 5.6 million people (Bultitude *et al.*, 2011). The first modern science festival, the Edinburgh International Science Festival, took place in 1989, and featured talks, tours, and exhibitions (Nolin *et al.*, 2006). Today it aims to inspire people to "discover the wonder of the world around them" and is one of Europe's largest science festivals (Edinburgh International Science Festival, 2013).

Today, many festivals are organized on a large scale and occur annually in countries including New Zealand, South Africa, Singapore, the United Arab Emirates, Sweden, Spain, the United Kingdom, and the United States. The European Science Events Association (EUSEA) has around 90 member organizations from 36 different countries. In 2009 John Durant formed the Science Festival Alliance (SFA) in the United States, which currently has 15 member festivals. According to the SFA, "science festivals bring whole communities together to celebrate science as a vital local force — as important to our culture as it is to education and the economy" (SFA, 2012b).

Due to the recent advent of science festivals, there is little evidence documenting their impacts. Based on its member festival data, however, the SFA noted that 91% of festival attendees reported an increased interest in STEM topics, and 86% reported feeling better connected to STEM activities in their region (SFA, 2012a). The growing popularity and prevalence of these types of public events suggest they are becoming an increasingly significant form of public science communication and engagement — and one deserving of further study (Bultitude *et al.*, 2011).

5.2.5 Nature Areas and Parks

As noted in Chapter 2, Canada's geography and natural landscape also affect science culture, by shaping the recreational opportunities available to Canadians, and providing them with access to a relative abundance of natural and provincial parks and other areas. Canada currently has 44 national parks and over 300 provincial parks. According to Parks Canada, approximately 20 million people visit parks across Canada each year (Parks Canada, 2013). Any experience in nature has the potential to affect an individual's attitudes or interest in science (particularly biology, ecology, geology, etc.); however, parks and nature areas also provide educational content for visitors. Fostering public appreciation and understanding of science is one of Parks Canada's strategic goals (Parks Canada, 2013). National parks provide guided nature trails and hikes with information about local flora and fauna and educational resources for students and teachers, and, in some cases, organize special public outreach or educational events. Nature areas offer opportunities for other types of scientific pursuits such as star-gazing (see Box 5.5). Parks Canada has recently undertaken initiatives directly aimed at fostering engagement with Canadian youth and connecting them to their natural and cultural heritage (Parks Canada, 2012).

Nature areas also provide a setting for educational field trips and summer camps for students, which aim to develop both knowledge and interest in the natural environment.[26] In addition, other organizations facilitate youth access to nature and wilderness experiences, such as Scouts Canada and Girl Guides of Canada, both of which provide a variety of programming for youth involving nature and outdoor experiences. Some of this programming is dedicated to developing scientific knowledge and skills. Girl Guides of Canada has a long history of supporting science education and involvement and, in 2012, Scouts Canada launched a new five-year program on STEM education (funded by Imperial Oil), which focuses on hands-on science learning and engaging youth in science (Scouts Canada, 2012).

Box 5.5
Canada's Dark-Sky Preserves

Another way in which Canada's nature areas provide opportunities for engaging in a scientific pursuit is through Canada's system of dark-sky preserves. Managed by the Royal Astronomical Society of Canada (RASC), these are designated areas where no artificial lighting is visible and where measures are in place to educate the public and promote the reduction of light pollution. There are now 17 officially recognized dark-sky preserves in Canada, and an inventory by the RASC suggests that Canada is home to more dark-sky preserves than any other country (RASC, 2013; Welch & Dick, 2012). These areas provide the public with an opportunity to experience the night sky in the absence of artificial light and are consequently prime star-gazing locations. In some cases preserves are becoming tourist attractions in their own right, with local businesses and tour guides offering targeted services to visitors interested in experiencing Canada's pristine night skies (McMahon, 2013).

26 A substantial body of research explores the impacts of summer camp experiences on a variety of outcomes, both in Canada and in other countries. A short review of this research is provided by Fine (2012), and a number of recent Canadian studies are listed on the website of the Canadian Camping Association, http://ccamping.org/resources/camping-research/.

5.2.6 Interactions with Family and Peers

Interactions with family members and peers also provide Canadians with opportunities to learn about science and engage in activities related to scientific pursuits. While unstructured and lacking explicit learning goals, these interactions can be a substantial source of science learning and foster interest and appreciation in science (NRC, 2009). Such experiences can include everything from a casual conversation with family members to building a model rocket or playing computer or video games with friends.

The NRC (2009) discusses these types of social interactions as a mode of "everyday science learning," or science learning that occurs in everyday settings, and distinguishes between two categories of this type of science learning. The first consists of "spontaneous, opportune moments of learning that come up unexpectedly." The second encompasses "focused pursuits that involve science learning and may grow into more stable interests and activity choices" (i.e., science-related hobbies or recreational pursuits). Both types contribute to the development of science culture, though the latter is more sustained and systematic and more likely to lead to the development of related social groups, with their associated opportunities for social interaction and engagement.

While it is impossible to systematically catalogue these types of experiences for Canadians and there is little documented evidence on their importance in the Canadian context, data from the Panel's survey indicate the extent to which these experiences may be a factor in supporting science culture in Canada. As shown in Table 5.1, 79% of Canadians report having discussed a science and technology story in the news with a family member, friend, or colleague at least once in the past three months, and collectively 34% of Canadians report engaging in a hobby related to science and technology either "regularly" or "occasionally."

5.3 SCIENCE IN THE CANADIAN MEDIA

Canadians receive information about science and technology from numerous sources including mainstream print, television, and radio media, and through a number of Canadian programs with dedicated coverage of science and technology stories.

5.3.1 Dedicated Science Television and Radio Programming in Canada

Table 5.2 lists a selection of the main anglophone and francophone science programs on television and radio, and their respective estimated audience sizes. The most prominent dedicated science English-language programs are the Canadian Broadcasting Corporation's (CBC) "The Nature of Things" and "Quirks and Quarks", and the Discovery Channel's "Daily Planet".

"The Nature of Things" is a weekly television program currently hosted by David Suzuki. Now in its 53rd season, CBC describes it as "one of the most successful series in the history of Canadian television" (CBC, 2013d). Originally broadcast in black and white, and hosted by Patterson Hume and Donald Ivey (see Figure 5.7), the show has been positively received by audiences and critics, and has won many awards over the years including six Gemini Awards for best documentary series, and two nominations for International Emmys in both the best documentary and non-fiction categories (CBC, 2013d). "Daily Planet" is Canada's only science television series that is broadcast daily. Originally airing in 1995, it provides science and technology news coverage as well as feature segments.[27]

"Quirks and Quarks," a science radio program broadcasted nationally on CBC Radio, features science news stories and interviews with scientists. The series is currently hosted by Bob McDonald and has won more than 80 national and international awards (CBC, 2013b). It has also been broadcast on American Public Radio and is available through podcasts online at the CBC website.

Table 5.2

Major Canadian Science Media Programs on Television and Radio

Program	Audience Size
Anglophone	
The Nature of Things (CBC)	557,000[a]
Daily Planet (Discovery Channel)	251,000[b]
Quirks and Quarks (CBC Radio)	340,700[c]
Francophone	
Découverte (Radio-Canada)	587,000[d]
Les années lumière (Radio-Canada)	35,000[e]

Data Source: CBC Research (BBM Canada); [a]figure is for 2012–2013 regular season, and includes audience for repeat broadcast. [b]Bell Media (BBM Canada); figure is for week of Feb. 11–15, 2013, the most-watched week of the series to date. [c]CBC Research (BBM Canada); figure is for 2012–2013 regular season and includes audience for repeat broadcast. [d]Radio-Canada (BBM Canada); figure is for 2012–2013 regular season. [e]Radio-Canada (BBM Canada); figure is for the 2012 fall season. When also accounting for podcast and web downloads, the show estimates that approximately 100,000 people listen every week.

The table identifies the most prominent dedicated science media programs in Canada, along with their viewer/listener numbers. Note that "Daily Planet" is broadcast daily, while the other programs listed are broadcast weekly.

27 Jay Ingram, a member of this Panel, was a co-host of "Daily Planet" between 1995 and 2011.

Courtesy of CBC Still Photo Collection

Figure 5.7

The Original Co-Hosts of CBC's "The Nature of Things"

The photograph shows Patterson Hume and Donald Ivey on CBC's "The Nature of Things." First broadcast in 1960, it is one of the most long-standing television programs in Canadian history.

Though targeting a relatively smaller population, there are also a number of dedicated French-language science media programs. "Découverte," a weekly, hour-long science television documentary series hosted by Charles Tisseyre has been broadcast on Radio-Canada since 1988. "Génial!" is a Télé-Québec show, based around a game show format, that aims to promote understanding of scientific phenomena (the format for the show is adapted from "Clever!," a German game show) (Télé-Québec, 2013). "Le Code Chastenay," a Télé-Québec television program, has been broadcast since 2008, and presents research conducted in Quebec universities (Télé-Quebec, 2014). And "Les années lumière" is a weekly science radio program on Radio-Canada broadcast since 2002, currently hosted by Yanick Villedieu. Previous French-language science media programs include "Les Débrouillards," a science television show for youth that aired periodically throughout the 1990s and early 2000s, and "Omniscience" (1988–1996) and "Le Club des 100 Watts" (1988–1994), the latter of which encouraged young people to pursue careers in science and reached over 400,000 youth between the ages of 9 and 12 (Schiele *et al.*, 1994).

5.3.2 Print Journalism

Dedicated science coverage is notably absent from the majority of newspapers and other print journalism in Canada. As shown in Table 5.3, none of the top 11 newspapers by weekly readership in Canada has a dedicated science section, including nationals such as *The Globe and Mail* and *National Post*. Nine of these newspapers have dedicated technology sections, which sometimes contain sub-sections with broader coverage of science or environment stories; however, story coverage tends to be dominated by technology or business (or gaming) stories. Few Canadian newspapers have dedicated science journalists on staff, and *The Globe and Mail* is unique among Canadian papers in having a science reporter, a medicine and health reporter, and a technology reporter.

Table 5.3

Science and Technology Content in Major Canadian Newspapers

Newspaper	Weekly Paid Circulation	Science & Technology Content
Toronto Star	1,932,385	No science or technology section
The Globe and Mail	1,906,336	Technology section, with sub-section on science; dedicated science reporter
Le journal de Montréal	1,420,214	Technology sub-section, with focus on technology and electronics
La Presse, Montréal	1,305,435	Technology section
The Vancouver Sun	1,011,799	Technology section, with sub-sections on science, space, and future technologies
The Toronto Sun	956,482	Technology section
The Province, Vancouver	918,048	Technology section, with sub-sections on the environment, space, technologies, and science
Calgary Herald	915,048	Technology section, with science coverage
Winnipeg Free Press	823,184	No technology or science section
Ottawa Citizen	822,711	Technology section with sub-sections on technology, gaming, business, internet, and space
National Post	814,898	Technology section

Data Source: Circulation numbers from Newspapers Canada (2012)

The table shows the science and technology content and weekly circulation numbers for the top 11 daily newspapers in Canada. None has a dedicated science section. For most, science stories are now covered in technology sections, which often prioritize technology, gaming, and business content over general purpose science stories.

Canada also lacks a dedicated science magazine for adults, with the exception of *Canadian Geographic* which focuses on geographic and environmental content.[28] In Quebec, French-language magazine *Québec Science* provides commentary on science, technology, and society, and celebrated its 50th anniversary in 2012. Canada has two science magazines for youth: the English-language *OWL* (now a related series of magazines for children aimed at three different age groups), which has been published since 1976; and the French-language *Les Débrouillards*, which now includes an interactive website and affiliated blog. Other nationally syndicated news magazines such as *Maclean's* provide regular or semi-regular coverage of science and technology stories as well.

5.3.3 Science Blogs and Other Sources of Online Information

Science blogs are another potential source of information about developments in science and technology. A database compiled by the Canadian Science Writers' Association, as of March of 2013, lists 143 Canadian science blogs, covering all areas of science and other aspects of science such as science policy and science culture (CSWA, 2013). Some blogs are individually authored and administered, while others are affiliated with larger networks or other organizations (e.g., Agence Science-Presse, PLOS Blogs). Canadian science blogger Maryse de la Giroday has also published an annual round-up of Canadian science blogs on her blog (www.frogheart.ca) for the past three years, and a new aggregator of Canadian science blogs was launched in 2013 (www.scienceborealis.ca).

Data from the Panel's survey suggest that blogs are becoming a more prominent source of information about science and technology for the general public. As noted at the beginning of the chapter, 46% of Canadians report having read a blog post about science or technology at least once in the past three months. Blogs are also influencing the way that scientific research is carried out and disseminated. A technical critique in a blog post by Canadian microbiologist Rosie Redfield in 2010, for example, catalyzed a widely publicized debate on the validity of a study published in *Science*, exploring the ability of bacteria to incorporate arsenic into their DNA. The incident demonstrated the potential impact of blogs on mainstream scientific research. CBC highlighted the episode as the Canadian science story of the year (Strauss, 2011), and *Nature* magazine identified Redfield as one of its 10 newsmakers of the year in 2011 as a result of her efforts to replicate the initial study and publicly document her progress and results (Hayden, 2011).

28 Another potential exception is *Sky News: The Canadian Magazine of Astronomy and Stargazing*. However, it is a specialized magazine with a niche audience, and is not widely circulated.

The impact of online information sources, however, is not limited to blogs, with 42% of Canadians reporting having heard about a science and technology news story though social media sources like Twitter and Facebook in the last three months. And, as noted earlier, the internet is often used to search for information about specific science and technology topics, both for general issues such as climate change, and more personalized information on medical and health issues.

5.3.4 Science Journalism and Communication Programs

There are currently several science journalism programs in Canada. Mount Saint Vincent University in Nova Scotia launched a new Bachelor of Science degree program in science communication in 2010. Science North and Laurentian University in Sudbury collaborate to offer a unique Science Communication graduate diploma. There is also a science journalism program at Concordia University, and science journalism courses feature in other journalism programs (e.g., UBC School of Journalism, Ryerson University, Carleton University). In Quebec, a certificate in journalism offered by Université Laval also provides training in science media and communication. An intensive two-week summer immersion course in science communication is offered through the Banff Centre as an opportunity for professional training.

5.3.5 Other Science Media Organizations and Supporters

A number of other organizations also play a supporting role in Canada in facilitating coverage of science and technology stories in the media. Agence Science-Presse and the Science Media Centre of Canada (SMCC) are two examples.

Founded in 1978 with the motto *Parce que tout le monde s'intéresse à la science* ("because everyone is interested in science"), Agence Science-Presse is a not-for-profit organization in Quebec that supports media coverage of science by distributing articles on scientific research or other topical science and technology issues to media outlets in Canada and abroad. The organization also supports science promotion activities aimed at youth. For example, it currently edits and maintains an aggregation of blogs designed for young science enthusiasts and science journalists (Blogue ta science).

The SMCC is based on similar models in the United Kingdom, Australia, and New Zealand. Its objective is to support coverage of scientific stories in the media by helping connect reporters to relevant scientific experts and providing other supporting background information on science and technology issues. In part a response to the increasing scarcity of dedicated science journalists, organizations such as SMCC are predicated on the notion that science stories are now frequently covered in mainstream media by general assignment reporters who often do not have the background, connections, or knowledge needed to cover what are often stories with a great deal of scientific or technical complexity (Kirby, 2011).

5.3.6 International Comparisons

Few studies have investigated either mainstream media coverage of scientific issues in Canadian news outlets, or documented the impacts of existing dedicated science programs. Earlier studies on Canadian science journalists and science reporting (Dubas & Martel, 1973; Einsiedel, 1992) were carried out over 20 years ago when the traditional media landscape was dominated by newspapers, magazines, television, and radio, which often had science reporters on staff. By 1994, about half of Canada's daily English-language newspapers did not have a science reporter (Saari *et al.*, 1998), and most of the coverage was in the form of news briefs (Zimmerman *et al.*, 2001). Structural changes in the media environment in the last 15 years have resulted in a corresponding disappearance of specialized science journalists, with coverage of science news falling to general reporters, a trend documented in the United States, Canada, and globally (Brumfiel, 2009). Science coverage on television and radio in Canada, on the other hand, has remained particularly notable with CBC Radio's long-running "Quirks and Quarks" and "The Nature of Things," currently in their 35th and 53rd seasons respectively.

The implications of the lack of a dedicated science magazine in Canada are unclear. On the one hand, it is unlikely that this limits Canadians' access to science journalism given the ready availability of periodicals from other countries. For example, an analysis of Canadian subscription rates to several science magazines confirms that Canadians subscribe to international periodicals in significant numbers. Table 5.4 compares Canadian and U.S. subscription rates to *National Geographic*, *Science*, *Nature*, and *Scientific American*. As shown here, on a per capita basis, with the exception of *Science*, Canadians subscribe to these magazines at rates nearly equal to Americans. On the other hand, magazines from other jurisdictions are less likely to carry content specific to Canada such as stories about Canadian scientists and researchers.

Table 5.4

North American Readers of Selected U.S. Science Publications

Publication	Total Circulation	Circulation by Country		Subscribers Per 100,000 Adults[a]
National Geographic	4,833,989[b]	United States	3,575,801	1,524
		Canada	295,455	1,111
Science	111,597[c]	United States	91,186	38
		Canada	2,843	10
Nature	45,345[d]	United States	21,445	9
		Canada	1,611	6
Scientific American	496,874[e]	United States	444,743	189
		Canada	35,687	134

Data Source: Statistics Canada (2013a); United States Census Bureau (2011); Alliance for Audited Media (2014a, 2014b); BPA Worldwide (2013a, 2013b)

While Canada may not have many of its own dedicated science publications, major U.S. science publications have notable Canadian audiences. [a] Adult population figures are based on the 2010 U.S. census and 2011 Canadian census, and include those 18 years of age and older. [b] Represents paid and verified circulation between July and December 2013 for English-language publication only. [c] Represents total qualified circulation for May 10, 2013 issue. [d] Represents total qualified circulation for May 30, 2013 issue. [e] Represents total paid and verified circulation for August 2013 issue; this figure does not include the international circulation of *Scientific American*, which totals approximately 58,000.

5.4 OTHER SOURCES OF SUPPORT FOR SCIENCE CULTURE IN CANADA

5.4.1 Industry

Some Canadian firms also support science culture through public science education and outreach initiatives. Firms may partner with local not-for-profit organizations dedicated to promoting science education and awareness, or contribute funding to local post-secondary educational institutions. Although the extent to which Canadian firms participate in such activities is unknown, individual examples of such support are common. Many of the organizations in the preceding sections (e.g., science centres and museums, youth programs and camps) benefit from corporate support to varying degrees.[29] TELUS has provided substantial financial support to science centres in Vancouver, Edmonton, and Calgary (collectively referred to under the umbrella term of "TELUS World of Science"). Since 1994 Sanofi-Aventis has hosted the BioGENEius Challenge Canada, an annual science competition for youth aimed at raising public awareness of biotechnology and its applications (Sanofi BioGENEius Challenge Canada, 2013). Atomic Energy of Canada, Limited offers a number

29 CASC survey data report that 60% of member organizations receive corporate support (CASC, 2011).

of programs such as resources for teachers, a community speakers program, and the Deep River Science Academy (AECL, 2013). Amgen Canada has partnered with Let's Talk Science in a recent study of science learning in Canada, involving a survey of Canadian youth (Amgen Canada Inc. & Let's Talk Science, 2012). As mentioned in Section 5.2.5, Imperial Oil is now engaged in a partnership with Scouts Canada on STEM education. Many similar initiatives are sponsored by firms across the country.

While the role of industry in promoting science culture has been little studied in Canada, a 2008 analysis by The Impact Group reveals some insights about these activities. Based on interviews with 15 firms active in supporting science and technology outreach programs, the study (Crelinsten & The Impact Group, 2008) makes the following observations:

- Many firms, particularly oil and gas and chemical firms, view science and technology promotion as important to the sustainability of their business, due to their ongoing need for scientific and engineering skills, and the importance of cultivating a broader social understanding of the science and technology issues related to their R&D efforts.
- Most firms prefer to be active in the regions where they have a presence, and use third-party organizations that specialize in science and technology promotion or funnel support through their own charitable foundations. Firms often encourage employees to volunteer with partner not-for-profit organizations, and provide non-financial incentives.
- Firms provide more support to post-secondary programs than to those targeting younger students. Some firms target support specifically to underrepresented groups in the science and engineering community, such as women and Aboriginal students.

5.4.2 Government

Federal, provincial, and municipal governments all play a role in supporting science culture in Canada. As funding bodies for research in the natural and social sciences, governments are involved in supporting the production of knowledge and in training new researchers. Governments also support informal science learning, through direct funding programs or support for the relevant institutions (e.g., CBC, science centres and museums, etc.), and through the provision of supplementary educational or science promotion resources. Government-run research organizations often provide opportunities for the public to engage in discussions and decisions about the general focus of publicly funded research programs. Finally, governments have a key role to play in articulating a national vision for science in society, and its relevance to other public and social objectives.

Municipal Governments

Municipal governments contribute to the establishment and maintenance of science venues across the country, from small community parks to large-scale tourist attractions. The City of Montréal groups the Biodôme, Insectarium, Botanical Garden, and Rio Tinto Alcan Planetarium together into one park called Space for Life (SFL, n.d.). The Toronto Zoo is an agency of the municipal government and roughly one-quarter of its revenue is provided by the City of Toronto (Toronto Zoo, 2011). In 2012 the City of Calgary provided over one-fifth of the total revenue for TELUS Spark, a science centre based in Calgary (TELUS Spark, 2012).

Provincial and Territorial Governments

Provinces and territories provide financial and organizational support to a variety of institutions and initiatives that have an impact on science culture, including the formal education system, science centres, provincial parks, science events, media, and research organizations. Provincial government strategies and activities often differ by region so as to address the unique language, industry, geographic, and cultural needs of their populations. Quebec, Yukon, and the Northwest Territories, for example, have outlined visions for science promotion and provided support to encourage the inclusion of science in the lives of both youth and adults. Ontario, Saskatchewan, and Alberta have focused support for science on skills development and investment in innovation for regional industries. Manitoba and the Atlantic provinces have developed programs to complement provincial science curricula, and most support science centres, parks, and museums to differing degrees. There has been no recent systematic study of provincial government activities in public science outreach and engagement. While an exhaustive inventory of provincial activities would require a separate study, some representative samples are highlighted here.

British Columbia

The B.C. government often collaborates with Science World to support science outreach initiatives such as Scientists in the Schools and Program for the Awareness and Learning of Science, but recently cancelled support for a number of popular science outreach programs (Adamski, 2012). BC Year of Science, a cross-government initiative in the 2010–2011 school year, included almost 200 events led by the Ministry of Advanced Education and Labour Market Development (Filion, 2010). The initiative aimed to ignite interest in science, increase the number of new entrants to the science and technology industry, and develop a further understanding and action plan to address the science capacity issues facing the province.

Prairie Provinces

The Prairie provinces provide some support for science centres, museums, and youth educational science programs connected to the science curriculum with a focus on industry and innovation. In Alberta the Ministry of Innovation and Advanced Education acknowledges the need to promote public awareness of and engagement in its research and innovation responsibilities (AMIAE, 2013). A science strategy initiated for the Alberta Park Division of the Department of Tourism, Parks and Recreation aims to improve communication and dissemination of research, and to establish research centres in provincial parks (GoA, 2010).

The Saskatchewan government supports the Canadian Light Source, a world-class research facility with academic and industrial partnerships, which also provides science and engineering outreach (CLS, 2013). It is a partner in supporting the Saskatchewan Science Centre, and has created the Innovation and Science Fund to provide additional support to universities, colleges, and research institutes that receive federal grants (GoS, 2013).

The Manitoba government, in connection with the province's action plan for science education, has provided support for special programs and activities including Manitoba Mindset activities, Manitoba Envirothon, the International Students' Science Fair, and the Youth Encouraging Sustainability (Y.E.S.) Showcase (GoM, 2013).

Ontario

The Ontario government has played a role in establishing and maintaining science venues across the province including three government agencies: the Ontario Science Centre, Science North, and the Royal Ontario Museum. It commissioned the Ontario Science Centre in 1964 as part of Canada's centennial celebrations (OSC, 2013), and the Ministry of Tourism, Culture and Sport has continued to provide substantial support to it over the years (GoO, 2005, 2009). In 2010–2011, provincial funding accounted for $15.8 million of the Ontario Science Centre's revenues (OSC, 2011). Based in Sudbury, Science North was established in 1984 through contributions from Inco Ltd., Falconbridge Ltd., and the provincial and federal governments (Science North, n.d.). In 2012, $6.9 million of Science North's revenues came from provincial government grants (Science North, 2012). The Royal Ontario Museum (ROM) focuses on natural history and world culture, and attracted almost a million visitors during 2011–2012 (ROM, 2012). The ROM received over $28 million in operating revenue from government grants in the same period, the majority of which come from the provincial government (ROM, 2012). In addition, over $1 million in funding for science initiatives has been provided through the provincial government's Ontario Trillium Foundation for Let's Talk Science, regional science fairs, public speaker series, and environmental initiatives (OTF, 2013).

Quebec

Provincial interest in science culture dates back to the mid-1960s (CST, 2002a). In 1972 the province established the Conseil de la politique scientifique, which evolved into the Conseil de la science et de la technologie (CST) in 1983. The CST provided the government with advice on science and technology policy, and in 2002 issued an assessment on the province's science culture. The assessment noted a lack of coordination between government departments with regard to science culture promotion activities, but found that on a societal level the uptake of science and technology in the province was high relative to the rest of Canada and other OECD countries. The assessment also found (based on partial budget information) that government support for science culture in the province appears to be higher than that provided in other regions (CST, 2002a).

Much of the provincial government's support for science culture in Quebec is now provided by the Ministère de l'Enseignement supérieur, de la Recherche, de la Science et de la Technologie (MESRST). Created in 2012 with a mandate covering post-secondary education, research, and science and technology, the MESRST leads a provincial research and innovation strategy supported by $3.7 billion in funding between 2014 and 2019 (MESRST, 2013a). Of this funding, $41 million is allocated to efforts to foster science culture across the province. To encourage youth interest in science careers, the strategy supports youth education, internships, and initiatives to inform youth about science career options. Creating excitement about science and innovation is seen as a way to spark youth interest in science careers. Science culture support organizations are funded through the strategy, which proposes linking science culture with other aspects of culture, including the arts, through a new partnership with museums across the province (MESRST, 2013a).

The MESRST is also a key source of funding for many other organizations involved in science culture including the Conseil de développement du loisir scientifique and its network of nine regional councils that offer science-related leisure activities across the province; Expo-Sciences, the province-wide science fair; l'Association francophone pour le savoir, which promotes scientific activity, research, and knowledge dissemination; Compétences Québec, which promotes careers in science and technology; and Les Scientifines, which promotes development of life skills through science among girls from disadvantaged backgrounds (MESRST, 2013b).

Other government departments also play complementary roles in supporting science culture. The Ministère de la Culture et des Communications has a mandate to support cultural activities including museums across the province, while the Ministère de l'Éducation, du Loisir et du Sport funds provincial education.

Atlantic Provinces

Support for science culture in the Atlantic provinces is focused primarily on youth science education. The departments of education and economic development of Nova Scotia provide some financial support to the Nova Scotia Youth Experiences in Science initiative (NS YES!, 2013). Nova Scotia also provides support for the Discovery Centre (Discovery Centre, 2013) and the Museum of Natural History, and the Ministry of Education and Early Childhood Development hosts various science videos for parents and educators on its website (GoNS, 2013). Techsploration, a not-for-profit organization supported in part by the Nova Scotia Department of Labour and Advanced Education, aims to increase the number of women working in science, trades, and technology occupations (Techsploration, 2014).

The New Brunswick government supports agencies like BioAtlantech that work with the private sector to support various science industries (BioAtlantech, 2013). The New Brunswick government also supports Science East, an institution that aims to inspire and inform through hands-on experiences. The Department of Education and Early Childhood Development of Prince Edward Island hosts a Science and Technology Awareness Site that offers, organizes, and connects to external sources of science resources and events, information for science educators, a community newsletter, and an "ask an expert" resource (GoPEI, 2013). Following a 2011 declaration by the Minister of Education, the month of March in Newfoundland is celebrated as Youth Science Month (GoNL, 2011, 2013). Additionally, the Department of Innovation, Business and Rural Development contributes to some youth science events such as the Eastern Science Fair (ENSTF, 2012).

Territories

Canada's northern territories have developed science agendas designed to support research and have a positive impact on individual citizens. The Nunavut Department of the Environment provides environmental education, community engagement, and outreach programming in the form of camps, teacher training, and classroom visits (GoNU, 2013). The Northwest Territories recently released its Science Agenda, *Building a Path for Northern Science*, which describes steps to promote, support, and encourage scientific research related to government priorities (GoNWT, 2009). The Government of Yukon includes an Office of the Science Advisor to advise on scientific matters and policies, develop and apply scientific knowledge, and increase scientific awareness and literacy (GoY, 2013d). The Office is developing a Government of Yukon Science Strategy and maintains a database of science practitioners, professionals, and activities (GoY, 2013c, 2013b). Additional ministries provide leadership and funding for various public and youth science outreach programs including the Science Community of Practice (SCOPe) initiative of the Interdepartmental Science Committee (GoY, 2013a).

Federal Government

Canada's federal government also supports the development of science culture through a range of programs and activities. These take place in many different departments and agencies and relate to a variety of objectives, including promoting a national vision for science culture, and supporting public science outreach, engagement, and education.

Promotion of a National Vision for Science Culture

One overarching role that governments perform is to articulate a national vision for science culture and the role of science in society. Canada's current national science and technology strategy does this to a limited extent. One of the three pillars of the strategy is maintaining and cultivating Canada's "people advantage" (i.e., ensuring that Canada has the highly educated and skilled workforce needed to compete in a global economy increasingly oriented around knowledge and technology). In that light, the policy commits the government to "increase the number of Canadians pursuing education and careers in S&T by bringing Canadians involved in science promotion together to coordinate our efforts and increase our impact" (Industry Canada, 2007).

The strategy also discusses the benefits of science and technology for society, and the role that science and technology play in promoting economic growth and national competitiveness. In addition, it committed the government to developing an action plan to increase the number of people pursuing educational and career opportunities in science and technology; however, this action plan has not materialized (Industry Canada, 2007).

Promoting a national vision for science and technology can also be done in less formal ways, through speeches by senior government officials and political leaders on the role of science in society. For example, Canada's Governor General, David Johnston, recently took a step to promote science culture by publicly announcing the goal of increasing the number of Canadian scientists who win major scientific awards (Johnston & Alper, 2013).

Federal Science Promotion, Outreach, and Education

Federal support for public science outreach and education in Canada takes many forms, ranging from support for organizations such as science museums and centres to government programs aimed at fostering public science outreach and engagement. While there is no current, systematic inventory of such programs, a 2006 federal government study of science promotion activities identified over 70 separate initiatives, undertaken by 14 different departments and agencies, which together accounted for approximately $24 million in public expenditures (Impact Group, 2006).

The federal government currently supports several science-oriented museums. The Canada Science and Technology Museums Corporation consists of three museums in the Ottawa area that hosted over 650,000 visitors in 2012–2013: the Canada Agriculture Museum, the Canada Aviation and Space Museum, and the Canada Science and Technology Museum. Together, they received $30 million in federal funding in 2012–2013 (CSTMC, 2013). The Canadian Museum of Nature, which also receives over $30 million in federal funding, hosted over 400,000 visitors in 2011–2012 (CMN, 2012).

In addition to its network of museums, the federal government supports other activities directly aimed at public science promotion or outreach. In some cases, direct support for science promotion programs is provided through federal funding programs. For example, NSERC's PromoScience program offers financial support for organizations "working with young Canadians to promote an understanding of science and engineering." Total annual program funding is now up to $2.75 million (NSERC, 2013d). The federal government also grants awards that recognize exceptional accomplishments in science education and promotion. NSERC's Awards for Science Promotion program honours two recipients (one individual and one group) each year who have made an outstanding contribution to the promotion of science in Canada (NSERC, 2013a). The Prime Minister also provides awards for teaching excellence at the K–12 level, which recognize outstanding science teachers (Prime Minister's Awards, 2013).

The federal granting agencies provide funding to researchers studying science education and learning, both in formal and informal contexts. Canadian research in education is generally funded through SSHRC; however, NSERC has also funded initiatives relating to science education. One example is NSERC's Centres for Research in Youth, Science Teaching and Learning (CRYSTAL) program, which funded five centres of research aimed at improving K–12 science and mathematics education, including one, CRYSTAL Atlantique, focused primarily on science learning and education in informal contexts (see Box 6.6 in Chapter 6). With its Chairs for Women in Science and Engineering Program, NSERC also supports increased participation of women in science and engineering (NSERC, 2013c). The program funds regionally based chairs who split their time between research and efforts to encourage girls and women to pursue educational and career opportunities in the sciences.

The federal government also provides funding and support for initiatives aiming at celebrating the role of science and technology in Canadian society, of which Canada's National Science and Technology Week is the most prominent. Coordinated by the Canada Science and Technology Museums Corporation, it provides the opportunity for a week-long celebration of science and technology, with sponsored events occurring across Canada (in 2012, 249 events were hosted by 253 partner organizations, including 10 government departments and agencies) (GoC, 2013).

Federal departments and agencies sometimes administer their own public science outreach and engagement programs. CIHR's Café Scientifique, for example, provides opportunities for the public to engage with scientific experts in an informal setting. CIHR organizes its own events, but also establishes partnerships with other organizations across Canada to host them. According to CIHR more than 540 Café Scientifique events have been held (CIHR, 2013a). Another CIHR program, Synapse — CIHR Youth Connection, aims to connect young Canadians with CIHR-supported health researchers to provide mentorship and career guidance (CIHR, 2013b).

In addition to these science outreach programs, many government departments and agencies provide educational resources for students and teachers on subjects related to their mandate. For example, in the past Statistics Canada ran an education outreach program, providing educational resources relating to statistics for teachers and students (Statistics Canada, 2013f). Currently, Parks Canada provides educational resources on the environment (Parks Canada, 2013); Health Canada provides resources on health topics to educators (Health Canada, 2013); Natural Resources Canada provides educational resources on geology and earth sciences (NRCAN, 2013); and the Canada Space Agency provides educational resources relating to space science and astronomy (CSA, 2013b). These resources are often available through the department or agency's website.[30] The federal government has an online portal (www.science.gc.ca) with information on science and technology initiatives undertaken by the government, links to educational resources and science blogs, and profiles of Canadian scientists and research institutions.

30 The current status of some of these educational programs is now uncertain. Statistics Canada's education outreach program officially ended in 2012. Many government websites were restructured in 2013 and some educational content is either no longer available or less accessible. Educational resources at the National Research Council, Environment Canada, and Statistics Canada are now only available as archived content, despite having been available on the main websites of these agencies when the Panel began its work.

Engagement in Publicly Funded Research

As a research funder, the federal government can provide opportunities for the public to engage in discussions on the nature and direction of public support for scientific research. One institution that has been active in this area is CIHR. Its citizen engagement framework identifies four areas in which it seeks to increase public engagement, one of which is to provide meaningful opportunities for citizens to participate in research priority setting and knowledge translation. The framework notes that this is a growing trend internationally, and that supporting relationships between citizens and CIHR-funded researchers is "mutually beneficial because citizens' input can be used to comment on the relevance of proposed research, to identify research gaps, and to inform research priorities, while the experience of being part of the research process can empower communities and can increase scientific literacy" (CIHR, 2012). Mechanisms to accomplish this include involving citizens in the "merit review" of funding applications, and developing community-based research models that actively engage relevant communities in the development and implementation of the research program. CIHR cites its HIV/AIDS Community-Based Research Program as a successful example (CIHR, 2010).

Science Advice and Public Policy

Effectively incorporating scientific information and insights into the policy-making process is another aspect of promoting a strong science culture. Canada's federal government has a number of mechanisms for this purpose. The Science and Technology and Innovation Council, established by the 2007 federal science and technology strategy, is an advisory body of 18 experts who provide policy advice to the government on science and technology issues. The federal government has a funding agreement with the Council of Canadian Academies to produce independent, authoritative, and evidence-based expert assessments (such as this one) on scientific issues of public importance. The government has also periodically established other independent external panels or committees to provide guidance on scientific issues.[31]

The not-for-profit Partnership Group for Science and Engineering (PAGSE) is a non-governmental source of support for bringing science into policy-making in Canada. PAGSE collaborates with NSERC to offer the monthly "Bacon and Eggheads" breakfast, one of few opportunities for parliamentarians to engage with the scientific community and learn about topical scientific issues (PAGSE, 2013a). PAGSE also works with SMCC to develop Science Pages, short briefs for politicians and policy-makers aimed at summarizing the current state of knowledge on policy issues with science and engineering at their core (PAGSE, 2013b).

31 Recent examples include the panel led by Tom Jenkins, which reviewed government programs aimed at supporting business R&D, and the aerospace industry review panel chaired by David Emerson.

International Comparisons

Comparing government support for science culture across countries is methodologically challenging given the lack of comparable data and the heterogeneity of these programs. However, while Canada's federal government engages in a range of programs that both directly and indirectly support science culture, comparisons with other countries suggest that it has been less active in this area than many of its peers.

In promoting a national vision for science culture or science in society, for example, both Australia and the United Kingdom have strategies that articulate national goals on science and society and on engaging the public in science and technology. In Australia the *Inspiring Australia* strategy provides "a national strategy for engagement in the sciences" aimed at promoting science and science literacy in Australia (Commonwealth of Australia, 2010). In the United Kingdom the Department for Business, Innovation and Skills has engaged in extensive work and consultations around the theme of science in society over the past decade, and has an explicit policy on engaging the public in science and engineering (BIS, 2013). Both countries have also developed national skills strategies. In the United States the Obama administration has been active in promoting science education, with much of this work now organized under the rubric of its "Educate to Innovate" campaign (The White House, 2013). In comparison, Canada's brief mention of public science outreach and engagement within the context of its overarching science and technology strategy does little to signify that it is an issue of national importance.

Some countries have also been more assertive in creating opportunities for the public to engage in discussions about science and technology. The United Kingdom and Denmark, for example, have explored various models for increasing public engagement in science. Denmark's Board of Technology developed a distinctive consensus conference model in the 1980s, which involves a combination of lay investigation and expert testimony in a public forum (Einsiedel *et al.,* 2001). In the United Kingdom concern about the adequacy of institutional support for public engagement led to the development of the Sciencewise Expert Resource Centre in 2007, a national centre aimed at supporting "public dialogue in policy-making involving science and technology issues" (SW, 2013). No similar institution exists to promote public engagement in science and technology issues in Canada.

Finally, another characteristic of federal support for science culture in Canada is the lack of a leading source of funding and support for research on informal science learning. In the United States the National Science Foundation's Informal Science Education Program[32] serves as a source of funding support for organizations exploring new models or approaches to delivering informal science learning and engagement experiences, and generates new research and knowledge on U.S. science learning in informal contexts. The absence of a similar national funding program in Canada limits financial support for new types of science education and outreach in informal contexts, and also constrains the development of knowledge on the effectiveness and impacts of Canadian informal science learning institutions and programs.

5.4.3 Formal Science Education in Canada

While this chapter focuses on documenting informal science engagement and learning opportunities in Canada, limiting the discussion to informal science interventions risks creating a misperception about the relative roles and importance of formal and informal science learning in two respects.

First, formal and informal science learning providers are linked. Many informal science learning organizations such as science centres and museums also provide support for the formal education system through the provision of instructional materials or opportunities for teacher training and professional development. As illustrated in Section 5.2.1, on average nearly one-third of total visitors to science centres are schoolchildren. At the post-secondary level, universities and colleges often offer camps, classroom visits, online resources, clubs, competitions, public lectures, travelling performances, and mentorship programs. Such programs aim to promote science awareness, interest, engagement, and appreciation in their local communities, and some universities employ full-time science outreach coordinators (RU, 2013). Outreach programs may be supported by particular departments or faculties or partnered with outside organizations. Some special events, such as the UBC Celebrate Research Week, are sponsored by the university (UBC, 2013). Given the extent of these types of support and collaboration at all levels of instruction, formal and informal science learning providers are more productively viewed as partners in supporting science learning and engagement in Canada.

32 This funding program is now called the Advancing Informal STEM Learning (AISL) program; see http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504793.

Second, exposure to science in the formal education system is a primary driver of science culture. The Panel's analysis found that exposure to science courses in university and educational attainment in Canada accounted for a large amount of the variation in science knowledge across individuals (see discussion in Appendix D). Analyses of the United States, (Miller *et al.*, 1997; Miller 2002, 2012) have found that exposure to college-level science courses is the single greatest predictor of an individual's level of scientific knowledge. Miller (2012) points to this finding in explaining the relatively high level of public science knowledge in the United States, which is unique among European and Asian countries in requiring all college and university students to complete a year of college science as part of their general education requirements for a baccalaureate program. Thus exposure to science throughout the formal education system, including at the post-secondary level, is the single most influential factor in determining overall levels of scientific understanding and knowledge in the public.

Canada's relatively strong performance on international student assessments such as PISA and TIMSS suggests that its formal science education system is competitive relative to most of its international peers, though declining scores indicate a danger of falling behind. One factor possibly underlying this success is the *Common Framework of Science Learning Outcomes K to 12,* which provides the basis for most provincial science curricula in the K–12 system (see Box 5.6). While a detailed examination of Canada's formal science education system was beyond the Panel's mandate, the formal education system and its associated curricula, instructional practices, organizational supporters, and learning environments are clearly significant determinants of Canada's national science culture.

Box 5.6
The Common Framework of Science Learning Outcomes K to 12

Arguably the most important factor influencing the design of current provincial science curricula in Canada is the *Common Framework of Science Learning Outcomes K to 12*, published by the Council of Ministers of Education, Canada in 1997. Intended to provide direction for science curriculum development across Canada, the framework identifies learning outcomes for students from Kindergarten to Grade 12. It was designed around four inter-related foundations:

i. *Science, technology, society, and the environment*: Students will develop an understanding of the nature and relationships of science and technology to social and environmental contexts of science and technology.
ii. *Skills*: Students will develop the skills required for scientific and technological inquiry, for problem solving, for communicating scientific ideas and results, for working collaboratively, and for making informed decisions.
iii. *Knowledge*: Students will construct knowledge and understandings of concepts in life science, physical science, and Earth and space science, and apply these understandings to interpret, integrate, and extend their knowledge.
iv. *Attitudes*: Students will be encouraged to develop attitudes that support the responsible acquisition and application of scientific and technological knowledge to the mutual benefit of self, society, and the environment.

(CMEC, 1997)

The science framework aims to provide "all Canadians, regardless of gender or cultural background, [with] an opportunity to develop science literacy" (CMEC, 2010). Its general intent was to harmonize curricular standards for science education across provinces. Prior to its development, limited science instructional material with Canadian content existed. However, the development of a pan-Canadian science framework stimulated the creation of textbooks and resources specific to Canada's science curriculum and more representative of the Canadian social, cultural, and geographic environment.

5.5 THE FUNCTIONAL ROLES INVOLVED IN SUPPORTING CANADA'S SCIENCE CULTURE

As suggested in the previous section, neat distinctions between different types of science learning providers are often overly simplistic. In addition, an exclusive focus on types of organizational supporters (or learning contexts) for science culture can obscure the variety of roles involved in developing a stronger science culture. Many types of organizations pursue similar learning or engagement objectives, and a single organization may be involved in activities with multiple objectives. A more productive framework for analyzing the system of organizations involved in supporting science culture in Canada takes into account organizational types and their respective functional roles.

In considering the spectrum of activities necessary for the cultivation of a strong science culture, the Panel identified 10 core roles that science culture supporters fulfil, ranging from sparking and sustaining interest in science, to developing advanced science and technology skills, providing entertainment and information to the public, and supporting the incorporation of scientific evidence and methods into public policy development. Both formal and informal science learning providers are involved in this system, as are a number of other types of institutional supporters. Table 5.5 provides a framework mapping different organization types to their respective functional roles in the system. The attributions made in the table represent the Panel's collective judgment, with the acknowledgment that there will inevitably be organizations whose activities extend beyond the roles identified here.

This framework is helpful in disentangling the stereotypes about the roles of different organization types. Both formal and informal science learning providers, for example, contribute to developing core science knowledge and competencies, though, in the case of the latter, this may be a secondary objective, depending on the context and program in question. Both these types of institutions, however, are also involved in sparking and sustaining interest in science. The framework also illuminates potential opportunities for collaboration in the support system. In no case is one of these functions relegated to a single organizational type, though a single type of organization plays a leading role in some cases. The framework emphasizes that cultivating a strong science culture includes a broad range of activities associated with supporting and undertaking scientific research itself, communicating and sharing research results with the public, and engaging the public in decision-making related to support for science and technology.

Table 5.5

Institutional and Social Support for Science Culture: Organization Types and Functional Roles

	Formal Science Learning Providers		Informal Science Learning Providers						Other Organizations		
Functional Roles	Primary & Secondary Schools	Colleges & Universities	Science Centres & Museums*	Science Media	Youth Programs & Camps**	Science Festivals	Family & Peers	Nature Areas & Parks	Industry	Governments	Research Institutes & Labs
Sparks and sustains interest in science	√	√	√	(√)	√	√	√	√			
Develops core science knowledge and competencies	√	√	√		√		√				
Provides advanced scientific and technical training		√							(√)	(√)	√
Supports discovery research in the sciences		√							(√)	√	√
Provides information on new developments relating to science and technology			(√)	√			√		(√)	(√)	(√)
Fosters public science awareness and appreciation			√	(√)	(√)	√	(√)	√		(√)	(√)
Provides opportunities for the public to engage in and inform scientific research		√								√	√
Provides entertainment through exposure to science and technology	(√)		√	√	√	√		√			
Articulates the role of science in society	(√)	(√)	√	(√)	(√)	(√)	√			√	
Incorporates science into public policy development		(√)								√	(√)

The table indicates both the range of organization types involved in supporting science culture in Canada, and the functional roles involved in providing that support. *Includes zoos, aquariums, and botanical gardens. **Includes science fairs. (√) Denotes secondary focus.

5.6 CHAPTER SUMMARY

Given the lack of internationally comparable data, it is impossible to rigorously ascertain the relative strengths or weaknesses of different parts of the informal system that supports science culture in Canada. The discussion in this chapter has therefore been primarily descriptive rather than analytical. The evidence base, however, does support a number of informed observations on the state of institutional and social support for science culture in Canada.

Canadians have access to a diverse constellation of informal science learning and engagement opportunities. Canada is home to an extensive network of science centres and museums, which is on par with networks in leading countries such as the United States in terms of attracting visitors. Canadians also benefit from substantial public outreach activities supported by organizations, and Canadian youth have access to opportunities created by a number of youth science education and outreach programs that are national in scope. There are a growing number of annual science festivals across the country and many opportunities for science learning through experiences in the natural world.

With respect to science in the media, Canada has a number of successful, long-standing, and iconic science media programs in radio and television, but general coverage of science in Canada in the English-language media appears comparatively underdeveloped. There are few dedicated science columnists at major newspapers and no nationally distributed science magazine outside of *Canadian Geographic* (though *Québec Science* is a long-standing Francophone science magazine). While a lack of Canadian sources may not result in an overall constraint on the availability of science content due to ready access to periodicals from other countries, it does limit exposure to content targeted at Canadians and about Canadian researchers or institutions.

Examples of the involvement of industry in supporting and promoting public science education and outreach in Canada are not difficult to find. However, there is no available base of evidence for evaluating either the extent or effectiveness of this source of support. Although it is also difficult to compare government support for science culture across jurisdictions, Canada's federal government has not been as active as some of its peers abroad in promoting a national vision for science culture. Canada also lacks a dedicated funding program for research on informal science learning like the one provided by the National Science Foundation in the United States. This limits financial resources for informal science learning initiatives, and, more importantly, curtails the amount of available information on the effectiveness and impacts of existing programs and initiatives in Canada.

Finally, since the formal and informal science learning systems are linked, experiences in formal science education are major drivers of national science culture. In this respect, Canada's internationally competitive science education system at the primary and secondary levels likely contributes to Canadians' comparatively high levels of scientific knowledge and engagement.

6

Cultivating a Strong Science Culture

6 Cultivating a Strong Science Culture

Key Findings

- Practices, strategies, and support systems conducive to strengthening science culture can be organized under five themes: supporting lifelong science learning, making science inclusive, adapting to new technologies, enhancing science communication and engagement, and providing national or regional leadership.
- Developing public science knowledge depends on two complementary resources: an effective formal education system that provides students with a grounding in basic scientific concepts and information acquisition skills, and a range of informal science learning resources that adults can continue to access throughout their lives.
- Science interest and engagement are unequally distributed throughout the population, and one strategy for strengthening science culture is to target these existing inequalities. Tailoring science learning and engagement to the social and cultural contexts of groups traditionally underrepresented in the sciences can make science more inclusive.
- New technologies can connect learners with a wide range of online resources, offering new possibilities for science engagement and learning (e.g., citizen science, social media, blogs). New technologies are also changing how many science learning and engagement providers reach out to their audiences.
- Effective science communication takes into account the audience's social and cultural context and characteristics. Creating incentives and building capacity of scientists to share their work can enhance the quality and quantity of public science communication. Engaging the public in two-way communication throughout the scientific process can make science more relevant to society and build public science knowledge.
- Governments can play a role in articulating a national (or regional) vision for science culture, which can provide a framework for action across organizations and a foundation for coordination. Governments can also celebrate science and scientists, strengthen science learning through the formal education system, and coordinate efforts across a wide range of organizations through leadership and information sharing.

The previous two chapters have assessed the state of science culture in Canada and examined its institutional and social support system. However, science culture is not static in any society. It can be strengthened along the dimensions explored in this report. Building from an evidence base that includes academic publications, grey literature, and a review of government and organizational practices across countries, the Panel identified a range of strategies, practices, and support systems that can be used to cultivate a stronger science culture in

Canada and other countries. In some cases, these support systems and practices can already be observed in Canada, while in others they are emerging or notably absent. The approaches selected by the Panel fit broadly under five themes:

- **Supporting lifelong science learning:** What can be done to increase science knowledge and understanding in the public?
- **Making science inclusive:** How can science instruction and engagement be tailored to various social and cultural contexts to make science and science culture more socially inclusive?
- **Adapting to new technologies:** How can emerging technologies best be harnessed to build science knowledge and engagement? How can science culture supporters adapt to a rapidly changing technological landscape?
- **Enhancing science communication and engagement:** What strategies are used to enhance science communication with the public and engage the public in two-way communication on science issues?
- **Providing national or regional leadership:** What strategies and practices can governments apply to develop a strong science culture?

The nature, volume, and quality of evidence used to inform the Panel's analysis of these interventions is highly variable. Effective practices pertaining to science education and science communication and engagement have been the subject of significant research efforts. As such, the Panel had a well-established evidence base from which to draw. In contrast, effective practices for using technology to support science learning and engagement are still emerging; thus the evidence base is less established. Some countries have emerged as leaders in fostering a national science culture, and shared approaches to promoting science culture across countries implicitly reveal some degree of consensus about effective practices for governments. However, the evidence base on the effectiveness of specific government policies or programs is sparse.

The focus in the following discussions is on general lessons emerging from the available evidence, applicable not just in Canada but in other jurisdictions as well. However, specific implications for Canada are noted where relevant, taking into account the Canadian context and the data presented in the previous chapters.

6.1 SUPPORTING LIFELONG SCIENCE LEARNING

Developing public knowledge and understanding of science relies on both effective science instruction in the formal school system, and on providing continued opportunities for individuals to learn about science throughout their lives. Research on public science knowledge has demonstrated a strong link between educational attainment and scientific understanding in all countries, with more highly educated individuals predictably exhibiting higher levels of scientific knowledge and understanding (EC-DGR, 2010; Miller, 2012; NSB, 2012) (see discussion in Section 5.4.3).

This does not, however, negate the role that access to informal science learning opportunities can play in supporting the acquisition of science knowledge during an individual's lifetime. In the United States use of informal science learning resources is the third most significant determinant of science knowledge, after the number of college science courses and educational attainment (Miller, 2012). Research on informal science learning and engagement often notes that time spent in formal school environments represents a small portion of an individual's total lifespan (NRC, 2009). Falk and Dierking (2010) report that the average American spends less than 5% of their life in classrooms, and also point to the comparatively greater range of informal science learning opportunities in the United States as a possible factor in explaining that country's higher levels of public science knowledge.

It is also critical to consider the respective roles of formal and informal science learning systems in supporting the development and acquisition of public knowledge. The formal education system provides instruction in basic scientific constructs and processes of the type necessary to make sense of a wide range of scientific information. It also gives students the opportunity to develop the skills needed to understand and acquire scientific information in the future. Teaching science content in the formal education system is often viewed as a means for teaching students about scientific processes and methods, and developing their analytical and critical reasoning skills. The formal education system, however, cannot supply an individual with all of the scientific knowledge they will require during their lifetime as a citizen in a modern, technologically advanced society. Although the large majority of adults living today, for example, were not taught about the science of climate change or stem cells while students, as adults and citizens they are expected to be able to make sense of competing arguments on these issues in the public sphere and express their views and preferences through the democratic process. There is no reason to expect the pace of scientific and technological change to abate in the future, and today's students will likely be faced with scientific issues as adults that are not anticipated in current curricula.

This points to the need for complementary opportunities for adults to seek out information on scientific issues and subjects throughout their lives — opportunities that can be accessed through a range of informal science learning providers and resources. Science centres and museums, science programs on radio and television, science magazines and journalism, and online resources can all help fulfil this function by providing accessible resources for adult science learning, and by anticipating emerging information needs based on topical issues.

Most informal science learning organizations already provide these opportunities to varying degrees; however, this conception of the relative roles of informal and formal science learning providers differs from the traditional understanding, which often emphasizes how informal environments can foster engagement in science (particularly among youth), thereby triggering additional interest and the later acquisition of knowledge (Miller, 2010b). Such a focus may be appropriate for youth programming, but neglects the role that these institutions can play in ongoing education for adults, who often seek out information on science based on specific, well-defined interests or needs (e.g., a medical diagnosis, a newspaper article on the threat of a viral pandemic, a new technology brought into the workplace) (Miller, 2012). Informal science learning providers can take advantage of such opportunities by anticipating these needs, providing useful and accessible information, and then simultaneously building and deepening knowledge of the underlying science through additional content.

In extending science learning opportunities beyond formal environments, it is also important to recognize how new technologies are affecting the ways that individuals seek out information about scientific issues throughout their lives. The internet is now the dominant channel used by individuals to learn about many scientific issues (NSB, 2012) (also see this Panel's survey data as reported in Chapter 5). Miller (2010b) reports that use of traditional science media such as newspapers, television, and radio has been declining in the United States since the mid-1980s, as has attendance at science centres and museums. At the same time, access to computers and reliance on the internet has grown exponentially, and public science knowledge has continued to increase. The Panel's survey data show that Canadians are also now routinely using online sources to look for information on science and technology (see Section 5.1). All types of science learning providers (both formal and informal) will need to continue to adapt to a rapidly changing technological landscape (Miller, 2010b), in part by extending their approach to supporting science learning and information acquisition into online spaces.

Both formal and informal science learning environments have a role to play in the development of public science knowledge. Effective practices that support science learning are often widely applicable over an individual's lifetime and in a wide range of venues including classrooms, museums, afterschool programs, and adult learning programs. Falk (2001) argues that "there is no convincing evidence that the fundamental processes of learning differ solely as a function of the physical setting." A full review of pedagogical and learning strategies is beyond the scope of this assessment, but science learning providers have many resources and practices from which to draw.[33] At the level of a society, however, the critical implication is that public science knowledge depends on two complementary resources: (i) an effective formal education system that provides young people with a basic conceptual understanding of science and the tools to recognize situations where science is relevant to their lives and seek out new information, and (ii) a diverse set of informal science learning opportunities that provide adults with resources for learning about emerging scientific issues of public importance and for continuing to deepen their understanding of science throughout their lives.

The evidence reviewed by the Panel indicates that Canada is well positioned in terms of developing both of these assets. Canadian students perform well on international assessments of science and mathematics such as PISA, though declining scores are raising concerns about future performance. However, Canada still ranks second among G7 countries in both science and mathematics (Brochu *et al.*, 2013). Data presented in Chapters 4 and 5 also suggest that Canadians often use informal science learning resources relative to citizens of other countries, and benefit from access to a relatively wide range of these resources. Going forward, Canada can continue to build on these assets in strengthening adult science knowledge in the population. Informal science learning environments should continue to provide adults with timely access to scientific information, and consider how they can adapt to an environment where those adults are increasingly seeking information through online channels in response to specific needs and interests.

6.2 MAKING SCIENCE INCLUSIVE

Many dimensions of science culture are not equally well established across all segments of the Canadian population, though in this respect Canada differs little from other industrialized countries. One strategy for strengthening science culture is therefore tailoring science learning and engagement to the social and cultural contexts of groups traditionally underrepresented in the sciences and addressing existing inequities in scientific knowledge or engagement in the population. The inclusion of alternative cultural perspectives in science instructional practices can extend the ability to understand and participate in scientific thinking of a larger cross-section of society than would otherwise be the case (Marginson *et al.*, 2013).

This section explores strategies that have been demonstrated to support science learning among two groups in particular: Aboriginal students and girls and women. The Panel did not attempt to identify strategies relevant to all underrepresented groups in Canada, and acknowledges that these are not the only groups for which

33 The NRC (2009) report on informal science learning provides an extensive survey of strategies applicable to informal science learning contexts.

it may be important to tailor science learning and engagement strategies.[34] The discussion of practices provided here is not intended to be exhaustive; rather a selection of promising practices are highlighted as examples of potential approaches for addressing the existing inequities in Canada's science culture.

6.2.1 Supporting Science Learning and Engagement in Aboriginal Populations

Aboriginal populations represent one group that is traditionally marginalized when it comes to involvement in science in Canada. Compared with non-Aboriginal students, Aboriginal students in Canada are underrepresented in high school science enrolment, which can result in a cascading effect including low participation in post-secondary science-related programs and low employment in science-related sectors (Richards & Scott, 2009). In 2012, 72% of off-reserve First Nations people, 42% of Inuit, and 77% of Métis aged 18–44 had a high school diploma, compared with 89% of non-Aboriginal people. In 2011 about half of Aboriginal peoples had a post-secondary qualification, compared with about two-thirds of non-Aboriginal people (Bougie *et al.*, 2013). In terms of science, factors identified as barriers to Indigenous participation include the degree to which Indigenous students experience marginalization in science classes (Aikenhead & Elliott, 2010); a mismatch between Aboriginal world views and the science curriculum and pedagogy; and the exclusion of Indigenous knowledge and pedagogy from the Canadian educational system (Hatcher & Bartlett, 2010). As a result, some education researchers have suggested that the system has failed First Nations children and have called for pedagogies that are more sensitive to cultural differences (Battiste, 2002).

Educators interested in culturally based approaches to informal and formal science education argue that there are alternative perspectives and ways of knowing that support Indigenous learners in both urban communities and reserve settings, instead of always focusing instruction on scientific understanding (Aikenhead, 1996; Cobern & Aikenhead, 1997; Brayboy & Castagno, 2008). Culturally relevant science education (CRSE) is about building bridges between a child's home culture and school culture by teaching scientific and cultural understandings of nature alongside one another to improve school performance (Klug & Whitfield, 2003). Educators have been interested in a pedagogy that more effectively coincides with the home and school environment for children,

34 The Panel did not attempt to present a comprehensive overview of strategies relevant to all socio-demographic groups underrepresented in science. Other groups may also be relevant; for example, *Learning Science in Informal Environments* explores science learning for "four nondominant groups for which a research tradition has developed: girls and women, American Indians, individuals from rural communities, and individuals with disabilities" (NRC, 2009).

particularly those children whose home setting contrasts with their school in terms of language and social norms (Ladson-Billings, 1995; Wlodkowski & Ginsberg, 1995; Martin, 1997; Phuntsog, 1998; Gay, 2000).

Researchers and informal and formal educators regard culturally responsive schooling as essential because Indigenous students possess different learning styles and cultural practices (Brayboy & Castagno, 2008). For Indigenous students, there may be a misalignment between the scientific perspective on nature and their own world view (Aikenhead, 1997, 2006). CRSE is viewed by many scholars as necessary because "its goal is to produce students who are bicultural and thus knowledgeable about and competent in both mainstream society and tribal societies" (Brayboy & Castagno, 2008). In the formal education system, current science curricula often emphasize the importance of conclusions that can be generalized beyond the local context, de-emphasizing the importance of localized knowledge, an integral component of Indigenous knowledge.

Research studies suggest that creating culturally relevant learning environments fosters better student engagement (Snively, 1990; Nelson-Barber & Estrin, 1995) and greater family involvement (Hagiwara, 2002). In Canada some formal and informal initiatives have resulted in more CRSE practices for Aboriginal students. For example, Aikenhead (1997) has advocated and developed a cross-cultural science-technology-society curriculum that emphasizes what he calls "cultural border crossing" to enhance students' capabilities to draw upon both Aboriginal culture and science and technology, in order to make decisions related to economic development, the environment, and cultural survival. In an attempt to produce more culturally relevant teaching, Saskatchewan reformed its science curriculum and now incorporates Indigenous perspectives alongside supporting teaching resources. The Saskatchewan Ministry of Education collaborated with publisher Pearson Education Canada to develop a series of science textbooks that incorporate Indigenous knowledge (Aikenhead, 2013). Moreover, organizations such as Actua provide locally and culturally relevant community-based programming to 20,000 Aboriginal youth annually through science, engineering, and technology outreach initiatives (Actua, 2014).

In addition to existing practices, studies have investigated potential approaches to creating culturally relevant learning to improve student engagement. Hatcher and Bartlett (2010) set out an approach of "two-eyed" seeing, a form of inclusive education in which Aboriginal students become more than knowledge seekers: they become active participants. Crucial elements in this approach include co-learning, the connection of culture and community, Indigenous pedagogy, and a psychologically safe environment. The authors suggest that this approach, which acknowledges cultural differences and helps students resolve contradictions between school life and home life, is more effective than a focus on commonalities between groups, which may ignore values and knowledge from outside the dominant group (Hatcher & Bartlett, 2010).

In an attempt to describe the components necessary to create a lifelong model for successful science education in Canadian Indigenous communities, Sutherland and Henning (2009) convened a workshop that included Indigenous and non-Indigenous science teachers, administrators, and consultants working in Indigenous communities across Manitoba. Following presentations of culturally relevant science programs offered across the province, workshop participants identified reoccurring themes in Indigenous science education. According to this collection of educators involved in science learning across Manitoba, there are four pillars to a lifelong model for science education in Indigenous communities. The model includes the importance of Elders, Language, Culture, and Experiential Learning, which need to be incorporated into any science education program to support science learning among Indigenous students (Sutherland & Henning, 2009).

Battiste (2002) notes the importance of science instruction that incorporates Indigenous knowledge and respects Indigenous languages. According to Sutherland and Swaze (2013),

> Language, especially in contemporary times, is perhaps the most challenging aspect of Indigenous knowledge and science education because in order to have access to both knowledge systems one must be able to communicate in the languages of each system. In Canada for the most part science education takes place in the official languages (English or French) and the majority of Aboriginal children do not speak their native language.

Although it is not uncommon to observe educators using Indigenous languages to convey scientific concepts to students (Horcajo, 2000), Indigenous language in the science classroom cannot simply be used as a technical tool decontextualized and separated from culture. McKinley (2005) argues that a utilitarian approach to language use means that “culture is deontologized — it becomes an object, an artifact” and that “one of the main ways in which Indigenous knowledge systems can survive and thrive is through the establishment of programs taught through Indigenous languages so that a dialectical relationship between language and knowledge is established that continues to act as the wellspring.”

6.2.2 Supporting Science Learning and Engagement Among Women

Chapter 4 provided evidence that women in Canada are less knowledgeable about science than men in general, less interested in new developments in science and technology, and hold greater reservations about science than men. In addition, women continue to be underrepresented in many (though not all) fields of science, particularly engineering and computer science. However, Canada is not unlike other countries, which also exhibit significant gender differences in many of these measures (EC-DGR, 2010; NSB, 2012).

In response to the continued underrepresentation of women in the sciences, many strategies and practices have been explored that would further engage and support women in developing an interest in science and pursuing educational and career opportunities in the sciences. More comprehensive reviews of this issue and related strategies can be found elsewhere.[35] However, several programs and practices identified by the Panel have shown promise in addressing this aspect of cultivating a more equitable science culture. Such practices include highlighting the social benefits of science careers, addressing negative perceptions of the sciences among girls and young women, promoting work-life balance, providing mentorship opportunities, and engaging in informal science learning.

Girls have an interest in science-related fields, particularly those that value social engagement and offer opportunities to help others (Fadigan & Hammrich, 2004). Even in adulthood, women with an interest in science-related careers select occupations that underscore social engagement and help people (Fadigan & Hammrich, 2004). Examples of such careers can include professions such as psychologists, social workers, physicians, dentists, veterinarians, and researchers (CCA, 2012a). This provides an opportunity for both formal and informal science learning institutions to increase awareness of the social impact of scientific study. The University of British Columbia has undertaken such a challenge and implemented community service learning in its curriculum. Through the program, students and faculty are encouraged to use their intellectual capacity and skills to solve complex community-based challenges (UBC, 2014a). One such example is the retrofitting of a sailboat trailer for kayakers with disabilities (UBC, 2014b). Initiatives such as these communicate to youth how a science and engineering career provides opportunities to help people.

A survey of female students and science and mathematics teachers in five Canadian schools found that limited knowledge and understanding of engineering and technology careers among young women prevent them from aspiring to these careers. Further, participants had negative perceptions of engineering and

35 For one recent example, see CCA, 2012a.

technology occupations. Providing greater insights into the ability to effect positive change through these careers can therefore foster greater interest among young women (Tomas & O'Grady, 2009). For example, Academos Cybermentorat is an online mentorship program designed to provide career guidance among young Quebecers, aged 14 to 30. The program pairs youth in CEGEPs and high schools with mentors who give insights into the characteristics of a profession and inspire and support the development of their mentee. Mentors come from a cross-section of professional sectors including manufacturing, metallurgy, engineering, health care, construction, IT, and telecommunications. According to participation statistics for 2012–2013, 80% of participants reported that their mentor had a positive impact on their career choice and 90% reported having had a rewarding experience. The program has received several awards in recognition of its success (Academos Cybermentorat, 2013).

There is also evidence that work-life balance considerations may influence career choice. An analysis of the U.S. Survey of Doctorate Recipients revealed that "family formation — most importantly marriage and childbirth — accounts for the largest leaks in the pipeline between PhD receipt and the acquisition of tenure for women in the sciences" (Goulden *et al.*, 2011). Tomas and O'Grady (2009) point out that perceptions of work-life balance challenges in science careers may be an early deterrent. Some recent evidence suggests that the timing of peak periods of competition may also be important in career selection (see Box 6.1).

Box 6.1
Understanding Different Participation Rates in Medical and Academic Careers

While some suggest that careers that offer greater work-life balance will be more successful in attracting and retaining women, Adamo (2013) points to the high participation of women in medical careers as a counter-example. She argues that despite long hours and shift work, women are more likely to pursue and maintain medical careers than academic research careers in the biological sciences because the highly competitive period for doctors occurs when applying to medical school, whereas for academic positions it occurs after PhD completion when applying for post-doctorates and faculty positions. This period occurs later in life and is more likely to coincide with decisions about marriage and children. Policies that limit enrolment in graduate programs so that there is less competition for faculty positions upon graduation could help women succeed in science academia (Adamo, 2013).

The Council of Canadian Academies' Expert Panel on Women in University Research identified mentorship as a key tool to build networks, observe women as role models participating in science careers, and develop ease with the culture of physical sciences, computer sciences, mathematics, and engineering (CCA, 2012a). The NRC (2010) found that men in academia were more likely to engage in discussions about research, salaries, and benefits than female counterparts, pointing to one potential contribution of mentorship. Formal mentoring programs may also help overcome a lack of natural and informal mentorship opportunities for individuals who may not fit within an established norm in a field, which may include women or minority groups (Caprile & Vallès, 2010).

Evidence suggests that involvement in informal science learning and engagement can also have a significant impact. A recent Canadian study of over 600 Grade 7, 8, and 9 students found that girls are 2.7 times more likely to consider careers in science, math, and engineering if they participate in science fairs, competitions, science camps, and other informal science-related activities (Franz-Odendaal *et al.*, 2014). In comparison academic marks and teachers were found to have a significantly lower impact on career intentions (Franz-Odendaal *et al.*, 2014). Actua, through its National Girls Program, has had a positive impact on over 48,000 girls in Canada through its summer youth camp, and has improved their confidence in their own abilities, their awareness of the importance of science, and their interest in pursuing advanced academic training in science and technology (Actua, 2012).

6.3 ADAPTING TO NEW TECHNOLOGIES

Science culture in Canada and other countries is now evolving in a rapidly changing technological environment. Individuals are increasingly turning to online sources for information about science and technology, and science communicators and the media are also adapting to the new channels of communication and outreach provided over the internet. As people engage more with new forms of technology in their home and work lives, organizations may be able to identify new ways to take advantage of available technologies to support learning and foster science interest and engagement. At the same time, as noted in Chapter 2, this transition is also challenging traditional models of operation for many organizations such as science centres, museums, and science media providers, forcing them to develop new strategies.

Examples of the use of new technologies to support learning are now commonplace. Nesta, an innovation-oriented organization based in the United Kingdom, conducted a study investigating the extent to which new technologies are transforming learning among students (Luckin *et al.*, 2012).

The research, which drew from 124 examples identified in academic literature and 86 examples in informal literature, examined the role of technology in supporting different types of learning. The authors found that technology holds particular value in supporting interactive learning, creating opportunities for practice, offering opportunities to document and express learning in new ways, extending learning across venues, and facilitating assessment. In the majority of examples reviewed, technology simultaneously supported multiple types of learning (Luckin *et al.*, 2012).

Technology has been identified as a tool to support independent work, allowing learners to pursue information of most interest to them and presented in ways that align with individual learning styles (Banks *et al.*, 2007). Technology can also support self-directed learning. Sugata Mitra's experiments installing public computers in poor and remote communities in India have demonstrated that with computer access only, children can teach themselves computer skills, English, and complex subject content (Mitra & Dangwal, 2010). In one experiment, he found that children aged 10 to 14 could teach themselves molecular biology, achieving significant learning gains independently and even greater gains when an adult with no content knowledge encourages and supports them. In the presence of adult encouragement, learning outcomes were equivalent to those achieved in a private school where students were fluent in the language of instruction and had qualified teachers (Mitra & Dangwal, 2010).

Recent discussions in *Nature* have explored the implications of massive open online courses (MOOCs) for university science learning. One concern with online learning is the absence of opportunities for hands-on engagement and lab work. Waldrop (2013) highlights recent efforts to use websites, applications, and games to provide online enquiry-based learning opportunities. For example, one ecosystems course centres on a multi-user virtual environment where students explore a virtual pond, working in teams to collect and analyze data and explain the phenomena they are observing. Sive and Shama (2013) note the potential for online lectures to free up classroom time for student-teacher engagement.

Emerging websites assess the validity of different online information resources, directing learners towards more credible information sources. This is critical to ensure their science knowledge base is not skewed. Fausto *et al.* (2012) point to the value of scientific blogs, and Research Blogging in particular, as a tool that can help learners appraise the quality of science information, separating science from pseudo-science. In the case of Research Blogging, posting guidelines combined with community supervision are used to assure the quality and reliability of blog posts (Fausto *et al.*, 2012).

Organizations are also increasingly using social media to create excitement and wonder about science. During Canadian astronaut Chris Hadfield's time at the international space station, the Canadian Space Agency released YouTube videos showing the astronaut going about daily activities in space, explaining the impacts of living in a gravity-free environment, and sharing photographs taken from the spacecraft. Some of the YouTube clips have attracted millions of viewers (CSA, 2013a) and Hadfield has over a million Twitter followers (Twitter, 2013). Nearly all science learning providers are now relying on these tools to some degree as a means of communicating with the public and their communities.

Technology can support engagement in science activities. Science venue visitors can use cellular phones and audio players to tailor their own experiences and focus their visit on themes or exhibit types that are of greatest interest (NRC, 2009). Through a partnership with CANARIE (providers of an ultra high-speed information sharing network), the Canadian Museum of Nature offers visitors to its RBC Blue Water Gallery access to data and images from the NEPTUNE underwater ocean observatory (CANARIE, 2010). Social media offers unprecedented reach and an opportunity to engage broader audiences in science culture; in March 2013 Facebook had 655 million people using the site on a daily basis and Twitter had over 200 million active users (Facebook, 2013; Wickre, 2013).

It is also important, however, for organizations to think strategically about their adoption and reliance on new technologies. Some researchers have cautioned that technology is a tool for learning and engagement rather than an end in itself. In the case of science centres, the challenge can lie in "avoid[ing] burying the message in the glitzy technology" (Beetlestone *et al.*, 1998). These researchers recommend that organizations focus on making the best use of available technologies to support learning rather than trying to acquire cutting-edge technologies as they become available (Luckin *et al.*, 2012). Technologies are also most useful when paired with appropriate training to give teachers and other program providers the capacity to use these new tools effectively to support instruction and programming (Luckin *et al.*, 2012).

Finally, these pervasive and far-reaching technological developments are having an impact on the business models and programming of nearly all organizations involved in supporting science culture. Technology has changed the timing and nature of people's habits in accessing information, with learners increasingly relying on a "just-in-time" approach to seeking out information. Miller (2010b) highlights the opportunity for museums to become a more sought-out provider of adult science education and respond to information needs as they arise. They can do so by making museum resources available outside of the bricks-and-mortar building in other media, particularly by improving the quality of virtual learning offerings on their websites, adjusting to a just-in-time information model that demands information be accessible at any time, and using specific information requests as an avenue into other related learning (Miller, 2010b).

While this discussion has highlighted ways in which new technologies are being harnessed in support of science education and learning across various contexts, the rapid evolution of these technologies portends an uncertain future. As a result, all organizations involved in public science education, outreach, and engagement need to continue to closely monitor these trends and how they are affecting public modes of interaction with science, and be prepared to experiment and adopt new strategies or approaches as needed based on changing conditions. Strategies that were successful in the past may not be so in the future.

6.4 ENHANCING SCIENCE COMMUNICATION AND ENGAGEMENT

Science communication is an important avenue for strengthening science culture due to its reach across the population, the frequency of people's engagement with science through media, and a 24/7 news environment that can lead to rapid shifts in public opinion as new science-related stories break (e.g., Riise, 2012). There is often a lack of incentives for scientists to communicate with the public and a lack of training for scientists to be effective communicators to public audiences. There is also a general recognition that one-way communication is not enough: scientists need to become better communicators *and* better listeners in their interactions with the public. Public engagement throughout the scientific process can benefit both the public and the science itself, and various strategies have been adopted to increase public engagement in science.

6.4.1 Providing Incentives for Science Communication

Scientists are not commonly encouraged to hone their communication skills and dedicate time to public communication. Particularly in academia, existing organizational cultures and reward structures are more likely to encourage communication among scientists, through academic publications and conferences, than with wider society. A Royal Society (2006) survey of U.K. university-based scientists and engineers identified the following trends:

- Scientists who place more value on communication spend more time communicating.
- Demands to spend time conducting research are the most common barrier to spending time communicating.
- Existing incentive structures do not encourage communication.
- Scientists see a role for funders to support outreach efforts on an optional basis.

Communication-related training is also often absent, leaving scientists unsure of the best communication approaches to pursue. In the Royal Society survey, the majority of respondents had not received training in speaking to the media, communicating, or engaging with the public (RS, 2006). Let's Talk Science conducted a survey of over 900 researchers in Ontario and reached similar conclusions: time constraints and reward structures limit outreach activities. Almost 40% of respondents did not feel equipped to do outreach (Let's Talk Science, 2007). To achieve tenure or be promoted in Canadian universities and colleges, scientists must currently fulfil the requirements of teaching, research, and administration. Outreach activities and informal teaching are normally not considered as evidence of these activities. The European Research Advisory Board recommends integrating communication training into university programs and factoring engagement activities into career development (EURAB, 2007). According to the European Commission, engagement should be an essential component of excellence in science (EC, 2007).

Tying the award of research grants to public science communication and outreach activities has also been explored as a tool to encourage communication activities (Metcalfe *et al.*, 2012) (see Box 6.2). While such strategies can provide impetus for a broad range of communication efforts, in the Panel's view, it may be more beneficial to focus on supporting scientists with an interest in and an aptitude for communication activities, rather than on creating across-the-board requirements for all scientists to engage in such activities.

Box 6.2
Encouraging Science Communication Through Research Funding

The U.S. National Science Foundation assesses the quality of grant applications based on their intellectual merit and the "broader impacts" of the project, which includes social impacts that could be achieved through education and outreach, involvement of unrepresented groups, or the project outputs themselves (March, n.d.). This second criterion relating to the broader social impacts is controversial and has raised concerns about whether peer reviewers selected to assess the intellectual merit of a proposal are actually well-suited to undertake this evaluation. Questions have also been raised about the criterion's focus on the benefits of research to the exclusion of possible negative impacts (Holbrook & Frodeman, 2007; Frodeman & Parker, 2009; Holbrook, 2010).

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Canada's main funding program for discovery research, NSERC's Discovery Grants Program, places less emphasis on public outreach. It assesses proposals based on the qualifications of the researcher, the proposal's merit, and the extent to which the project will train and develop skilled personnel. While public outreach activities are not prominent in the criteria, they are mentioned as an element that could be used to evaluate researcher excellence and the project's potential to develop skills for the future (NSERC, 2012, 2013b). CIHR places a stronger emphasis on communicating research findings with interested audiences throughout the research process (CIHR, 2013c). CIHR's largest open funding program, the Open Operating Grant, includes the objective of "contribut[ing] to the dissemination, commercialization/knowledge translation, and use of health-related knowledge," and proposals are evaluated in part based on the "appropriateness and adequacy of the proposed plan for knowledge dissemination and exchange" (CIHR, 2009, 2013d).

6.4.2 Governments and Science Communication

In 2003 Canada's former Council of Science and Technology Advisors (CSTA) issued a report providing advice on government science and technology communication. The CSTA identified several strategies that support effective communication while balancing transparency and accountability, including to (i) communicate about issues, making use of relevant science as a tool to illuminate those issues rather than as the focal point in and of itself; (ii) favour openness; (iii) ensure that information is reliable to maintain confidence; and (iv) develop communication approaches that strengthen stakeholder relationships (CSTA, 2003). Given the significance of government science in many areas of research, government science communication constitutes an important vector for increasing public awareness and understanding about science. In Canada current policies governing how scientists working in federal departments and agencies are allowed to interact with the media and the public have come under heavy criticism in recent years (see Box 6.3).

The OECD (1997) underscores the importance of conveying not only scientific facts, but also scientific thinking and debate, which will help the public to understand the potential and limitations of scientific research. The public interest should also guide decisions about when and how governments communicate scientific findings to the public. In particular, governments are best served by seeking communication opportunities that foster public understanding and engagement in science, while at the same time safeguarding the public and improving government transparency and accountability (RS, 2006).

Box 6.3
The Canadian Government's Media and Communication Policies

Concerns about the federal government's current policies on government scientists' communication with the media have been widely reported in Canadian and international press in recent years (e.g., Ghosh, 2012; CBC, 2013c; Gatehouse, 2013; Hume, 2013; Mancini, 2013; Munro, 2013). These concerns were also recently voiced by the editorial board of *Nature* (2012), which unfavourably compared Canada's current approach with the more open policies now in place in the United States. Scientists at many U.S. federal agencies are free to speak to the media without prior departmental approval, and to express their personal views as long as they clearly state that they are not speaking on behalf of the government. In response to such concerns, and to a formal complaint filed by the Environmental Law Clinic at the University of Victoria and Democracy Watch, on April 2, 2013 Canada's Information Commissioner launched an investigation into whether current policies and policy instruments in seven federal departments and agencies are "restricting or prohibiting government scientists from speaking with or sharing research with the media and the Canadian public" (OICC, 2013).

Since these concerns have come to light, many current and former government scientists have discussed how these policies have affected their interactions with the media. Marley Waiser, a former scientist with Environment Canada, has spoken about how that department's policies prevented her from discussing her research on chemical pollutants in Wascana Creek near Regina (CBC, 2013c). Dr. Kristi Miller, a geneticist with the Department of Fisheries and Oceans, was reportedly prevented from speaking publicly about a study she published in *Science*, which investigated whether a viral infection might be the cause of declines in Sockeye salmon stocks in the Fraser River (Munro, 2011).

According to data from Statistics Canada (2012), nearly 20,000 science and technology professionals work for the federal government. The ability of these researchers to communicate with the media and the Canadian public has a clear bearing on Canada's science culture. Properly supported, government scientists can serve as a useful conduit for informing the public about their scientific work, and engaging the public in discussions about the social relevance of their research; however, the concerns reported above raise questions about the extent to which current federal policies in Canada are limiting these opportunities for public communication and engagement.

6.4.3 Understanding the Audience

In a synthesis of literature on successful science communication, Nisbet and Scheufele (2009) point out that science communication strategies are often not based on evidence. They observe that recent research has demonstrated that public views of science are shaped by many factors including past experience and impressions of vested interests of scientists; science understanding is only one factor. The authors advocate for a new approach informed "by an empirical understanding of how modern societies make sense of and participate in debates over science and emerging technologies." They highlight the importance of framing in science communication and choosing frames that encourage public engagement and debate as well as learning. In a paper emerging from an interdisciplinary science communication workshop funded and hosted in Canada, Bubela *et al.* (2009) observe:

> Frames are used by lay publics as interpretative schemas to make sense of and discuss an issue; by journalists to condense complex events into interesting and appealing news reports; by policy-makers to define policy options and reach decisions; and by scientists to communicate the relevance of their findings.

The current framing of some intractable issues may contribute to communication problems (Nisbet & Scheufele, 2009). For example, debates on climate change are often framed around conflict, or the Pandora's box of possible consequences, but reframing climate change using an economic development or public health angle may be more productive (Nisbet & Scheufele, 2009). Of course, any choice of frame must preserve the integrity of the communication (Bubela *et al.*, 2009).

Communicators also need to consider how personal and cultural values influence the way that people process information (Nisbet & Scheufele, 2009). A recent analysis of beliefs about the threat of climate change revealed that cultural views are more important in predicting opinion than scientific literacy or numeracy (Kahan *et al.*, 2012). The study authors explain this result by noting that peer acceptance is very important to individuals whereas their own individual beliefs about climate change will not have an impact on the scale of the problem; thus it is in an individual's self-interest to support the belief held by peers. The authors conclude that communication needs to move away from polarizing debate towards language that will resonate with diverse groups (Kahan *et al.*, 2012). In an opinion piece in *Nature*, Kahan (2010) notes that, although this phenomenon is better understood than the practices that can be used to overcome it, two communication strategies may be of assistance: (i) presenting information in an intellectually honest way that aligns with the audience's values, and (ii) demonstrating that diverse experts from various cultural communities hold the same scientific view.

6.4.4 Leveraging Popular Media Platforms: Opportunities and Constraints

Media platforms are now sometimes leveraged to engage the public in science-related issues. Examples of these non-traditional approaches include the pairing of scientists with filmmakers to incorporate science in film;[36] provision of financial support and resources to assist screenwriters in creating films with strong science themes and the portrayal of scientists in prominent roles (IEEE, 2008); new programming available on networks like the Discovery Channel; greater emphasis on local science stories; and greater coverage of science in comedy programming such as "The Daily Show" and "The Colbert Report" (Nisbet & Scheufele, 2009). However, opportunities to apply these practices may be limited by the economic climate for major media firms. A 2009 survey conducted by *Nature* suggests that traditional media are shedding full-time science journalists while increasing the workload of the science reporters who remain on staff, and, in some instances, entire newspaper science sections have been shut down (Brumfiel, 2009).

However, the extent to which mass media can effectively support science communication is limited. While fictional programming can use science ideas, the facts of the science may not be very important to the storyline, and, even in the case of news media, short segments and the need to simplify may shape the ultimate message, as will the anticipated popularity of the item (Kitzinger, 2006). Kitzinger (2006) also points out that the messages that people take from media may not be as the science communicator intended, suggesting that people often turn to media to reaffirm an existing view, and cultural and demographic contexts can also shape the meaning of media messages. In addition, the journalistic approach to communication is fundamentally different from that of a research scientist, with journalists relying more heavily on individual accounts, and research papers being more quantitative and oriented towards an expert audience (Bubela *et al.*, 2009).

Balanced reporting also presents challenges for science communication. An analysis of U.S. print media coverage of global warming between 1988 and 2002 shows that reliance on balanced reporting — that is, the need to report both sides of a story — contributed to biased coverage in the sense that the media discourse was not consistent with the predominant discourse in the scientific community (Boykoff & Boykoff, 2004). For example, during that period over half the articles gave equal attention to theories of human and natural causes of climate change (Boykoff & Boykoff, 2004).

36 The U.S. National Academy of Sciences runs The Science and Entertainment Exchange, a service that "connects entertainment industry professionals with top scientists and engineers to create a synergy between accurate science and engaging storylines in film and TV" (The Exchange, 2013).

6.4.5 Engaging Society in Two-Way Communication

Much of the research on public understanding of science emphasizes an evolution from a "deficit model," focused on one-way communication from scientists to the public, to a two-way engagement model that gives the public a voice throughout the scientific process (Bauer, 2009). There is a broad consensus that a range of science communication and two-way engagement efforts can strengthen policy outcomes by pulling in more voices, building support for science, growing interest among youth, encouraging science careers, improving science knowledge, and boosting the overall value of science to society (CSTA, 2003; RS, 2006; Commonwealth of Australia, 2010). Upstream public engagement in science in particular can raise questions that open up new research directions, alert researchers to potential social concerns stemming from their work, foster legitimacy, and help inform outreach strategies (EURAB, 2007). Understanding society's needs and interests also helps enhance science's value to society, as demonstrated through contributions of the U.K. Alzheimer's Society to disease research (Wilsdon *et al.*, 2005; EURAB, 2007).

Two-way public engagement can be achieved through many approaches. The public can engage in the research process itself, working with scientists to determine research questions, collecting and analyzing data, or discussing and sharing results (Bonney *et al.*, 2009b). Participatory activities such as citizen science programs (see Box 2.1) can foster interest and community engagement, help the public better understand not only a specific scientific issue but also the scientific process, and develop science skills (Bonney *et al.*, 2009b). Other public engagement forums include consensus and deliberative workshops, which are typically university-based or run by an NGO and match local demands for scientific knowledge to expert advice (EC, 2003; EURAB, 2007).

These engagement activities, however, need to be carefully crafted to meet their desired objectives. Powell and Colin (2008) note that a common pitfall is the lack of mechanisms to tie engagement outcomes concretely to policy-making processes. Engagement activities need to avoid simply seeking affirmation from participants; rather, organizers should be prepared to accommodate a range of possible outcomes (EURAB, 2007; Powell & Colin, 2008). The OECD's recommendations for effective public engagement include the following: describe the relevance of the issue for society, include stakeholders in framing and preparation, be transparent about process, be clear on goals (and that they can be met fully or partially), involve policy-makers to reinforce credibility, distinguish risk from uncertainty, and do not insist on consensus (OECD Global Science Forum, 2009). *Inspiring Australia* states that activities that draw in more diverse participants will be more successful in fostering greater levels of interest and engagement, while also offering more valuable information and inputs for researchers (Commonwealth of Australia, 2010). Engagement is seen to be most effective when it occurs over time, creating new opportunities for public input as the science evolves from basic research to innovation and eventually deployment, and also building capacity among a group of citizens (EC, 2007; Powell & Colin, 2008).

The Sciencewise Expert Resource Centre is a U.K. government-funded organization that works with government departments to engage with the public on science issues, with a view to mainstreaming public engagement and using public attitudes to inform public policy decision-making (SW, n.d.). A recent evaluation found that Sciencewise has been successful in developing and implementing public dialogue projects that have shaped public policy, and noted positive perceptions of the program's value among participants. It also identified a need to put more effort into using the outputs of public dialogue sessions to the fullest extent possible (SW, 2013).

6.4.6 Acknowledging Debate and Controversy

Many organizations including science centres and museums, research centres, and even governments may be perceived as having a science promotion agenda that portrays only the benefits of science. As a result, these organizations are not always seen as promoters of debate through questioning, which is a crucial part of the scientific process. Acknowledging complexity and controversy is another means to improve the quality of public engagement in science in a range of different contexts. Durant (1996) makes several suggestions for science museums in this regard. First, traditional museum exhibits can be complemented with timely displays that address current issues. Second, opportunities for visitors to engage with exhibits, other visitors, and staff can allow them to raise questions and concerns. Third, language can be used to promote questions and acknowledge differing views rather than simply being instructional.

Some science centres and museums are increasingly experimenting with this kind of approach. For example, the U.K. Science Museum opened a new permanent gallery in 2010 devoted to climate science, shortly after leaked emails from the University of East Anglia caused widespread controversy about the reliability of climate science. The aim was to make the gallery a space that "engage[s] and interest[s] those who accept that man-made climate change is real, as well as those who are unsure and those who do not" (Rapley, 2010).

6.4.7 Linking Science to the Arts and Design

U.S. advocates for "STEM to STEAM" call for an incorporation of the arts in discussions of science, technology, engineering, and mathematics in an effort to "achieve a synergistic balance" (Piro, 2010). They cite positive outcomes such as cognitive development, reasoning skills, and concentration abilities. Piro (2010) argues that "if creativity, collaboration, communication, and critical thinking — all touted as hallmark skills for 21st-century success — are to be cultivated, we need to ensure that STEM subjects are drawn closer to the arts." Such approaches offer new techniques to engage both student and adult audiences in science learning and engagement opportunities.

The trend to merge science and art provides scientists with a medium to access new audiences for their work (Webster, 2006). In an evaluation of the U.K. Wellcome Trust's 10-year Sciart funding program, which distributed almost £3 million (approximately C$5.5 million) to 118 projects that combined science and art, the authors identified a wide variety of program benefits including educational value for audiences as artists found new ways to communicate scientific information, ethical value as new forums provided a way for the public to challenge and be critical of science, and cultural value in supporting interdisciplinary work (Glinkowski & Bamford, 2009). Roughly three-quarters of survey respondents who had received project funding agreed that their project had encouraged greater public engagement with science, though some respondents questioned the accessibility of these projects, in one case suggesting that combining science and art actually enhanced complexity (Glinkowski & Bamford, 2009).

In Canada one example of this approach is found in the work of Michael R. Hayden, who has conducted extensive genetic research on Huntington disease. In the lead-up to the 2000 Human Genome Project World Conference, Hayden commissioned Vancouver's Electric Company Theatre to fuse "the spheres of science and art in a play that explored the implications of the revolutionary technology of the Human Genome Project" (ECT, n.d.). This play, *The Score*, was later adapted into a film. Hayden believes that his play "transforms the scientific ideas explored in the world of the laboratory into universal themes of human identity, freedom and creativity, and opens up a door for a discussion between the scientific community and the public in general" (Genome Canada, 2006).

In 2008, the Museum of Modern Art in New York developed "Design and the Elastic Mind," an exhibit that brought designers and scientists together to offer a survey of "designers' ability to grasp momentous changes in technology, science, and social mores, changes that will demand or reflect major adjustments in human behavior and convert them into objects and systems that people understand and use" (MoMA, n.d.). *The New York Times* praised the exhibit, highlighting the role of "designers as agents of change, translating technological and scientific advances into solutions to the world's problems" (Rawsthorn, 2008). In the Panel's view, these types of initiatives may owe their success to establishing full partnerships between scientists and artists, respecting both elements of the project rather than treating art as a superficial add-on to a scientific undertaking.

6.5 PROVIDING NATIONAL OR REGIONAL LEADERSHIP

Governments also play a significant role in the development of science culture. While there is little peer-reviewed literature on the effectiveness of government interventions to foster science culture, a comparison of government policies and programs reveals some congruence across countries on promising approaches. Providing an overall national or regional vision, celebrating science and scientists, incorporating science into government decision-making, enhancing the formal education system, and providing a coordinating function stand out as five key areas of activity.

6.5.1 Articulating a National or Regional Vision for Science Culture

Articulation of a vision for science culture can provide a framework for action across organizations and a foundation for coordination. Several countries have made efforts to articulate such a vision or at least identified the need for it, either broadly relating to science in society or more narrowly focused on fostering science knowledge. In 2012 the Australian government released *Inspiring Australia*, an extensive strategy for developing a national science culture. Consultations highlighted the importance of a national vision for providing leadership and establishing a framework that can help stakeholders work towards common outcomes (Commonwealth of Australia, 2010). *Inspiring Australia* articulates four outcomes for the science strategy:

> A society that is inspired by and values scientific endeavor;
> A society that attracts increasing national and international interest in its science;
> A society that critically engages with key scientific issues; and
> A society that encourages young people to pursue scientific studies and careers.
>
> (Commonwealth of Australia, 2010)

In a recent science research priority-setting exercise in New Zealand, a National Science Challenges Panel was convened to recommend priority scientific research areas for the country. In addition to recommending 12 National Science Challenges, that panel identified "science and society" as a distinct national challenge that is more important and pressing than any of the 12 challenges (NSCP, 2013). It noted that "a greater appreciation and understanding of science was necessary for knowledge to be well diffused and of utility to the policy, private and community sectors." Fostering scientists' communication skills, engaging society in early discussion of new technologies to secure a social licence, and improving coordination and evaluation of public understanding of science activities were identified as examples of activities that could be pursued within this science and society theme (NSCP, 2013).

The Chinese government also sees science promotion as an important policy objective, particularly given high levels of superstition and pseudo-science in the media and society. Goals have been established and the current focus is on improving literacy among young people, farmers, the urban workforce, and civil servants (Shi & Zhang, 2012). Other governments have noted the need to establish national goals for science culture, but they have not yet been confirmed in a national strategy (Blandin & Renar, 2003; DIUS, 2008).

Advantage Canada, a federal economic strategy released in 2007, focuses on fostering three Canadian strengths: entrepreneurship, knowledge, and people. It is underpinned by a science and technology strategy, *Mobilizing Science and Technology to Canada's Advantage*. This strategy establishes a goal of boosting excitement about science and technology, noting that federal government departments provide roughly $24 million in annual funding to over 70 science promotion activities (Impact Group, 2006; Industry Canada, 2007). In a review of the role of the federal government in promoting a knowledge economy, The Impact Group (2006) points to a need for a vision that focuses on the economic and social impacts of science and the importance of developing skills among youth. Federal policies and programs in Canada may also be informed by science promotion activities already underway in the provinces (see Box 6.4 for a brief discussion of Quebec).

Box 6.4
Quebec's National Research and Innovation Policy: Supporting Quebec's Science Culture

In 2013 the Quebec government launched the National Research and Innovation Policy. The policy consists of five thematic areas with the goals of knowledge development, transmission, circulation, and mobilization. Embedded in the overall strategy is a commitment of $41 million over five years towards the promotion of science culture in Quebec. In particular, the government prioritizes the support of organizations that promote science, increase awareness of science careers among youth, and promote scientific and technological literacy in young people and the public. These organizations include the network of Quebec museums, Conseil de développement du loisir scientifique, and the Réseau des conseils du loisir scientifique. In addition, support for the development of science activities in unconventional places such as youth centres, malls, family celebrations, and libraries is emphasized (Government of Quebec, 2014).

Pairing stated goals with measurable outcomes and metrics is also critical in assessing progress towards these objectives. *Inspiring Australia* identifies indicators that correspond to each of the outcomes in the strategy and notes that program evaluation, benchmarking, and state of the nation reports are activities that should be undertaken at the national level. Indicators range from levels of attendance at science events to levels of awareness of Australian involvement in international scientific research activities (Commonwealth of Australia, 2010). Similarly, Science for All Americans has developed benchmarks for science literacy and blueprints for reform (AAAS, 1998).

At the same time, it should be recognized that establishing a national or regional vision for science culture is not solely the prerogative of government. Such a vision requires broad support and participation from the community of affected stakeholders to be effective, and can also emerge from that community in the absence of a strong governmental role. The informal science learning environment in the United States, for example, is not guided by a single vision of public science engagement or outreach put forward by the federal government, and it is questionable whether many in the community would view such a vision as desirable. Other levels of government, such as provinces and municipalities, may also undertake to provide this leadership role, and organizations can collaboratively develop their own visions and partnerships without any direction or support from government.

6.5.2 Publicly Celebrating Science and Scientists

Governments can foster science interest and engagement as well as positive attitudes towards science by supporting public celebrations of science and publicly acknowledging the achievements of scientists. National science weeks publicly celebrate the value of science, and are used in Canada, Australia, the United Kingdom and other countries to raise interest and engagement, though the nature and scale of these undertakings may vary. The Canada Science and Technology Museums Corporation coordinates National Science and Technology Week each October. A synthesis of science in society activities across Europe notes the use of science festivals, public events at universities and research centres, and student contests (Mejlgaard *et al.*, 2012b). India's National Children's Congress for Science brings together youth aged 10 to 17 for a week of science activities designed to encourage research, creativity, and a connection of science to society (NCSTC, n.d.). In the United States, President Barack Obama has hosted science fairs at the White House to recognize the importance of science learning and research (Fried, 2013).

Advantage Canada, Inspiring Australia, and a report from the French Senate all identify prizes as one tool to raise the profile of science achievements (Blandin & Renar, 2003; Industry Canada, 2007; Commonwealth of Australia, 2010). Some of the noted awards administered nationally include the Manning Innovations Awards, the Steacie Prize for Natural Sciences, and the Gairdner Awards. In a 2013 *Globe and Mail* commentary, the Chair of Canada's Science, Technology and Innovation Council and the Governor General called for more efforts to nominate Canada's leading researchers to major international prizes and for greater awareness and celebration of Canadian successes. They concluded:

> It is so important that we recognize excellence, because our researchers and scholars are tackling problems and developing knowledge in science and engineering, in health and medicine and in the social sciences and humanities — in short, they are seeking answers to some of the most pressing questions of our time. Their success is our success, and that is a fact worth celebrating.
>
> (Johnston & Alper, 2013)

6.5.3 Incorporating Science into Government Decision-Making

Effectively incorporating science into government decision-making is another critical component of developing a strong science culture. A review of science in society measures in place across European countries considered the processes for incorporating science advice into decision-making, and distinguished countries according to two dimensions: (i) the formalization of the science advisory process, and (ii) the extent to which science advice has an impact on decision-making (Mejlgaard *et al.*, 2012a). The United Kingdom was identified as one of the countries whose science advice was seen to be highly formalized and impactful. The U.K. national science advisor along with departmental science advisors ensure decision-makers are provided with high-quality science evidence to inform deliberations (GOS, 2009). A collection of essays prepared for the incoming U.K. national science advisor emphasizes the role of science advisors as intermediaries and translators of information, recognizes that they offer one source of science advice among many, and highlights the value of drawing from the evidence base to identify effective practices in providing science advice (Wilsdon & Doubleday, 2013).

In addition to the network of science advisors, the U.K. government conducts science reviews to assess the role of science and engineering within departments to identify deficiencies and best practices (GOS, 2009). Also, the Royal Society coordinates a pairing scheme that links scientists with parliamentarians and civil servants, which has led to 180 matches since 2001 (RS, 2013b). This scheme benefits parliamentarians and civil servants by providing them with a deeper understanding of the science underlying public policy issues and benefits scientists with a greater understanding of how policy-making works (RS, 2013b).

In his inaugural address in 2009, U.S. President Barack Obama committed to "restore science to its rightful place" (The White House, 2009b). Early in his tenure, the President issued a memorandum on scientific integrity to the heads of government departments and agencies, underscoring the importance of science and the scientific process for decision-making (The White House, 2009a). The memorandum identified hiring based on scientific credentials, relying on rigorous scientific processes, and disclosing science information used in decision-making among the strategies that can support scientific integrity. The Director of the White House Office of Science and Technology Policy was mandated to establish plans that would ensure scientific integrity throughout the executive branch (The White House, 2009a). Since that time, departments and agencies have developed their own tailored scientific integrity policies (Holdren, 2011).

Like other organizations engaged in science culture, governments must balance promoting the values of science with fostering science engagement, which can include critical engagement with science as well (see Section 6.4.6). An early audit of Australia's implementation of its science strategy found that there is more emphasis on "celebrating and promoting science, rather than about getting people to participate in the science and critically evaluate it" (Metcalfe *et al.*, 2012). In Europe the public is more distrustful of science institutions than the science itself (EURAB, 2007). As a result, in 2007 the European Commission underlined the critical importance of renewing the governance of science institutions for the future of science in the region (EC, 2007), suggesting that governments be cautious about focusing on promotional strategies without creating opportunities for debate and dialogue about science's role in society.

6.5.4 Enhancing Science Learning in the Formal Education System

Governments can work with others in the formal education system to identify and pursue opportunities for improvement. Amgen and Let's Talk Science (2012) recommend "a system-wide review of science, technology, engineering and mathematics (STEM) curricula across Canada to develop programs that increase interest and participation in STEM studies." Chapter 5 commented on Canada's formal science learning system and highlighted how many provincial science curricula are guided by a common framework. Extensive reforms to Quebec's education system demonstrate the impact of assertive government policy changes (see Box 6.5).

Box 6.5
The Reformation of Quebec's Education System

Over the past half-century, Quebec's education system has undergone a massive transformation. In the early 1960s, education in the province was administered through the Catholic church and focused primarily on the humanities (Lenoir, 2005). Enrolment levels and equality of access were both concerns (CSE, 1988; Pigeon, n.d.). In 1961 the Royal Commission of Inquiry on Education in the Province of Quebec, or the Parent Commission, initiated a multi-year review of education, recognizing a need to improve performance, modernize, compete with other North American jurisdictions, and adapt to the scientific and technological revolution underway (CSE, 1988; Lenoir, 2005).

The Parent Commission's findings and recommendations ultimately led to the overhaul of the education system, towards a model characterized by a focus on pragmatic skills development, a declining role for the church, a greater emphasis on sciences, and a more student-focused and active approach to learning (Lenoir, 2005). This reform is credited with major improvements in student enrolment and performance (CSE, 1988; Pigeon, n.d.).

Today, results from PISA show that Quebec students lead the rest of the country in mathematics performance, and rank among the top global performers alongside Korea and Finland (Knighton *et al.*, 2010). Quebec's students perform slightly below the Canadian average in the sciences but still rank highly relative to international peers (Knighton *et al.*, 2010). From an historical perspective, this education reform was part of a sustained effort to articulate, fund, and deliver a strong science and technology strategy in the province.

6.5.5 Promoting Coordination and Alignment

The OECD (1997) calls on governments to network organizations that play a role in science outreach and to coordinate internationally. In an assessment of the extent to which U.S. informal science education organizations function as an integrated community of practice, Falk *et al.* (2011) conclude that the array of organizations assessed do not function effectively as a group, though some sub-communities (e.g., science centres and museums) are more cohesive owing to their shared missions, content, and practices. Professionals in the field have noted that the fragmented nature of this community limits its ability to achieve many common goals (Falk *et al.*, 2011).

Canada's science and technology strategy also recognizes the potential role of government in supporting coordination:

> Many science-promotion initiatives in Canada are small in scale and lack a forum to combine their efforts in order to increase their impact. The government will bring these players together to shape a shared vision, and coordinate and focus our respective efforts.
>
> (Industry Canada, 2007)

Inspiring Australia articulates a national framework-local action approach, noting the need for the national government to provide leadership, convene working groups on priority issues, establish connections, and share best practices (Commonwealth of Australia, 2010). Since 1958 China has relied on the China Association for Science and Technology to coordinate science promotion across the scientific community, the governing party, and the government (Commonwealth of Australia, 2010). India's National Council for Science & Technology Communication is involved in many science promotion initiatives, and also coordinates activities with stakeholders and internationally (DST, 2005). Such coordination can support the development of complementary programming, thereby boosting overall effectiveness. Cooperation across formal and informal education initiatives stands out as particularly important. Even during the most intensive years of schooling, only about 20% of an individual's time is spent in formal schooling (Banks *et al.*, 2007).

Campbell *et al.* (2004) suggest that, for youth to continue along a STEM career path, a "trilogy" of factors are needed: engagement in the subject matter, knowledge, and opportunities that support advancement. They point to examples of successful programs that have met this criterion by combining features such as intensive STEM education, university visits, internships, museum visits, and parent information sessions. This type of approach necessarily calls for collaboration between multiple organizations. At the same time, it is important to recognize that creating effective collaborations is not always easy. Lessons learned through one NSERC initiative point to the potential of collaboration, but also illustrate some of the challenges that may arise when multiple organizations or actors with differing priorities and vantage points work together (see Box 6.6).

Box 6.6
NSERC CRYSTAL Pilot Program

The NSERC Centres for Research in Youth, Science Teaching, and Learning (CRYSTAL) program was designed to identify resources and methods to enhance science and mathematics education (K–12) through collaboration between education and natural science researchers, science promotion communities, teachers, and education administrators. A mid-term review of CRYSTAL identified several program accomplishments: an improved understanding of the skills and resources needed to enrich the educational instruction and learning of science and mathematics; an enhanced capacity among participating education researchers to conduct research focused on science, mathematics, and technology education; and translation of research findings into teaching strategies that were being used by the education community.

At the same time, participation of natural science and engineering researchers was limited and the program faced some collaboration challenges. Factors that hinder collaboration include limited availability of researchers due to competing research activities; cynicism and a lack of comprehension about the program's research approaches and methodologies; a sense that research outputs were not immediately beneficial; poor communication between researchers; and a lack of recognition from faculties for participation in science education activities. The review concluded that future initiatives of this nature may need to further consider how to properly incentivize, and remove impediments towards the active collaboration of researchers, educators, and administrators from multidisciplinary backgrounds.

(NSERC, 2008a, 2008b)

A variety of organizations that support science culture can work together to develop complementary offerings. Australia's national strategy states: "Activities need to build on each other, providing pathways to develop awareness and involvement" (Commonwealth of Australia, 2010). The Canada Science and Technology Museums Corporation partners with over 20 Canadian organizations, primarily science centres and museums, to deliver Let's Talk Energy, a multi-year initiative aimed at engaging Canadians in a discussion about energy, the economy, and the environment through film screenings, information kiosks, social media discussions, and virtual and on-site exhibits across the country (CSTMC, n.d.).

Science organizations can also use non-traditional partnerships with organizations that work outside the science learning context to recruit new audiences and provide a wider range of services to the community. For instance, the Ontario Science Centre partnered with ABC Life Literacy Canada to host celebrations for Family Literacy Day in 2013 (ABC, 2013). Science culture organizations can cooperate to achieve a wider overall reach, and large national organizations can work with smaller regional organizations to provide programming outside of the large urban centres.

While nothing precludes individual organizations from forming such collaborations independently, governments can play a role in catalyzing their formation by providing a common framework and vision around which they can be developed.

6.6 CHAPTER SUMMARY

Science culture is multidimensional, and practices to support and cultivate a stronger science culture in Canada extend across a wide range of actors and activities. This chapter has discussed five key areas of intervention critical to cultivating a strong science culture: supporting lifelong science learning, making science inclusive, adapting to new technologies, enhancing science communication and engagement, and providing national or regional leadership. The quality of the evidence on these practices is variable. While a substantial body of research exists on effective practices to support science learning, evidence on other aspects of promoting public science engagement and outreach is less developed and less definitive. The Panel cautions that many areas could benefit from additional research, particularly in evaluating the effectiveness of practices that have been implemented in different contexts. Finally, the evidence that informs these practices is based on past experiences, but the rapid pace of technological change means that science culture in Canada and other countries is in a constant state of transition. As a result, traditional mechanisms for promoting science culture may require ongoing adjustment and adaptation in the years ahead.

7

Conclusions

- What Is the State of Canada's Science Culture?
- What Is the State of Knowledge About the Impacts of Science Culture?
- What Are the Indicators of a Strong Science Culture and How Does Canada Compare with Other Countries Against These Indicators?
- What Factors Influence Public Interest in Science?
- What Are the Critical Components of the System that Supports Science Culture in Canada?
- What Are the Effective Practices that Support Science Culture in Canada and Key Competitor Countries?
- Final Reflections

7 Conclusions

This chapter synthesizes the principal findings that emerged from the Panel's assessment of Canada's science culture. The findings are organized in response to the main question and sub-questions that comprise the Panel's charge. The summary answers to the questions represent the Panel's collective judgment based on the best available evidence, including the Panel's survey results and findings from previous studies.

7.1 WHAT IS THE STATE OF CANADA'S SCIENCE CULTURE?

As understood by the Panel, a society has a strong science culture when it embraces discovery and supports the use of scientific knowledge and methodology. Such a culture encourages education and training of a highly skilled workforce and development of an innovative knowledge-based economy. The concept of science culture is multidimensional, incorporating a number of distinct dimensions pertaining to how individuals and society relate to science and technology. The national context also strongly influences how science culture develops and is expressed.

The Panel's assessment of the state of science culture in Canada focused on four key dimensions that can be empirically measured with a reasonable degree of rigour and accuracy:

- public *attitudes* towards science and technology;
- public *engagement* in science;
- public science *knowledge*; and
- science and technology *skills* in the population.

International comparisons and trends over time are used to aid in the interpretation of these data.

7.1.1 International Comparisons

The majority of the evidence reviewed by the Panel speaks to the relative strength of Canada's science culture when compared with other countries. Key findings are highlighted here.

Canadians have positive attitudes towards science and technology and low levels of reservations about science compared with citizens of other countries. Like citizens of other industrialized countries, Canadians hold both positive and negative attitudes about science and technology, though positive attitudes predominate. Canada ranks 9th out of 17 countries on an index based on standard survey questions assessing beliefs about the promise of science and technology. Canadian views are generally supportive of science, but not any more so than those expressed by citizens of other countries. Relatively few Canadians, however, express beliefs such as "it is not important for me to know about science in my daily life" or "we depend too much on science and not enough on faith." Canada ranks 1st out of the same 17 countries on an index based on standard questions assessing public reservations about science, indicating low levels of concern about any potentially disruptive impacts of science and technology. There is, however, a portion of the Canadian population that still harbours significant reservations about science. One in ten Canadians believes that the world is worse off because of science and technology, and nearly one in five believes that science is not important to their daily life.

Canadians also express above-average levels of support for public funding of scientific research, and a strong majority of Canadians view science and technology as important in pursuing a range of social objectives such as environmental protection and improving Canada's economic prospects.

Canadians exhibit a high level of engagement with science and technology relative to citizens of other countries. Ninety-three per cent of Canadians report being either very or moderately interested in new scientific discoveries and technological developments. Canada ranks 1st out of 33 countries on this measure. Nearly one-third of Canadians reported having visited a science and technology museum at least once in the past year. Canadians are more likely to do so than citizens of any other country except Sweden. Canadians also report engagement levels on a par with or above most other countries for which data exist for the following measures: donating money to medical research, participating in science and technology activities of an NGO, and signing petitions or joining street demonstrations on nuclear power, biotechnology, or the environment.

Established, survey-based measures suggest that Canadians' level of science knowledge is on a par with or above citizens of other countries for which data are available. Public surveys in the United States and Europe have used a number of standard factual and open-ended questions to assess public understanding of science for several decades. Based on data from the Panel's survey, Canadians have a relatively high level of understanding of core scientific constructs and methods. On individual questions assessing factual knowledge, Canadians answer these questions correctly at rates comparable to the best-performing jurisdictions such as Sweden or the United States. For example, 58% of Canadians are correctly able to identify that electrons are smaller than atoms, whereas less than half of the population answers this question correctly in most countries. On an index of science literacy based on these questions, Canada ranks first among countries for which there are data. Around 42% of the population in Canada, compared with 35% in Sweden and 29% in the United States, exhibits a sufficient level of scientific knowledge to grasp basic scientific concepts and understand general media coverage of science and technology issues. These data should be interpreted with caution; part of the explanation for Canada's performance may be due to the more recent data for Canada. Public science knowledge in most countries has been improving over time and more current data would likely reduce the gap between Canada and others. These data, however, are consistent with international student assessments such as PISA and TIMSS, which show that, on average, Canadian students excel in achievements in science and mathematics compared with students in most other countries.

Canada's performance on indicators of science and technology skills development is more variable compared with other OECD countries. While Canada ranks first among OECD countries in overall post-secondary educational attainment (the portion of the population aged 25 to 64 with college and university degrees), only 20% of first university degrees in Canada are in the sciences and engineering. Canada ranks 19th out of 29 countries on this measure, well behind leaders like Korea at 32% and Germany at 30%. The proportion of students graduating with engineering degrees in Canada is particularly low — well below the OECD average and that of leading countries. Women account for 49% of these degrees, which is a high proportion by international standards. However, the participation of women by field of study varies considerably, from over 60% in the life sciences to less than 20% in computing. Canada also has a relatively low level of doctoral graduation compared with other OECD countries, but a large share of doctoral degrees are granted in the sciences and engineering. Finally, similar patterns are evident in OECD occupational statistics. The share of Canada's workforce employed in areas relating to science and technology is near the OECD average, and particularly low in the manufacturing sector. In interpreting this data, it should be remembered that student decisions about field of study may also be driven by economic trends and expectations about the labour market, and are therefore not solely a function of student interest and engagement in science.

7.1.2 Trends over Time

The analysis of trends in many of the above measures is hindered by the lack of long-standing systematic data collection in Canada. However, when compared with survey evidence from 1989, there are notable changes across many measures. Levels of science knowledge have increased in the Canadian population, with a greater share of the population able to correctly answer standard factual questions about science. Reservations about science have declined on average, and the percentage of the public reporting that they have visited science centres or museums in the last year is higher than it was two decades ago. However, since 2004, Canadians also appear to have become slightly more skeptical about the ability of science and technology to address social challenges such as protecting the environment, improving health care, or contributing to economic growth. In addition, while still high by international standards, Canada's PISA scores for mathematics and science have shown statistically significant declines since 2006, raising the concern that Canada is failing to keep pace with other leading countries.

7.2 WHAT IS THE STATE OF KNOWLEDGE ABOUT THE IMPACTS OF SCIENCE CULTURE?

Many claims have been advanced about the impacts of science culture on individuals and society, often in conjunction with advocating for the importance and value of a stronger science culture. Such claims are often plausible given the extent to which science and technology permeate modern societies. However, the Panel found limited empirical evidence to substantiate these claims, and in some cases the evidence points to more complexity in the way these impacts are manifested than is typically acknowledged. Much of this evidence suggests that, while a stronger science culture may contribute to a range of personal or social benefits, such as improved individual decision-making or enhanced public engagement, it is not always in itself sufficient to ensure the realization of those benefits. The Panel explored impacts on individuals, impacts on democracy and public policy, impacts on the economy, and impacts on scientific research.

Impacts on Individuals: It is often argued that improving public understanding of science benefits individuals by enhancing their ability to navigate a technologically advanced society. Improved science knowledge can help individuals better differentiate between fact and opinion, make more informed consumer choices, and better evaluate personal and public health risks. However, the ability of individuals to realize them may be constrained by other factors. For example, while a greater level of scientific knowledge may contribute to more informed decisions, decision-making processes are also affected by underlying cultural values and common cognitive biases and decision-making rules. Recent studies have also pointed to the type of science knowledge as a relevant parameter. It may be more useful for individuals to learn how to recognize in which situations science is applicable and acquire relevant information, rather than master a set body of conceptual knowledge about science.

Impacts on Democracy and Public Policy: It is also often argued that a stronger science culture can benefit public policy and democratic engagement through an increased public understanding of science. Adequately understanding many current policy issues, ranging from climate change to the safety of genetically modified foods or nuclear reactors, requires a sophisticated grasp of scientific concepts, methods, and findings. Democratic governments are predicated on the notion that citizens can effectively express their preferences on issues of public importance. Citizens without an adequate foundation of scientific knowledge cannot participate in these debates in an informed manner, thereby potentially compromising the effectiveness of the democratic process. A certain level of understanding of science is therefore a prerequisite for informed political participation on these issues. However, this is only one factor determining patterns of political participation and it does not guarantee increased or enhanced engagement. Any impacts on policy development are also a function of the range and types of venues created for public engagement, and depend on the existence of effective institutional mechanisms for incorporating scientific evidence in public policy-making.

Impacts on the Economy: Science culture can also potentially affect the economy, primarily through increasing the supply of science and technology skills. Economic theory recognizes technological innovation as a fundamental driver of long-term economic growth. Since advanced science and technology skills are a prerequisite for technological innovation, increasing the availability of these skills can be expected to bolster the economy's aggregate capacity for innovation. The Panel views the development of such skills as a defining feature of a strong science culture; however, other dimensions of science culture can also potentially stimulate skills development by increasing youth engagement in scientific activities and engendering more positive attitudes towards science. While the general role of such skills in supporting technological innovation is understood, there has been little study on the relative importance of different types of scientific skills, or on the overall level of skills required to support a robust level of technological development. Many other factors also determine rates of innovation and overall economic performance. As a result, it cannot be assumed that higher levels of science and technology skills will necessarily lead to improved economic outcomes in all contexts.

Impacts on Scientific Research: A stronger science culture can also have impacts on scientific research. In particular, increased public support for scientific research and participation in various forms of research such as clinical trials or provision of medical samples can bolster the capacity to undertake certain kinds of research. New technological platforms are also creating novel opportunities for the public to engage in scientific research.

7.3 WHAT ARE THE INDICATORS OF A STRONG SCIENCE CULTURE AND HOW DOES CANADA COMPARE WITH OTHER COUNTRIES AGAINST THESE INDICATORS?

Science culture consists of several dimensions, each of which has its own indicators and assessment strategies (Section 7.1 summarized the Panel's approach to assessing science culture). Public survey methodologies have been used for many decades and are now relatively well developed. These methodologies can be used with a reasonable degree of accuracy to measure constructs such as public science knowledge, attitudes towards science and technology, and levels of public engagement and participation in science. The Panel used other data sources on educational outcomes and occupational trends to assess the development of science and technology skills in the population. As noted earlier in the chapter, the Panel found that Canada compares favourably with other countries on many measures, with the exception of some indicators of science and technology skills.

Survey evidence on the dimensions of science culture has been systematically and regularly collected in other countries, particularly the United States and in Europe, to benchmark levels of public understanding of and engagement with science. Canada, however, has not regularly fielded comparable surveys. While the Panel's survey temporarily makes up for the lack of Canadian data, the full value of the data cannot be realized without regular, systematic surveys and a long-standing time series.

Science culture is composed of both individual and social aspects; the latter include the institutional support it receives. Internationally comparable data on this subject, however, are generally lacking. While statistical resources can gauge the relative levels of formal education across countries, few internationally comparable data allow for rigorous, structured comparisons of informal science learning opportunities. As a result, like preceding analyses, the Panel's review of institutional and social support for science culture in Canada has been primarily descriptive rather than analytical.

Part of the Panel's charge requested an examination of the relationship between "output" and "outcome" measures with respect to science culture. In general, the Panel has refrained from adopting this language, which it believes to be more suited to evaluations of individual institutions or programs than to society-wide assessments. The indicators referred to here could be useful in evaluations of individual institutions in some cases, which could then involve characterizing specific indicators as outputs (e.g., museum visits) and assessing their relationships to outcomes (e.g., impacts on science knowledge or attitudes). The Panel has not engaged in this kind of evaluative exercise, but notes that scholars such as John Falk have effectively linked output measures for individual institutions to community-wide impacts on dimensions such as science knowledge or attitudes towards science in the past (Falk & Needham, 2011). While it is often challenging to connect output measures for a single organization or program to higher-level assessments of public science knowledge or engagement, past evaluations indicate that informal science learning environments can have measurable impacts on their participants that, if scaled sufficiently, could influence population-wide measures of science culture such as those used in this study.

7.4 WHAT FACTORS INFLUENCE PUBLIC INTEREST IN SCIENCE?

Survey evidence such as that collected by the Panel can be used to identify and analyze demographic drivers of public interest in science such as age, gender, educational attainment, income bracket, ethnicity. Interest in new scientific discoveries and technological developments tends to be higher among men, younger respondents, more educated respondents, and higher income respondents. Gender differences are pronounced in Canada, with 60% of men, and only 40% of women, saying they are very interested in new scientific discoveries and technological developments. Generally speaking, these patterns are consistent with those found in other countries.

Among youth, science interest generally declines with age, and declines more rapidly for girls than for boys. Socio-economic background also shapes interest, with higher science interest levels reported by students living in households where parents have higher incomes and education levels. Interest in science is also higher among non-Caucasian youth. Youth report that learning how things work and engaging in hands-on activities contribute to science interest.

Informal science learning experiences can contribute to sparking and sustaining interest in science and technology among youth; however, empirical evidence systematically linking these experiences to an increased likelihood of pursuing scientific careers is limited. Youth interest in science and their eventual career decisions are affected by many factors including educational performance and aptitude; psychological factors (e.g., interest in science, internal beliefs, experiences); environmental factors (e.g., access to educational resources and learning opportunities); and sociological and cultural dimensions (e.g., family and peer support, factors related to gender). The combined influence of these factors in a changing and complex environment makes it difficult to quantify the impact of a single driver.

7.5 WHAT ARE THE CRITICAL COMPONENTS OF THE SYSTEM THAT SUPPORTS SCIENCE CULTURE IN CANADA?

Many types of organizations contribute to the advancement of science culture in Canada, ranging from formal science education providers to informal science learning institutions to other actors such as friends and family. In the Panel's view, a neat division between the roles of formal and informal science learning providers is overly simplistic. Evidence suggests that these systems are often linked through partnerships and collaborations.

The science culture support system is also dynamic. Any analysis of the system at a specific moment in time can quickly become out of date. Nevertheless, a 2011 inventory of science culture and communication initiatives in Canada identified more than 700 individual programs or organizations. These include over 400 initiatives related to museums, science centres, zoos, or aquariums; 64 associations or NGOs; 49 educational initiatives; 60 government policies and programs; 27 media programs; and a variety of other organizations and programs.

Given the lack of internationally comparable data, the Panel found no scientifically rigorous way of evaluating the strengths and weaknesses of Canada's system of informal science engagement and learning interventions relative to that of other countries. However, a number of informed observations can be made based on the available evidence.

The success of Canada's network of science centres and museums is reflected in their strong international reputations and relatively high numbers of annual visitors compared with those in other countries. Several long-standing, iconic Canadian science media programs (in French and English) contribute to informal science learning. General science coverage in the English-language Canadian media, however, is less developed, with few dedicated science reporters or journalists. *Canadian Geographic* is the only nationally distributed science magazine, though *Québec Science* is a long-standing French-language science magazine. While this may not result in an overall lack of science media given the ready availability of non-Canadian sources, it limits coverage of Canadian content (e.g., stories about Canadian scientists and their work).

Both private industry and research institutes support science culture in Canada, and research organizations play an active role in some forms of public science outreach and engagement. Canadians also benefit from opportunities to engage in scientific pursuits and hobbies in an extensive system of natural parks and nature areas. International student assessment exercises such as PISA and TIMSS suggest that Canada's formal science education system is internationally competitive, though potentially at risk of falling behind if Canadian scores continue to decline.

Federal, provincial, and municipal governments support science culture in Canada through a variety of programs. The federal government, however, has not been as active as some of its peers abroad in articulating a national vision or strategy for science culture, or promoting public engagement and understanding of science. Some provincial governments, most notably Quebec and Ontario, have been more active. Concerns about how federally employed scientists are allowed to communicate with the media have also been widely reported in the Canadian and international media in recent years, raising questions about the extent to which current policies limit opportunities for public communication and engagement.

Canada also lacks a dedicated funding program for research on informal science learning, like the one provided by the National Science Foundation in the United States. This has dual implications: (i) financial resources are more limited for informal science learning providers, and (ii) less information is available on the effectiveness of informal science engagement and learning opportunities in Canada due to the lack of support for evaluations of these programs.

7.6 WHAT ARE THE EFFECTIVE PRACTICES THAT SUPPORT SCIENCE CULTURE IN CANADA AND KEY COMPETITOR COUNTRIES?

The Panel's research on effective practices for building a stronger science culture identified relevant interventions under five broad themes. The quality of the evidence available to evaluate these interventions is variable. While science education and learning have been the subject of extensive academic research over the years, other practices reviewed by the Panel have received less study and could benefit from more research (e.g., determinants of effective science communication, and effectiveness of different forms of government support). In addition, while experiences in other jurisdictions can be instructive, they may not always be transferrable across different social, cultural, or political contexts.

Supporting Lifelong Science Learning: Exposure to science in the formal school system is a critical driver of the overall level of science knowledge in the general population. At the same time, individuals spend a small portion of their lives in formal school settings, and emerging scientific issues require the ability to continue to acquire new scientific knowledge throughout an adult's lifetime. Effective support for public science knowledge therefore recognizes the fundamental importance of educational settings in providing core scientific knowledge and information acquisition skills, while, at the same time, providing a variety of channels through which the adult population can continue to seek out information on science. A full review of science learning and pedagogical strategies was beyond the scope of the Panel's charge. However, many practices for supporting lifelong science learning and building science interest among individuals are widely applicable in both formal and informal learning venues.

Making Science Inclusive: Tailoring science learning and engagement to the social and cultural contexts of groups traditionally underrepresented in the sciences can help make science more inclusive. Canadian survey data indicate that interest and involvement in science are unequally distributed across the population. Specific strategies vary depending on the group. Young women are more likely to develop interest and pursue science learning when they can see the social relevance of the subject matter and are given the opportunity to engage with scientists and mentors. For Aboriginal populations, evidence suggests it may be useful to recognize and incorporate aspects of traditional knowledge into curricula and instruction.

Adapting to New Technologies: New technologies can be used to augment science education and engagement strategies in many ways. Internet-based resources can allow learners to tailor learning to their own style and interests. Technology can also enhance a variety of science outreach activities, and offer new modes of public engagement (e.g., citizen science) and communication (e.g., social media and blogs) for science culture organizations.

Enhancing Science Communication and Engagement: Scientists who are encouraged to communicate with the public and equipped with the tools to engage successfully can build support, knowledge, and interest across the population. Careful framing of science communication will factor in the audience's social and cultural context, and how different messages can be expected to resonate with diverse groups. Engaging the public in certain areas of science decision-making can also make science more relevant to society, and increase science knowledge of participants. Other approaches to facilitating public engagement in science include acknowledging debate and controversy, and linking science with other aspects of culture such as the arts.

Providing National or Regional Leadership: Governments can articulate a vision for science culture, which can provide a framework for action across organizations and a foundation for coordination. Governments can also celebrate science and scientists, strengthen science learning through the formal education system, and coordinate efforts across a wide range of science culture organizations through leadership and information sharing.

7.7 FINAL REFLECTIONS

Science culture in any society is a function of a complex array of forces, some of which may occasionally be in tension with one another. For example, although reservations about science and technology in Canada have declined in past decades, Canadians have also become slightly more skeptical about the ability of science and technology on their own to address social challenges such as protecting the environment, improving health care, or contributing to economic growth. While Canadians report high levels of interest in science and positive beliefs about the potential of science and technology careers, a smaller portion of Canadian youth actually pursue these opportunities (a fact that is perhaps less surprising given the comparatively low level of science and technology related employment in Canada). Finally, the high levels of engagement with science in Canada do not necessarily translate into government mechanisms or institutions that prioritize incorporation of scientific evidence into public policy-making and dissemination of scientific research to the public.

Such tensions speak to both the strengths of Canada's science culture and its potential weaknesses. While much of the evidence in this report suggests Canada benefits from a relatively strong science culture, Canada could learn from initiatives undertaken in countries in which governments and political leaders have been more active in promoting national or regional visions for science culture and in providing ways for the public to meaningfully engage in discussion about scientific research and issues. Canada could also benefit from a more systematic approach to periodically assessing its science culture and to critically evaluating initiatives, programs, and activities associated with informal science learning and engagement. Finally, Canadians could also work with their peers around the world to develop a more robust evidence base for assessing the adequacy of the institutional system of support for science culture, and to better track and understand the global drivers of science culture.

There are many rationales for cultivating a strong science culture, and a stronger science culture can be expected to improve society's capacity to harness science and technology in pursuit of a wide range of social goals. However, as stated by physicist Brian Greene (2008), one of the simplest reasons for developing a stronger science culture is that doing so helps foster a fuller, richer experience of science itself:

> Science is a way of life. Science is a perspective. Science is the process that takes us from confusion to understanding in a manner that's precise, predictive, and reliable — a transformation, for those lucky enough to experience it, that is empowering and emotional. To be able to think through and grasp explanations — for everything from why the sky is blue to how life formed on earth — not because they are declared dogma, but because they reveal patterns confirmed by experiment and observation, is one of the most precious of human experiences.

A strong science culture is also one that celebrates the experience of science in this light, and works to ensure that all individuals and segments of society have opportunities to share in the wonder and excitement of science. Canadians are fortunate to have many such opportunities, but science and society are both constantly evolving. Therefore, developing a stronger science culture in Canada — one with a nuanced understanding and appreciation of the myriad ways in which science is deeply ingrained in society — remains a work in progress.

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List of Appendices

Appendix A: Survey Questionnaire

The full text of the survey questionnaire is available online at: **www.scienceadvice.ca/en/assessments/completed/science-culture.aspx**.

Appendix B: Coding Protocol for Open-Ended Knowledge Questions

The protocol used for coding the three open-ended survey questions is available online at: **www.scienceadvice.ca/en/assessments/completed/science-culture.aspx**.

Appendix C: Science Culture Surveys

A table providing additional details on surveys cited throughout the assessment is available online at: **www.scienceadvice.ca/en/assessments/completed/science-culture.aspx**.

Appendix D: Structural Equation Modelling

Additional details on structural equation modelling conducted by the Panel are available online at: **www.scienceadvice.ca/en/assessments/completed/science-culture.aspx**.

Assessments of the Council of Canadian Academies

The assessment reports listed below are accessible through the Council's website (www.scienceadvice.ca):

- Science Culture: Where Canada Stands (2014)
- Enabling Sustainability in an Interconnected World (2014)
- Environmental Impacts of Shale Gas Extraction in Canada (2014)
- Aboriginal Food Security in Northern Canada: An Assessment of the State of Knowledge (2014)
- Ocean Science in Canada: Meeting the Challenge, Seizing the Opportunity (2013)
- The Health Effects of Conducted Energy Weapons (2013)
- The State of Industrial R&D in Canada (2013)
- Innovation Impacts: Measurement and Assessment (2013)
- Water and Agriculture in Canada: Towards Sustainable Management of Water Resources (2013)
- Strengthening Canada's Research Capacity: The Gender Dimension (2012)
- The State of Science and Technology in Canada, 2012 (2012)
- Informing Research Choices: Indicators and Judgment (2012)
- Integrating Emerging Technologies into Chemical Safety Assessment (2012)
- Healthy Animals, Healthy Canada (2011)
- Canadian Taxonomy: Exploring Biodiversity, Creating Opportunity (2010)
- Honesty, Accountability, and Trust: Fostering Research Integrity in Canada (2010)
- Better Research for Better Business (2009)
- The Sustainable Management of Groundwater in Canada (2009)
- Innovation and Business Strategy: Why Canada Falls Short (2009)
- Vision for the Canadian Arctic Research Initiative: Assessing the Opportunities (2008)
- Energy from Gas Hydrates: Assessing the Opportunities and Challenges for Canada (2008)
- Small Is Different: A Science Perspective on the Regulatory Challenges of the Nanoscale (2008)
- Influenza and the Role of Personal Protective Respiratory Equipment: An Assessment of the Evidence (2007)
- The State of Science and Technology in Canada (2006)

The assessments listed below are in the process of expert panel deliberation:

- Therapeutic Products for Infants, Children, and Youth
- The Future of Canadian Policing Models
- Canadian Industry's Competitiveness in Terms of Energy Use
- Memory Institutions and the Digital Revolution
- Wind Turbine Noise and Human Health
- STEM Skills for the Future
- The Potential for New and Emerging Technologies to Reduce the Environmental Impacts of Oil Sands Development
- RISK: Is the Message Getting Through?
- Timely Access to Health and Social Data for Health Research and Health System Innovation

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